FINAL REPORT

DEVELOPMENT OF A SMART FRAMEWORK BASED ON KNOWLEDGE TO SUPPORT INFRASTRUCTURE MAINTENANCE DECISIONS IN RAILWAY CORRIDORS

Grant Agreement number: 314031

PROJECT FINAL REPORT

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Project acronym: OPTIRAIL

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

1. FINAL PUBLISHABLE SUMMARY REPORT

1.1 EXECUTIVE SUMMARY

The **OPTIRAIL project** ("**Development of a smart framework based on knowledge to support infrastructure maintenance decisions in railway corridors**") was launched the **1st of October of 2012** and finished **30th September of 2015**. This project was completely aligned with the approach of the call, by developing railway corridor smart tools for improving European railway sector competition.

The main **objective** of the OPTIRAIL project has been to **develop new smart tools** that will help to **optimize railway maintenance operations** ensuring **higher railway availability**, **better cross-border coordination** and **improved efficiency**.

In order to be able to achieve the exposed objective, the OPTIRAIL Consortium has been compound by a well-balanced group of **9 partners** from **6 European countries** with complementary skills and expertise, including all the necessary profiles to deal with the scheduled project work plan. The leader of the project has been **VIAS**, Spanish railway infrastructure track work contractor, and the rest of the participants are: **FUNDACIÓN CARTIF, LULEA TEKNISKA UNIVERSITET, UNIVERSIDAD DE GRANADA, OSTFALIA UNIVERSITY OF APPLIED SCIENCES, STIFTELSEN SINTEF, MER MEC S.P.A., EVOLEO TECHNOLOGIES and ADMINISTRADOR DE INFRASTRUCTURAS FERROVIARIAS.**

This interdisciplinary group of the railway managers, railway suppliers, software & embedded systems developers, and technological R&D centres have efficiently coordinate their resources over 36 months duration of the project to be able to reach all expected project outcomes. The **final total real cost** of the project has been **4.044.014,14€**.

Finally, it must be highlighted the **strong impact** achieved by OPTIRAIL project as many partners obtained **successful close-to-the market exploitable results**. Furthermore, **social impact** achieved has been considered relevant, due to the **creation of a set of recommendations for improving the competitiveness of European railway sector**. According the relevance of technological and exploitation results obtained in the OPTIRAIL project, a **website** of the project has been created for the dissemination of those results. The link to the website is the following: **http://www.optirail.eu/optirail/**.

European transport networks have been growing over centuries as a consequence of continuous increase of volumes of passengers and goods. The existing networks have been straining beyond their capacity and, therefore, there is a need to modernize the transport systems in order to allow networks to become the arteries and lifelines of our society. Supporting the constantly increasing need for mobility, with no interruption of service, is the fundamental prerequisite for Europe to ensure its future prosperity and territorial cohesion as well as to remain a global level- playing actor under the pressure of the international market.

To that effect, the main changes in the European transport networks will focus on the available technology and a fair use of transport modes. On the one hand, the level of maintenance operations has to be risen up and adapted based on management tools and ICT systems. This will help to reduce congestions, delays and accidents, which will lead to provide users and operators with predictable services. On the other hand, there is a need to develop a European transport system capable of shifting the balance between modes of transport, revitalising the railways, among others.

In the last 20 years, the European Commission has been very active in restructuring the European rail transport market and strengthening the position of railways with respect to other transport modes. The Commissions efforts have concentrated on three major areas which are all crucial for developing a strong, transparent and competitive rail transport industry: (i) opening of the rail transport to market competition, (ii) improving the interoperability and safety of national networks and (iii) developing rail transport infrastructure.

Within this framework, OPTIRAIL project seek, as its general objective, to develop new smart tools that will help to optimize railway maintenance operations ensuring higher railway availability, better cross-border coordination and improved efficiency.

The **specific objectives** are:
▸ To analyse the specification and requirements for an efficient, reliable and sustainable maintenance of the railway systems (for passengers and freight), paying special attention to corridors in the selected case studies, both at the system level (technical and regulatory) and the end-users level (know-how and tools for infrastructure managers and track work contractors).

- To analyse the transferability of concepts, ideas and solutions from other sectors (electricity, oil & gas, water and airspace) to be applied to this railway domain.

- To design and validate smart and collaborative tools based on intelligent systems (and particularly on fuzzy logic) that become decision support and making systems for railway maintenance and its management.

- To design a new maintenance conceptual framework based on fuzzy systems that consider every functional and technological component to ensure the integration and linkage to existing maintenance platforms and ICT systems, and its performance and usability for infrastructure managers and track work contractors.

- To validate the design of the maintenance framework through an implementation and integration, total or partial, with an existing maintenance platform.

- To demonstrate the usability of the project outcomes on existing rail networks (case studies).

- To define the corresponding models for facilitating the broad deployment of the project results.

- To define the synergies and best practices between the cross-border networks and disseminate the project results to other corridors.

The **operational objectives** to ensure the objectives defined above are the following:

- Generation of bases of knowledge on regulations, policies, etc. regarding the railway maintenance. ICT implementation of these bases of knowledge to be used by the maintenance platform.

- Characterization of the main maintenance tasks and their impact from different points of view: economic, human and technical resources, serviceability, safety, environmental impact, etc.

- Development of models of behaviour and evolution of individual components and the whole infrastructure. This will provide the ability to prevent the appearance of security and service events that affect the asset by its own process of evolution and/or aging.

- Development of models of detection and classification of events that affect the infrastructure. Obtaining of a linguistic description of the domain in technical terms.

- Development of computational models of maintenance tasks implemented on the basis of expert knowledge.

- Development of computational models of decision making for railway maintenance.

- Development of multi-criteria optimal planning models (level of service, availability, economy, CO_2 footprint, traffic, etc.) for maintenance.

PROJECT ORGANIZATION

The OPTIRAIL project work plan has been conceived according to the following Work Packages structure shown in Figure 1.
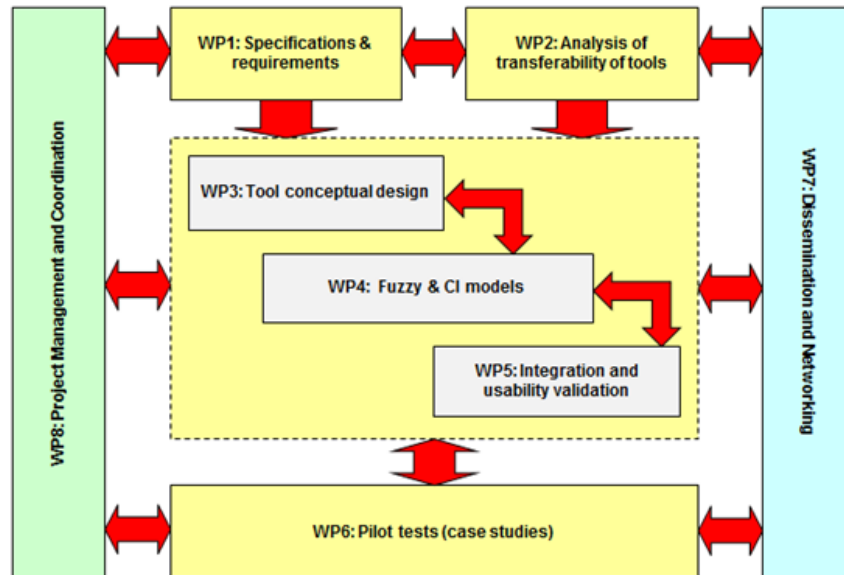

FIGURE 1. WORK PACKAGES STRUCTURE.

The main aim and activities to be implemented within the frame of each one of the Work Packages defined above are briefly explained next:

▸ **WP1 (Requirements & Specifications)** will undertake integrative analysis linking the main key actors/issues. Then, it will define the relevant elements, aspects and operations of the railway maintenance to be involved in this initiative, the data and expert knowledge to be considered for that goal, and the standards and regulations to be taken into account for these maintenance goals. Thus, functional requirements and technical specifications of new tools will be defined in order to design the conceptual model of this framework.

▸ **WP2 (Transferability)** will undertake the analysis of maintenance and linked decision support tools used in other sector (such as electricity, oil & gas and water distribution, and airspace) and their applicability to the railway domain. Once the functional requirements, including that maintenance aspects to be considered, and the technical specifications to be taken into account have been defined, WP3, WP4 and WP5 will start. These three Work Packages constitute the most relevant research and development activities within the project and will interchange advances periodically in order to ensure the compatibility of design, systems and protocols.

- ▸ **WP3 (Conceptual Design)** will ensure the alignment of the maintenance needs, ICT requirements and constrains, the case studies requirements and the Fuzzy-CI based core tool set, in order to design the correct integration of the functional and operative blocks for the proposal of a framework for a smart framework regarding railway infrastructure management. This WP will deal with the selection of the most suitable alternatives to solve the technological challenges to carry out the goals of this smart maintenance framework.

- ▸ **WP4 (Fuzzy and CI models)** will carry out the design and development of innovative tools based on fuzzy and CI techniques, which constitutes the core of the project. The fuzzy and CI approaches will deal with the development of smart solutions for the maintenance challenges proposed on WP1 and 2. This will result in smart tools supplying solutions such as: evolution and maturing models of the rail infrastructures, their components and systems involved, fault detection and isolation models, fuzzy knowledge bases extracted from databases and experts regarding maintenance tasks, management, consequences, etc., risk analysis based on imprecision and vagueness, optimization multi-criteria based maintenance planning models, and smart decision making models.

- ▸ **WP5 (Integration and usability validation)** will facilitate the general methodology regarding the validation tests to be considered for the implementations of the conceptual maintenance framework designed in WP3. A partial implementation and integration of this conceptual framework will be carried out based on an existing platform that will validate from ICT and CI points of view.

- ▸ Once the proposed solutions have been integrated and tested on a commercial platform, **WP6 (Pilot tests)** will consist of final testing stage of the integrated system. Two pilot tests will be carried out in Spain and Sweden in order to validate the use of the developed technology in the railway infrastructure.

- ▸ **WP7 (Dissemination)** will be focused on promoting an efficient communication, dissemination and further exploitation of the achieved project results.

- ▸ Finally, **WP8 (Coordination & Management)** will carry out the necessary management activities aiming at an adequate coordination of the overall project work plan.

1.3 MAIN S&T RESULTS/FOREGROUNDS

In this section OPTIRAIL project main results will be shown divided by WP. In particular, for every WP, a summary about the work carried out, the most remarkable results and the submitted deliverables will be described in the pages below this paragraph.

1.3.1 WP1. SPECIFICATIONS & REQUIREMENTS

This first WP of the project has sought to meet the following main objectives:

▸ To identify any barriers and define the requirements and specifications (technical and regulatory) to carry out the design, implementation and validation of a smart framework for efficient and reliable maintenance management: the case studies will provide special requirements and constraints.

▸ To identify the sources of knowledge that will allow dealing with the OPTIRAIL proposal.

TASK 1.1. DEFINITION OF CONSTRAINS (REGULATION AND OTHERS)

This task is divided into several sub tasks which merge into the deliverable 1.1.

A deep analysis about how the maintenance operations have been changing along the time, and how different rail track managers schedule and plan them, taking always into account rules, procedures, policies, etc. have been carried out. The Figure 2 shows a brief summary about main maintenance techniques applied in the studied corridors.

NORWAY :
RCM: set of generic maintenance routines with generic intervals. These intervals are to be optimized by formal methods in the future as part of a continuous improvement regime.

SWEDEN :
Maintenance is divided into preventive and corrective maintenance.
TRV is in favour of preventive maintenance and, as much as possible, condition based maintenance (CBM).

SPAIN :
"Condition based maintenance" or "by state". The basis of this system is to maintain continuous intensive monitoring of the elements and track geometry.

POLAND :
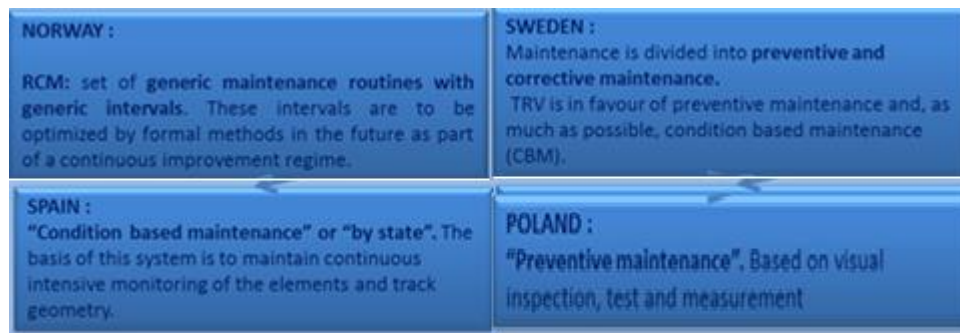"Preventive maintenance". Based on visual inspection, test and measurement

FIGURE 2. MAINTENANCE PLANNING AND SCHEDULING ALONG CORRIDORS.

In addition, a large study about the definition of the tracks, their elements and the construction techniques have been obtained. In this study, the differences between the tracks and also the different traffic characteristics have been analysed.

TASK 1.2. REQUIREMENTS AND SPECIFICATIONS

The main objective of deliverable D1.2 has been to analyse the EU requirements and needs for smart railway maintenance, paying attention to the case studies and defining the technical specifications of

the decision support system, including the sources of knowledge to be involved for dealing with the initiative challenges.

In a requirement process for cross border operations and maintenance, it is important to gain an overview of all regulations needed to be considered and to extract the relevant requirements from these regulations. As an aid to achieve this, the CoVeR method (Cover all Requirements) has been used for the deliverable D1.2.

TASK 1.3. ANALYSIS OF MAINTENANCE AND MANAGEMENT PROBLEMS (CASE STUDIES)

The work carried out in this task finished with the deliverable D1.3 "Traceable database of measurements and test, made over time on the track under study". In this deliverable, first, the main non-destructive testing methods currently used for the monitoring of the railway infrastructure (vision, ultrasonic, eddy current, radiography…) were described. Then, the different railway infrastructure parameters that have to be measured by means of those systems, in order to check the conditions of the permanent way components, were described in the report. The different measures applicable for railway maintenance are also described, such as track component renewal, grinding or tamping.

Finally, a description of the Decision Support System for Railway Infrastructure Maintenance & Renewal Management (RAMSYS) that has been developed to fully support condition based and predictive maintenance has been provided. To conclude, a first approach about the available data that are going to be provided by the railway administrators involved in the project is provided in the chapter called "data dumping".

TASK 1.4. FORMULATION OF FUZZY KNOWLEDGE BASE

This task focuses on what information will be truly available for OPTIRAIL, and how it can be harmonized. Deliverable D1.4 stresses the problem of data harmonization among corridors. Besides mandatory parameters that every National Agency at EU level must monitor, according to related regulations, each country has its own set of measures. This document also introduces the benefits of concept maps to gather expert knowledge and Computational Intelligence to represent knowledge and information in linguistic terms, even if this knowledge is imprecise or vague.

TASK 1.5. PROJECT TECHNICAL MANAGEMENT

The main objective of this task is to control that all the technical objectives are achieved in due time. To this end, all members defined Key Projects Indicators for the following areas of the project in Deliverable D1.5: Innovation & progress beyond state of the art; Collaboration between WPs; Implementation & exploitation; Access to data.

1.3.1.1 MAIN S&T RESULTS OF WP1

One of the most important points for the success of the project was to identify how the quality indices of the track are calculated and interpreted in the different countries (see TABLE 1). Moreover, the thresholds used by the different railway managers related to the geometric measurements, and the dynamics ones for high speed lines in Spain, as well as the data which was used to try to predict a maintenance operation in the next work packages, were also identified.

TABLE 1. QUALITY INDEX OF THE TRACK IN DIFFERENT COUNTRIES.

<table>
<tr><td colspan="4" align="center">QUALITY INDEX</td></tr>
<tr><td>PORTUGAL</td><td colspan="3" align="center">GEOMETRIC ANALYSIS FOR 200 METERS SECTION</td></tr>
<tr><td></td><td>Index</td><td>Limits</td><td>Action</td></tr>
<tr><td></td><td>QN1</td><td>≤ Warning Limit</td><td>Track section in good status</td></tr>
<tr><td></td><td>QN2</td><td>>Warning limit ≤ 1.3 times Warning Limit</td><td>Track section with maintenance needs for medium term.
Actions should be planned in line with the annual planning accordingly with the desired geometric quality and the known degradation trend.</td></tr>
<tr><td></td><td>QN3</td><td>>1.3 times Warning limit</td><td>Track section with strong evidence of maintenance needs in a very short term. Actions to be included on the annual maintenance planning.</td></tr>
<tr><td>NORWAY</td><td colspan="3">$K = \dfrac{\sum l}{L} * 100\%$</td></tr>
<tr><td>SWEDEN</td><td colspan="2">$Q\ \ 150 - 100 \left[\dfrac{=\sigma_H}{\sigma_{\overline{H}\,lim}} + 2\dfrac{\sigma_S}{\sigma_{\overline{S}\,lim}} \right] /3$</td><td>$K = \dfrac{\sum l}{L} * 100\%$</td></tr>
<tr><td rowspan="4">SPAIN</td><td>Conventional Lines</td><td colspan="2">$Q = 2,5 * \left(0,25 * \dfrac{S0 + S1}{2} + 0,12 * S3 + 0,60 * S4 + 0,35 * \dfrac{S6 + S7}{2} \right)$</td></tr>
<tr><td>High Speed Lines</td><td colspan="2">QN1: Value which advised a monitoring of the progress or removed in normal maintenance cycles</td></tr>
<tr><td></td><td colspan="2">QN2: Value that forces to make maintenance operations in a short period of time</td></tr>
<tr><td></td><td colspan="2">QN3: Unwanted situation.</td></tr>
</table>

Therefore, as shows TABLE 1, a rail engineer from Portugal should know, and vice verse, in order to get the interoperability through the European corridors, that the meaning of "QN3" in Spain is not the same as in Portugal. While the same term is used in these two countries, the level of restriction of the corresponding track section is not the same. In addition, other relevant information, such as what external factors affect the degradation of the tracks or some data about the life cycle of the materials, have also been analysed.

On the other hand, thanks to the work carried out within WP1 all relevant requirements for 2 European Directives, 7 TSIs (Technical Specifications for Interoperability) and 4 standards for cross border maintenance in Europe are made easily available from the results of the OPTIRAIL project. However, low level of specification of EU requirements may lead to differences in requirements between countries. This leads to large variations in practice along corridors and much is left to the infrastructure managers and the suppliers. For this purpose CoVeR methodology has been developed based on the TSI rules. It should be remarked that CoVeR for OPTIRAIL only deals with EU regulation and does not include national regulations. The outcome of CoVeR methodology is an excel file which main objective is that every person involved in a maintenance operation knows all the requirements.

Besides, an exhaustive description of the different systems based on non-destructive testing methods currently used for the monitoring of the railway infrastructure, was provided. Different railway infrastructure parameters and different measures applicable for railway maintenance are also described.

Moreover, a modular software platform that enables proactive management of a diverse set of railway assets through enhanced analysis of volumes of data, from the data collection to a maintenance planning, called RAMSYS has been developed.

Finally, main conclusions about data harmonization requirements among corridors have been defined. In this sense, one relevant achievement is that the OPTIRAIL platform could never be implemented in some existing platforms because the owners are not the railway administrators itself. Instead, they rent their use, but this is not a problem for the success of OPTIRAIL project. The only question is that the solution proposed in that cases could sound very simple, but OPTIRAIL will must go to find the information to a specific folder where the people in charge of the information will dump the data.

1.3.1.2 DELIVERABLES SUBMITTED IN WP1

Nº	DELIVERABLE NAME	DELIVERY MONTH
D1.1	Knowledge available on maintenance operations and surveying systems-high speed & conventional lines	M6
D1.2	Create and analyze an updated tools based on early version of CoVer	M7
D1.3	Traceable database of measurements and test, made over time on the track under study	M7
D1.4	Fuzzy knowledge base containing description regarding performance/objectives to be reached	M10
D1.5	Definition KPIs	M6

1.3.2 WP2. TRANSFERABILITY OF TOOLS

The main objectives that have been achieved within the execution of WP2 are:

▸ To describe frameworks and methodologies for maintenance optimization used in other sectors/industries with comparable infrastructures.

▸ To assess applicability of these methods for maintenance optimization for old railway infrastructure and, specifically, in railway freight corridors.

▸ To synthesize and adapt methods for use in maintenance optimization for railway infrastructure.

▸ To reformulation and improvement of these approaches based on fuzzy logic for subsequent computer based implementation.

TASK 2.1. MULTIOBJECTIVE MAINTENANCE FRAMEWORKS AND METHODOLOGIES IN HIGH CRITICALITY INDUSTRIES WITH DISTRIBUTED INFRASTRUCTURES

This task has been based on four case studies of multiobjective maintenance frameworks in high criticality industries with distributed infrastructures. Each case study constitutes one of four sub-tasks. The four industries studied were: 1) Electricity distribution, 2) Gas subsea distribution pipelines, 3) Water infrastructure, and 4) Aerospace infrastructure. Each case study can be found as an attachment to D2.1.

TASK 2.2. DEVELOPMENT OF ASSESSMENT MATRIX

Task 2.2 has consisted in two sub-tasks: 1) Development and population of assessment matrix and 2) Validation of assessment matrix. The assessment matrix summarizes the findings from the case studies in Task 2.1. It presents a total of 25 common elements related to maintenance identified in the case studies. These elements were stratified across the following five categories: i) Coordination and information; ii) RCM and maintenance strategy; iii) Data; iv) Analysis and methods; v) Decision support.

The matrix allows for the ranking of the different elements by the rail infrastructure administrators. This ranking can be updated throughout the project, and serve as input to the definition of the "Smart Maintenance Framework" of OPTIRAIL. An initial ranking is presented based on the view of Jernbaneverket (the Norwegian infrastructure owner). Maintenance experts from the domains of the case studies as well as maintenance experts with knowledge of railway infrastructure maintenance have revised the assessment matrix to ensure validity.

TASK 2.3. SYNTHESIZE AND ADAPT METHODS FOR RAILWAY INFRASTRUCTURE

Task 2.3 is summarized in Deliverable 2.2. The purpose of the deliverable is to synthesize identified practices into contributions to the OPTIRAIL smart maintenance framework and to the multi-objective framework for maintenance optimization.

TASK 2.4. REFORMULATION OF METHODS FOR IMPLEMENTATION IN COMPUTER BASED TOOL

Task 2.4 is summarized in deliverable D2.3. The deliverable expanded the literature review of D2.2, and considered especially technical and implementation-relevant aspects of the presented systems. Mathematical or algorithmic formulations, where possible, have been used so that the concepts are detailed up to a level where they could be potentially implemented. A deep review in the critical and strategic sectors (mainly electricity, water, and gas domain) due to the similarity with the railway domain was performed with a focus on management models, scheduling models and maintenance optimization policies. For each included work, D2.3 lists main contributions, provides a short summary, discusses relevance to OPTIRAIL and includes considerations from a domain expert in the consortium.

Outcomes of this literature review are further linked to D2.1 and D2.2 by analysing the papers according to the "Smart Maintenance Framework" of D 2.2.

Finally, deliverable 2.3 discusses the implementability of some of the most relevant approaches present in the literature, mentioning explicitly the tools, programming languages, etc. which could be used for such an implementation, and outlining the implementation. In the literature, often standard optimization methods are used, and adapted to specific problems. Hence, application specific questions of problem formulation, target functions, constraints formulation and definition of the objectives were discussed in more detail than the (standard) algorithms. Regarding the optimality criterion, the literature focuses on reliability, maintainability, maintenance cost, availability, and failure rate. Together with D2.1 and 2.2, D2.3 gives a good base of the state of the art in other domains, and outlines the procedures to follow on the way to the implementation of a working system. Therewith, it can be a helpful guideline for the implementation of the OPTIRAIL system.

1.3.2.1 MAIN S&T RESULTS OF WP2

One of the main results of WP2 is that the direct transferability of tools and methods is most relevant from the natural gas industry than for other studied sectors. This is due to the fact that the organization of the sector shares some characteristics with the rail sector, such as the purpose and topology of the infrastructure. In the sector, cross-border and cross-organizational coordination of

maintenance activities are successfully managed by the infrastructure operator. Maintenance must be planned well in advance (the year prior to execution) in order to be categorized as "planned", and the various actors in the gas value chain synchronize their maintenance plans in order to keep system down-time to the minimum. The sector also deals efficiently with opportunistic (shadow) maintenance.

However, a general trend in the four case studies is an increase in the amount of data made available to contribute to efficient maintenance management. The increase is the result of new technologies resulting in more detailed data on the condition of the infrastructure, as well as better routines in registering and storing data. The representatives interviewed in the case studies share the understanding of the potential for more effective and efficient maintenance based on use of the available data. There still exists, however, a high degree of manual input and subjective reasoning on the state of the infrastructure and the prioritization of maintenance and renewal activities. Although academic literature presents a range of methods and tools for maintenance management of critical infrastructure, adaptions by industry remains very limited.

In addition, an assessment matrix has been developed that compiles the findings from these four case studies. It presents a total of 25 common elements related to maintenance identified in the case studies. These elements were stratified across the following five categories: i) Coordination and information; ii) RCM and maintenance strategy; iii) Data; iv) Analysis and methods; v) Decision support.

Afterwards, the identified elements of interesting maintenance practices listed in the assessment matrix were discussed in detail in a project-internal workshop held in Granada in April 2013. As conclusion the following eight elements from the case studies were identified as the most relevant to railway maintenance:

- Regulations on cross-border coordination.
- Standardization and harmonization.
- Inter-European database on rail infrastructure (incl. failure data).
- Adaption to local conditions.
- Coordination and dialogue between actors (in the transport value chain).
- Monetization of effects/consequences.
- Holistic mindset.

▶ The Long-term perspective.

Besides, regarding the feasibility of adapting these elements to the railway maintenance, it has been concluded that, although the potential benefit of incorporating the elements in railway maintenance is substantial, several prerequisites must be in place for them to be successfully integrated in the OPTIRAIL tool.

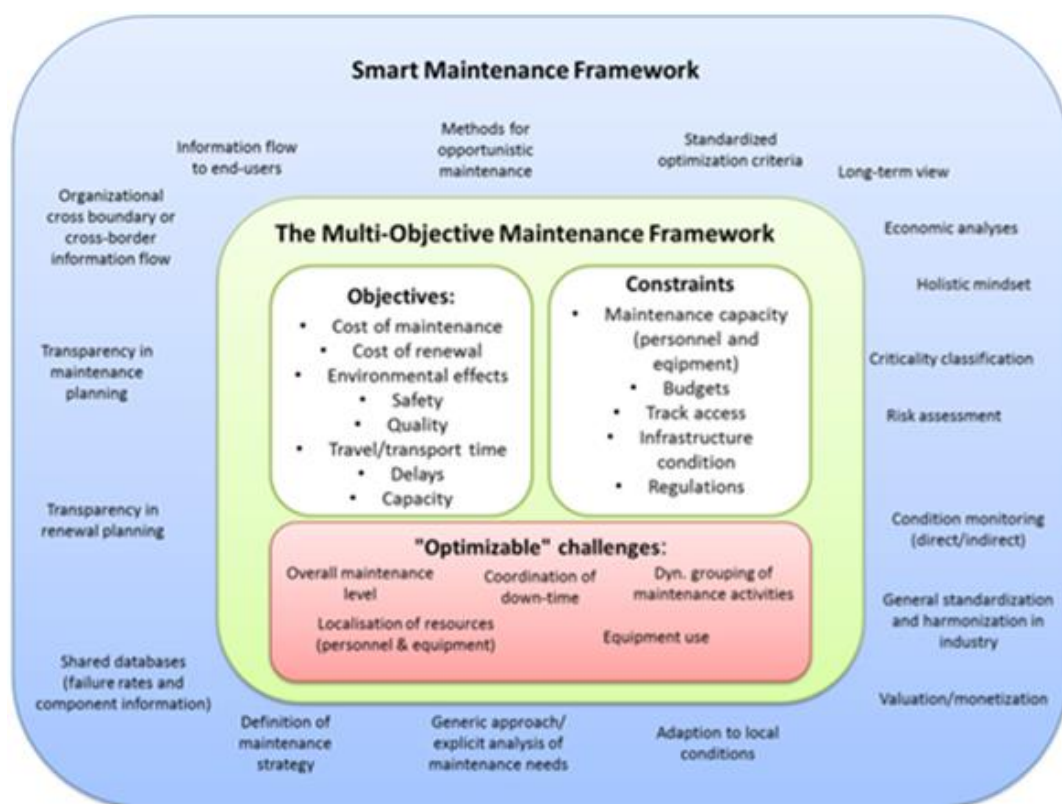For an illustration of the Smart Maintenance Framework, the assessment matrix elements and a Multi-Objective framework is presented, see FIGURE 3.

FIGURE 3. SMART MAINTENANACE, ASSESSMENT MATRIX & MULTI-OBJECTIVE FRAMEWORK.

Finally, the implementability of some of the most relevant approaches of computer based tools present in the literature, has been deeply analysed.

1.3.2.2 DELIVERABLES SUBMITTED IN WP2

Nº	DELIVERABLE NAME	DELIVERY MONTH
D2.1	Characteristics of different approaches to and frameworks for maintenance optimization methodologies	M6
D2.2	Detailed description of methodologies synthesized and adopted for use in maintenance optimization	M7
D2.3	Technical documentation of resulting methods based on fuzzy logic	M10

1.3.3 WP3. CONCEPTUAL DESIGN

The main objectives that have been achieved within the execution of WP3 are:

▸ To identify the data, information and knowledge to be used in WP4, and requirements and constraints derived from the analyses done in WP1 and WP2.

▸ To identify the ICT systems that collect and store the historic data from monitoring & information regarding the interventions on the railways, traffic and any other aspect involved regarding these interventions. These systems must supply the source data for the OPTIRAIL tools.

▸ To know the standards, requirements and hardware & software technology of the systems previously mentioned.

▸ To know how this information can be accessible/available for the OPTIRAIL tools by remote or/and local ICT tools/ways.

▸ To know the processing needed of this data to be used by OPTIRAIL tools and the tools needed for this goal.

▸ To identify the expert knowledge available for the OPTIRAIL tools and the methodology to transform it into a fuzzy knowledge base useful for the OPTIRAIL tools.

▸ To study the interoperability amongst all the technological components that must collaborate in order to reach a smart tool: standards, database technologies, communications, protocols, accessibility, etc.

TASK 3.1. ANALYSIS OF ICT SYSTEMS REGARDING RAILWAY DOMAIN

In order to integrate the OPTIRAIL approaches and tools in the workflows of the current maintenance systems and services, it is necessary to know which are the Information and Communications Technology (ICT) systems used by companies and managers for these tasks. Each partner involved in the project, in collaboration with its local railway infrastructure manager, has provided information on the ICT Systems that are used in the five corridors considered in the OPTIRAIL project:

▸ High Speed Lines in Spanish Corridors: ADIF as infrastructure manager and VIAS-CARTIF-UGR as partners involved in the WP.

▸ Conventional Lines in Spanish Corridors: ADIF as infrastructure manager and VIAS-CARTIF-UGR as partners involved in the WP.

▸ Norwegian Corridors: JBV as infrastructure manager and SINTEF as partner involved in the WP.

▸ Swedish Corridors: Trafikverket as infrastructure manager and LTU as partner providing information to CARTIF.

▸ Portuguese Corridors: Refer as infrastructure manager and EVOLEO as partner involved in the WP.

TASK 3.2. DEFINITION OF COMPONENTS, INTERFACES AND WORKFLOWS

Within this task the definition of main components, interfaces and workflows has been performed. This task is directly related with Task 3.3 and, as an outcome, the Deliverable D3.2 has been submitted.

TASK 3.3. DESIGN OF A GENERAL CONCEPTUAL FRAMEWORK

In this task, in cooperation with Task3.2, a general conceptual framework concerning smart maintenance management has been proposed, as well as the interrelation with the ERPs identified in the first task. Specifically, their workflows and interfaces have been defined and some technological solutions/alternatives to their implementation have been specified.

Finally, as part of the activities developed in the last two task of WP3, an initial standardization of cross-border procedures regarding data and management has also been proposed. This standardization is carried out through the three layers in SOA architecture: first level related to data and knowledge acquisition, second level related to the business logic and third level related to the user interface.

At the data & knowledge acquisition level, the standardization is achieved by considering a common list of geometrical parameters (those listed in the European Standard EN 13848-1:2003+A1:2008) and measurement procedures. The business logic level includes one proposal for a quality index standardization (OPTIRAIL predictive Index, OI) that could be used in cross-border operations. The user interface level includes the protocols and some guidelines to be used in cross-border maintenance. All these ideas were collected in Deliverable D3.3 in cooperation between CARTIF, VIAS, UGR and OSTFALIA.

1.3.3.1 MAIN S&T RESULTS OF WP3

First of all, within this WP a first outline of the ICT roadmap with the ERP application that the infrastructure manager use nowadays in the railway corridor has been defined. The FIGURE 4 shows a summary of the ICT applications that had been identified, whose descriptions are collected in Deliverable D3.1.
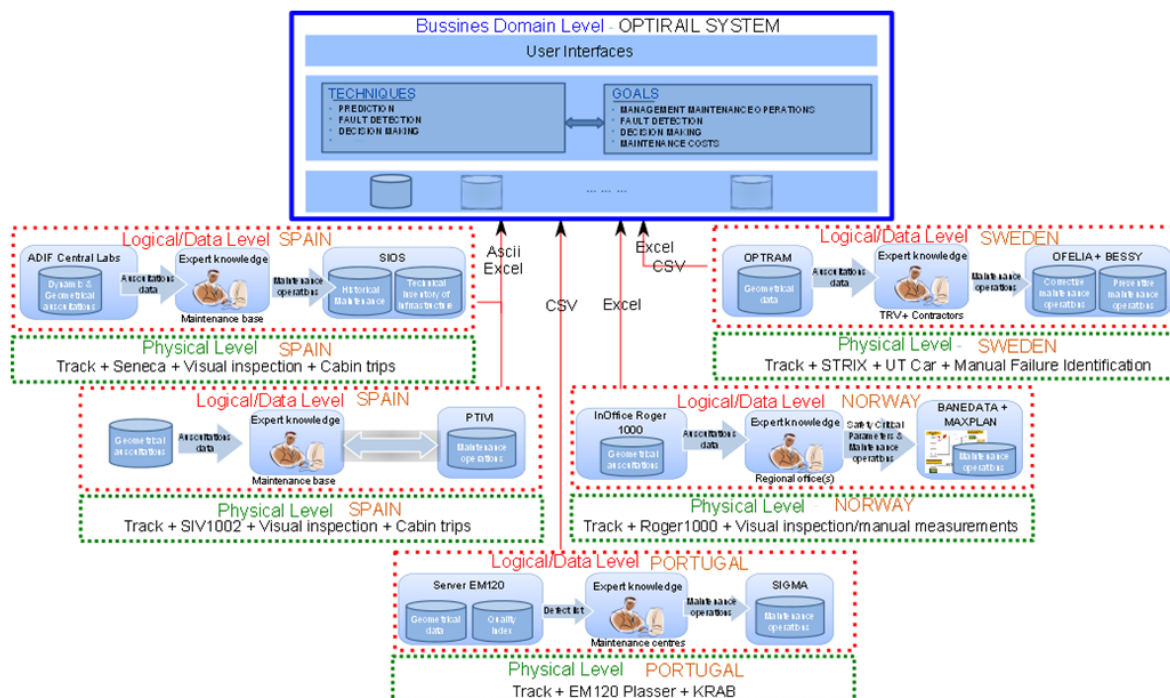
FIGURE 4. ERPS & OPTIRAIL FRAMEWORK.

Afterwards, a general conceptual framework concerning smart maintenance management has been defined, as well as the interrelation with the ERPs. In particular, their workflows and interfaces have been defined as well as some technological solutions/alternatives to their implementation.

The analysis of the available data and expert knowledge has allowed the design of the OPTIRAIL framework, as described in the DoW, based on SOA (Services Oriented Architecture) client-server architecture with three layers: user interface, business logic and data & knowledge acquisition (see FIGURE 5). All the different services necessary to obtain an optimized railway maintenance plan have also been specified by CARTIF with advice of VIAS, UGR, OSTFALIA, EVOLEO and MERMEC, as well as some use cases, class diagrams, the structure of the database and several sequence diagrams. All these diagrams, joined to a description of the programming protocol (user interactions, operations, deployment and validation, among others) provided by EVOLEO and the formats to interact with RAMSYS tool provided by MERMEC, have been included in the Deliverable 3.2.

It should be remarked that the framework has been designed with an open concept, so new data issues and alternative solutions can be added to each level of the OPTIRAIL framework to update and/or improve the OPTIRAIL performance at any moment through the possible best solutions for each issue.
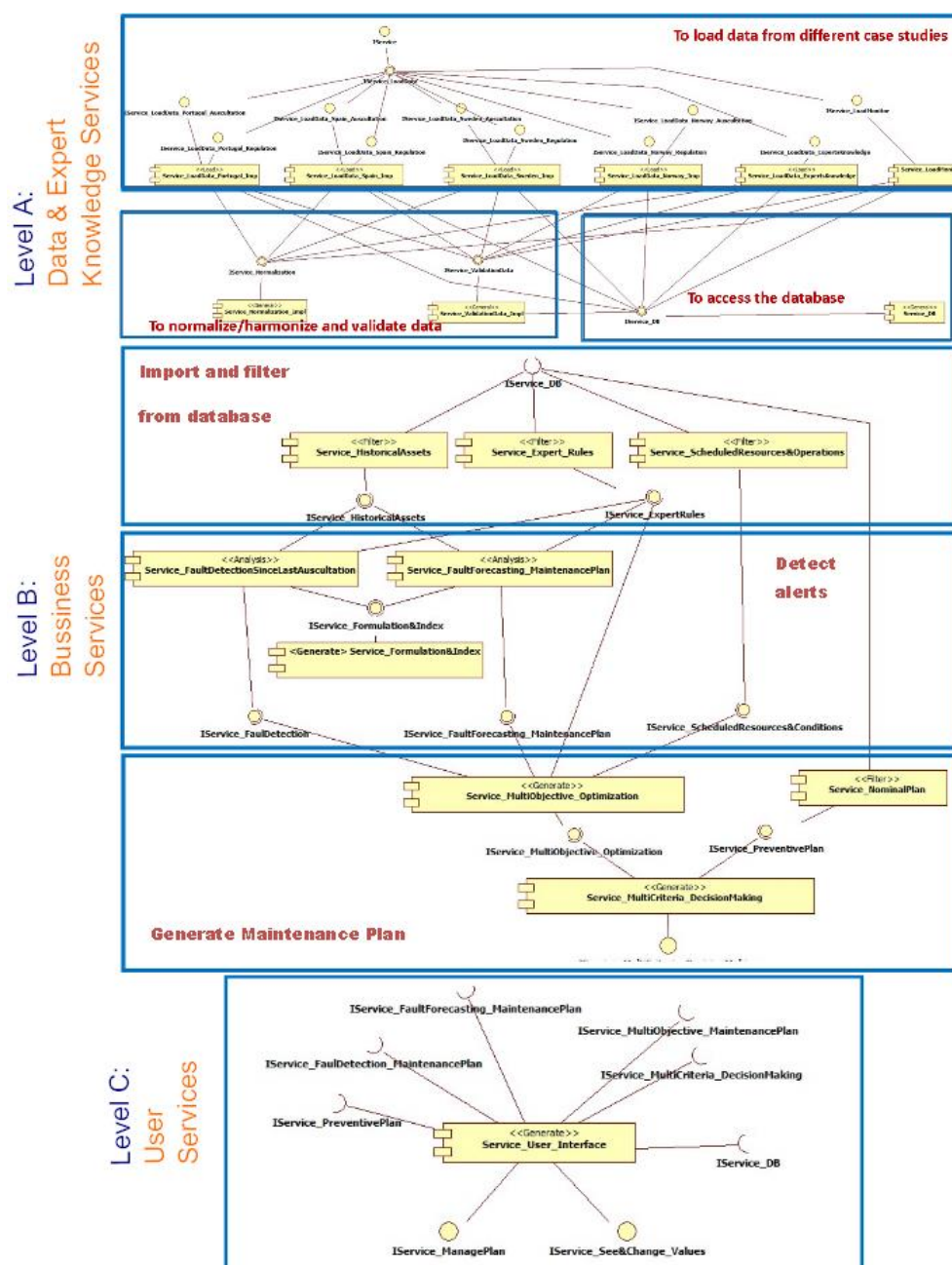
FIGURE 5. OPTIRAIL SOA ARCHITECTURE.

Finally, as part of the activities developed in the last two task of WP3, an initial standardization of cross-border procedures regarding data and management has also been proposed.

1.3.3.2 DELIVERABLES SUBMITTED IN WP3

Nº	DELIVERABLE NAME	DELIVERY MONTH
D3.1	Report on ICT systems	M9
D3.2	Report on the conceptual framework for the OPTIRAIL initiative	M14
D3.3	Report on standardization of cross-border procedures regarding maintenance data and management	M14

The main goals that have been achieved with the execution of WP4 are:

- To develop fuzzy and Computational Intelligence models from data for railway infrastructure and components.
- To develop fuzzy and Computational Intelligence models for maintenance, management and traffic processes gathering constraints.
- Knowledge extraction from experts.
- Knowledge and data-driven models cooperation for maintenance tasks.
- To develop procedures for multi-objective decision-making.

TASK 4.1. FUZZY MODELS FOR RAILWAY INFRASTRUCTURE AND COMPONENTS

Within this task a modelling was performed to simulate the behaviour of the infrastructure and its main components, as it is shown in Figure 6.

At the beginning only a very limited amount of data was collected, but finally thanks to the collaboration of LTU and ADIF, OPTIRAIL was able to collect data from Spain, Portugal, Norway, and Sweden. The proposed modelling was then performed according to the availability and quality of data. For the data from Sweden, the full modelling could be performed, and we could show that the proposed modelling framework is
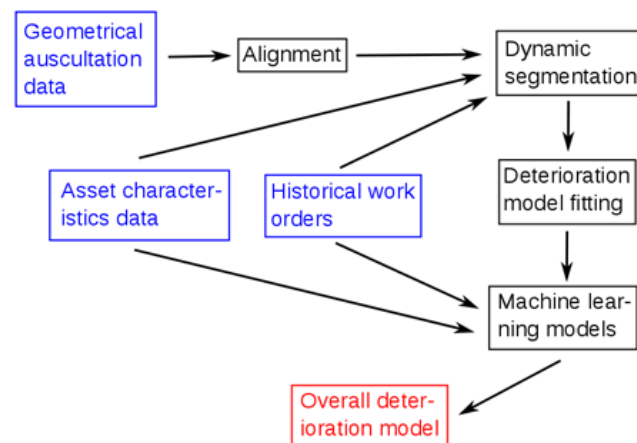

FIGURE 6. SCHEME OF THE INFRASTRUCTURE MODELLING.

feasible. For the other corridors, modelling was performed up to the degree the data allowed for, indicating what would be necessary to be able to perform the full modelling or to achieve better results.

Though fuzzy rule-based systems (FRBS) are suited for this type of modelling, we note that two main advantages of FRBS are that they can deal with linguistic, uncertain input, and that their output is interpretable as a rule-based system. However, in the type of modelling that was performed, there is no (linguistic) uncertainty in the input, and the interpretability of TSK-type FRBS which are used for regression is limited, so that it cannot be justified to focus solely on FRBS for this study, which is why also other promising state-of-the-art methods such as support vector regression (SVR) or random forests were used.

TASK 4.2. FUZZY MODELS FOR MAINTENANCE, MANAGEMENT AND TRAFFIC PROCESSES

In task 4.2, the modelling of maintenance operations was performed in different ways:

- **Data driven:** On the basis of the current geometric measurement and the work order history, fuzzy rule-based systems and other machine learning methods were used to model the maintenance operations necessary from the current measurement.

- **Expert knowledge based:** As this information was already available up to a certain level, relevant expert knowledge was recollected (in addition to task 4.3).

TASK 4.3. KNOWLEDGE EXTRACTION FROM EXPERTS

In task 4.3, expert knowledge through a questionnaire answered by experts from the railway maintenance domain of 6 countries was gathered. Within this task a study was carried out with considerable amounts of data and interesting results, both on infrastructure degradation and on some of the most relevant maintenance operations, being to the best of our knowledge the first studies of this kind using data from several different countries/railway managers, and to use and compare several state-of-the-art Computational Intelligence methods for the defined regression and classification problems.

TASK 4.4. COOPERATION OF EXPERT KNOWLEDGE AND DATA-DRIVEN MODELS

In this task two processes for the cooperation of expert knowledge and data-driven models have been established:

- **1.Guidance and delimitation:** the expert knowledge is used before data-driven models are built, in order to determine, which models are useful and which of the available data to use, and in which way. This expert knowledge is used for feature selection during for developing improved versions of deterioration models defined in deliverable D4.1.

- **2.Control and combination:** the expert knowledge is used at the same time of the use of the data driven models, and afterward. The output of the data-driven models is verified using the expert knowledge, inconsistencies can be detected and investigated further, and where no data is available but expert knowledge is, this knowledge can be incorporated in the models. In addition, this expert knowledge has been used to verify and validate data-driven models defined in D4.1.

TASK 4.5. DEVELOPMENT OF MULTICRITERIA DECISION-MAKING

The heart of the smart platform for railway maintenance is a decision-making procedure that, based on the deterioration models built in previous tasks of WP4 produces a set of candidate recommended maintenance plans. This system is designed and implemented within this task.

An overall scheme of the system is depicted in Figure 1.

1.3.4.1 MAIN S&T RESULTS OF WP4

The two core results obtained through the application of Computational Intelligence tools are data-driven models for infrastructure components and processes, and knowledge elicited from experts. For an effective maintenance plan both should be used in a cooperative fashion. In the OPTIRAIL project, this combination is done in two different ways: (i) to guide and delimit model building, and (ii) to verify, control, and complete the resulting models. The first case is used, e.g., to choose relevant data, to define structure and parameter values of the objective functions, and to define heuristic initialization procedures. The second case involves sanity checks of the results, interpretation of (simpler) relationships in the data, and analysis of the feasibility of time periods.

A key component of the smart abilities of the OPTIRAIL tool is a multi-objective optimization framework for maintenance planning. The improvement of the effectiveness of infrastructure maintenance can be measured using multi-criteria, which in many cases are competing and conflicting among themselves. This only gets worse when considering the different constraints to be met (e.g. imposed by regulations). In D4.4 a general analysis of the objectives and constraints in maintenance optimization, and an implementation of a multi-objective optimization framework, implementing a typical use case and the combination of objectives and constraints is presented. Concretely, a trade-off between maintenance cost of tamping and complete renewal operations, versus train delay/capacity loss in the same time period, is considered. Furthermore, we have available different optimization strategies, namely a simulated annealing approach and an evolutionary algorithm. The performed experiments output Pareto fronts with various candidate solutions from which the decision makers can choose a suitable solution. The results show that the algorithm is able to further improve the initial solutions, which are generated by a powerful heuristic that incorporates expert knowledge. The solutions are improved both in terms of delays/capacity loss and cost. This is achieved by re-organizing tamping and renewal actions within the planning horizon.

1.3.4.2 DELIVERABLES SUBMITTED IN WP4

Nº	DELIVERABLE NAME	DELIVERY

		MONTH
D4.1	Report on fuzzy systems built for railway infrastructure component modelling	M16
D4.2	Report on fuzzy systems built for maintenance processes modelling	M16
D4.3	Report on knowledge extraction process from experts and combination with data-driven fuzzy models	M16
D4.4	Report on multi-criteria decision making and multi-objetive optimization	M22

1.3.5 WP5. INTEGRABILITY AND USABILITY VALIDATION

This WP has been devoted to the design of a useful Lab validation scheme, from a technological point of view, for the conceptual framework design carried out in WP3. Through this scheme, a validation guideline has been provided for the full or partial implementations of the OPTIRAIL framework that ensures the key points and performances of the OPTIRAIL framework functionality and usability. Finally, in order to validate the OPTIRAIL concept and its models, as well as its integrability into commercial maintenance platforms, the new smart tool has been implemented in the RAMSYS Platform.

TASK 5.1. VALIDATION METHODOLOGY DESIGN AND METRICS DEFINITION

This task proposes a lab validation methodology to check and confirm, by mean of objective evidence, that the requirements that have to be met by the OPTIRAIL tool are fulfilled. This validation step must assure the quality of the results provided by the platform. Furthermore, the validation has also been performed through the preparation of a total or partial integration with an existing maintenance platform (RAMSYS).The overall validation phase assures at the end that the complete platform complies with its specifications.

The validation scheme defined in Task 5.1 has been used later in the implementation of the OPTIRAIL tool in Task 5.2 in order to ensure that it fulfils the requirements. Then, its functionality and performance regarding maintenance operation and management have been checked by comparison with the results of the implementation of the OPTIRAIL case studies in the RAMSYS platform, that have been performed in T5.4.

TASK 5.2. INTEGRATION MODELS INTO OPEN PACKAGE SW

In this task, the actual open framework SW tool of the OPTIRAIL concept has been designed, and it is available and downloadable at this address: www.optirail.eu. In particular, the following four main aspects have been taken into account to implement the OPTIRAIL design and solutions:

‣ The validated models from WP4 and metrics from task 5.1;
‣ The OPTIRAIL platform requirements in terms of functionality and operability;

- An open framework design approach;
- The need for interoperability with existing tools.

Finally, a software user manual describing how to install and configure the OPTIRAIL software and to stand alone operate, and an Interface document and integrate the OPTIRAIL tool into other platforms for which the OPTIRAIL tool has also been produced.

TASK 5.3. INTEGRATION OF THE OPTIRAIL TOOL IN RAMSYS PLATFORM

The integration of the smart OPTIRAIL framework into a usual ICT platforms in the railway domain has been performed in this task. On the one hand, the evaluation of the usability of the OPTIRAIL open source software has been performed by means of the implementation of the OPTIRAIL framework in the RAMSYS platform. On the other hand, in this evaluation process a verification of the interfaceability of the OPTIRAIL tool with RAMSYS has been carried out.
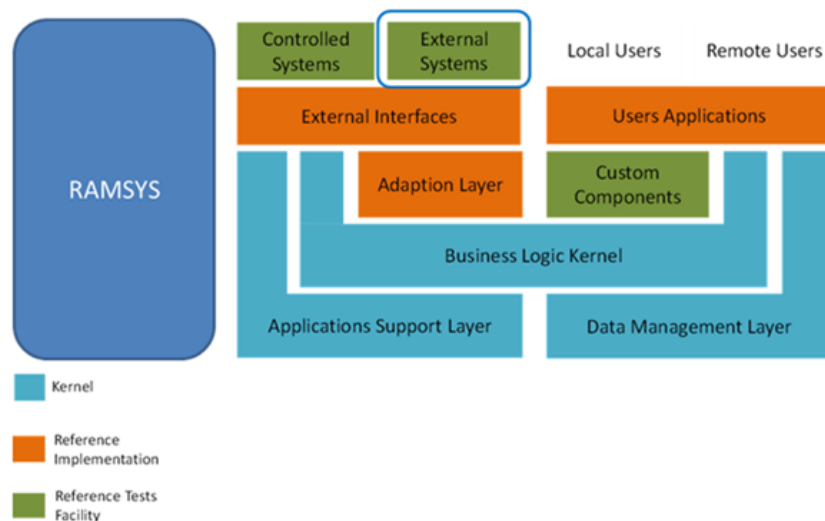

FIGURE 7. EXTERNAL SYSTEMS IN OPTIRAIL ARCHITECTURE.

TASK 5.4. VALIDATION OF THE INTEGRATION IN RAMSYS PLATFORM

This validation activity has checked the optimization of maintenance works in time and space. It has been carried out on a repository of structured and accurate data. The validation of the OPTIRAIL conceptual framework has been realized through its integration and comparison with the existing software platform RAMSYS for asset data management and decision support, as defined in task 5.1. This validation has followed the whole scheme for infrastructure modelling and maintenance prediction defined in WP4 (alignment, segmentation, deterioration models…).

First of all, a validation methodology has been obtained as a result of the work carried out within WP5. This validation metholodgy has included and developed the following tools and concepts:

▸ Definition of use cases that covers critical OPTIRAIL phases, design of several scenarios simulating the worst conditions;

▸ Definition of a measurement procedure to obtain objective measures of the quality of the platform;

▸ Evaluation of metric tools to measure the platform performance;

▸ Implementation and integration into an existing maintenance decision support tool (RAMSYS).

Second, the OPTIRAIL open source software has been developed within WP5. The following figures show some print screens with its main functionalities (more information can be found in D5.2): Login in; Look up information; Maintenance plan.
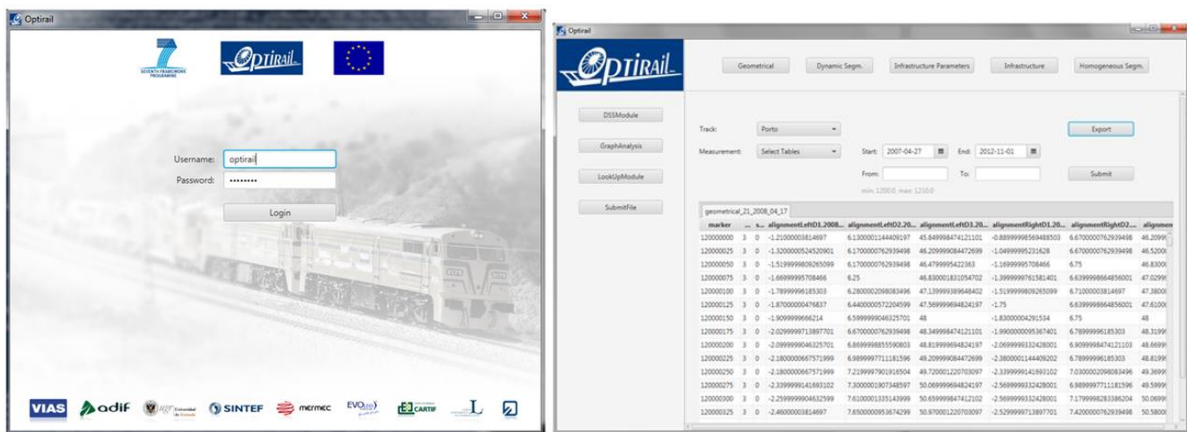

FIGURE 8. LOGIN SCREEN (LEFT) AND LOOK UP MODULE SCREEN (RIGHT).

FIGURE 9. DECISION SUPPORT SYSTEM MODULE: INFO DISPLAY.

Thirdly, the integration of the smart OPTIRAIL framework into a usual ICT platforms in the railway domain has been performed within this WP. In addition, the evaluation of the usability of the OPTIRAIL open source software has been performed by means of the implementation of the OPTIRAIL framework in the RAMSYS platform. Within this evaluation process a verification of the interfaceability of the OPTIRAIL tool with RAMSYS has been carried out.

Finally, the new OPTIRAIL smart and open tool has be implemented and validated by the RAMSYS platform in terms of data types and templates used to exchange input and output data. It has also been proved that OPTIRAIL track planning tool can be integrated with RAMSYS in order to generate track plans based also on the OPTIRAIL models and techniques.

1.3.5.2 DELIVERABLES SUBMITTED IN WP5

Nº	DELIVERABLE NAME	DELIVERY MONTH
D5.1	Reporting on validation methodology design and metrics definition for the OPTIRAIL Concept Design	M21
D5.2	Open Source Software Package	M24
D5.3	Reporting on the integration and usability of the OPTIRAIL tools in RAMSYS platform.	M29

1.3.6 WP6. PILOT TESTS

The main objective of WP6 has been to validate the usability of the developed tools for the railway industry. In particular, the main approach for the validation has been a variant of Living Lab (end-user involvement in systems design and development) specifically adapted for validation and evaluation of rail industry scenarios and functionality demands. By involving the end-user actively in the validation and tools design and development the results has been adapted to the "real-world" usage of the resulting tools and systems.

TASK 6.1. VALIDATION PROCESS PLANNING & ADAPTATION

OPTIRAIL has created one tool for maintainers as a result of the interaction of end-users with researchers and stakeholders. In particular, the method especially designed for the OPTIRAIL project has been based on the established Living Lab methodology and the findings from the pilot sites description of their own Best Cases.

The results from surveys and deployment have been gathered and analysed together in order to achieve the validation of the tool. These experiences and results have end up in the following eight Step Pyramid:

FIGURE 10. LIVING LAB METHODOLOGY WITH THE EIGHT STEPS PYRAMID.

TASK 6.2. VALIDATION METHODOLOGY DEVELOPMENT

Living Labs represents a research methodology for sensing, validating and refining complex solutions in multiple and evolving real-life contexts. Here, innovations such as new services, products or application enhancements, are validated in empirical environments within specific regional contexts. In this case, Optirail has provided a new product in a mature market where the expectations are high to go beyond to the regular products that the companies are already offering (the state of the art).

The individual is in focus in the role of a citizen, user, customer or worker. This case are two different costumer. Both are railway administrators (TRV and ADIF). The participation not only of the potential customers but also of all other stakeholders along the value-chain can be seen as the foremost required element for the successful operation of a Living Lab. In this case, inside of the consortium, there is one construction and maintenance company as VIAS that it can be potential user for the performance of its activities. In order to learn about the user experience and acceptance of the solution, the pilots have collected quantitative and qualitative feedback from users during the pilot test phases and cycles by deploying the following methods:

TABLE 2. DATA CAPTURE METHODS.

Method	Aim
Questionnaire	Quantitative feedback/ Qualitative feedback in open question
Interview	Qualitative feedback
Focus group/demonstrations	Qualitative feedback
Participant observation	Qualitative feedback
Data Logs	Quantitative feedback on usage

Each of these methods were selected to elicit a particular kind of data and to enable a full end-to-end analysis of the pilot services. All pilots have used questionnaires, interviews and demonstrations. Questionnaires allowed the consortium to gather quantitative feedback from a large number of end users about the user experience and acceptance but provided also more qualitative feedback by means of open questions where testers could express the negative aspects, positive aspects and recommendations for design purposes. Interviews and focus groups allowed in the evaluation phase to gain a deeper understanding of meaningful themes, practices and relationships from the interviewee's point of view. This will be circulated among different potential users from IM´s. Some workshops has also been prepared during the rest of the project.

TASK 6.3. VALIDATION INFRASTRUCTURE DEVELOPMENT

The goal of this task has been to define an appropriate state-of-the-art infrastructure to develop an e-maintenance cloud for the validation of an OPTIRAIL tool using the living lab approach. The overall system architecture has been based on a service-oriented multi-layer approach with the following objectives:

▸ 1. Enhance the agility, efficiency and productivity of an enterprise's system.
▸ 2. Provide platform-independent access to the services within the architecture.
▸ 3. Provide a wide range of data storage capabilities.
▸ 4. Provide web platforms for dynamic web applications.
▸ 5. Provide a virtualised hardware platform.

TASK 6.4. TEST CASE VALIDATION (PILOT TESTS)

OPTIRAIL has considered a living lab approach from the start of the project, it is at this point that the methodology is expected to positively affect the design of the prototype, its deployment in the pilot projects and the management of the feedback provided by the end users of the case studies. In particular, all contributors have been involved in the stages before the prototyping stage, but the outcome of the living labs has been deployed in two: Spain and Sweden.

TASK 6.5. VALIDATIONS CROSS ANALYSIS & PRACTICE DEVELOPMENT

In Task 6.5 an analysis of both validation test cases (Spain & Sweden) results and intermediary results has been performed as well as an evaluation of the overall effectiveness of the validation processes as a whole. Taking into account the results from this analysis evaluation an state of the art to be utilized in later efforts within the railway sector has been created.

1.3.6.1 MAIN S&T RESULTS OF WP6

The execution of WP6 has allowed to obtain a set of lessons learnt that have been compiled in the deliverable D6.5. Within this section, a brief summary about this relevant results and lessons learnt is provided.

As it is known the railway is one of the prime modes of transportation for humans and materials. Therefore, safety, reliability, sufficient capacity and availability are main requirements of a railway network (Patra, 2009). With the advancement of technology and increasing competition in all sectors of transportation, railways must restructure and upgrade their management and technology (Profillidis, 2006). In today's competitive market, they are called upon to reduce operating and maintenance costs whilst improving network capacity. This can be accomplished by changing the culture within operation and maintenance departments by shifting from a reactive to a proactive strategy.

In Europe, the government usually owns railway systems. This means the strategic objectives of railway networks are often based on political decisions (Espling, 2007). However, the European Union is moving toward an open access model for railroads in which track infrastructure administration is separated from train operation (Resor and Patel, 2002).

Track geometry is an important aspect of railway construction (Esveld, 2001) for the following reasons, as indicated by Jovanovic (2004):

▸ The degradation of many other track components is closely related to the track geometry condition;
▸ Track geometry is often used to trigger the entire range of track maintenance and renewals.

Track with good inherent quality provides a good ride and needs little maintenance; conversely, track with poor inherent quality results in poor ride comfort and requires much maintenance (Selig and Waters, 1994). For example, Karttunen et al. (2012) show the influence of lateral geometry irregularities on the mechanical deterioration of freight tracks.

Track maintenance consists of inspections and interventions (Lyngby et al, 2008). Inspections are carried out to ensure track safety by monitoring track condition and obtaining the information

necessary to set up maintenance scheduling. Inspections are manual or automated using a vehicle. Intervention refers to preventive and corrective maintenance, as well as renewal actions carried out to improve track quality.

In the past, railway maintenance procedures were usually planned based on the knowledge and experience of the infrastructure owner. The main goal was to provide a high level of safety, and there was little concern for economic issues (Lyngby et al,2008; Carretero et al, 2003). Today, however, the competitive environment and budget limitations are forcing railway infrastructures to optimise operation and maintenance procedures. The primary goal is to reduce the operation and maintenance expenditures whilst still assuring high safety standards (Lyngby et al.,2008; Carretero et al., 2003).

Optimising maintenance requires estimating track degradation and the consequence of this degradation, often in the form of cost (Lyngby et al., 2008). Obtaining knowledge about degradation helps a company estimate the right time for inspection, maintenance and renewal.

Track geometry degradation is a complex phenomenon affected by dynamic loads (Esveld, 2001). The rate of degradation is a function of time and/or usage intensity (Lyngby et al., 2008). According to Lichtberger (2001), the initial track quality, the initial settlement and the deterioration rate are the major parameters of track quality deterioration. The monitoring and evaluation of track geometry allow the infrastructure administration to control safety and plan track maintenance (Berggren et al., 2008).

1.3.6.2 DELIVERABLES SUBMITTED IN WP6

Nº	DELIVERABLE NAME	DELIVERY MONTH
D6.1	Validation Process & Planning Adaption	M24
D6.2	Validation Methodology Development	M28
D6.3	Validation Infrastructure Development	M28
D6.4	Test Case Validation.	M36
D6.5	Validation Cross Analysis & Practice Development	M36

1.4 POTENTIAL IMPACT

1.4.1 SOCIO-ECONOMIC IMPACT

IMPACT 1: STRENGTHEN GLOBAL POSITION OF TRANSPORT INDUSTRY

OPTIRAIL project has definitely contributed to **improve the European Railway competitiveness**, thanks to the development of the new solutions that will allow:

▸ To increase the overall network efficiency and safety: reduced disruptions and improve safety due to more effective planning and coordination.

▸ To enhance the maintenance process reliability: solutions will be defined to make the railway network available and reliable to carry on maintenance tasks before failure.

▸ To reduce the environmental impact: the proposed solutions tend to decrease traffic disruptions, by using the network more cleverly without impacting the system reliability. Moreover, increasing the efficiency of the network of rail freight in Europe will facilitate the movement of goods and commodities across it, reducing the dependence on others more polluting kind of transports.

▸ To reduce the cost of the system as the new system services provide coordinated solutions.

Furthermore, the OPTIRAIL project will allow further replication based on experimental data by bringing new technical evidence to coordinated decision making that will foster the promotion of the single European rail market.

The pilot tests performed in the OPTIRAIL have demonstrated the ability of the new tool to predict the state of a railway track supporting the decision process when an event happen and sudden decision needs to be taken for the safety and the successful operation of the network, providing reliable service for very long periods of time.

In addition, OPTIRAIL project has developed an intelligent management tool, in order to handle, in real time, in a safe and sustainable manner, the flows of passengers, vehicles and freight and their reciprocal interaction and dialogue with the infrastructure.

Finally, it should be remarked that, apart from the improved tools for railway corridors and the coordinated planning methodologies proposed for the pilot case studies, optimal integration will

mean that all the stakeholders involved in these integration experiments will benefit from the tested solutions.

IMPACT 2: CONTRIBUTION TO THE EU TRANSPORT POLICY OBJECTIVES

The EU White Paper "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" states that: Infrastructure shapes mobility. No major change in transport will be possible without the support of an adequate network and more intelligence in using it. For this reason, the improvement of European mobility needs new solutions and technologies in different areas such as the ones develepod within the OPTIRAIL project linked to maintenance management.

One of the main goals established in this EU White Paper for Transport Systems, is to shift by 2030 the 30% of road freight over 300 km to other modes such as rail or waterborne transport, and the 50% by 2050. To meet this goal it will be also needed to develop new infrastructures (like rail freight corridors) and novel and advanced management system (ERTMS). Moreover, it will also be necessary to approach others aspects such as the maintenance management and cross-border coordination, to ensure the availability of the infrastructure and optimize its exploitation.

The OPTIRAIL project is aligned with the EU transport policy mainly in the following aspects:
▶ the improvement of maintenance operations to increase the security,
▶ the increasing of railway transport efficiency (using new information systems to support maintenance decisions) and to contribute to the develop of a European Railway Network, and
▶ the achievement of a huge level of interoperability, between states and different types of transport.

Thus, the current EU cooperative project represents has shown the capacity for facing these industrial and technological challenges and, therefore, has contributed to accelerate the **development of the single European railway management system** in order to ensure **the future competitiveness of the EU railway industry**.

The achieved impacts of the OPTIRAIL project that contribute to reach the European Policy Objectives have been:
▶ Increase of competitiveness of the railway sector.
▶ Improved methodologies for maintenance planning.

- Increase of reliability and availability of the railway infrastructure.
- Easier introduction of new vehicles on the existing tracks.
- Development of new technologies for cross-border coordination.
- Development of Standards to be applied.

IMPACT 3: CONTRIBUTION TO REINFORCING EUROPEAN RAILWAY INDUSTRY LEADERSHIP

The OPTIRAIL project has shown to be aligned with the main EU Railway Policies through the development of innovative management solutions. In addition, the project has integrated existing scientific knowledge emerging from research initiatives at the European level, as well as from national and international research programs. For this purpose OPTIRAIL project has taken into account other national and international research activities and has shown how the developed technology relies on existing initiatives: European projects from 6th and 7th FP and basic papers from previous programmes, national and international research projects.

On the other hand, OPTIRAIL consortium has been built on the basis of one of the European leaders in the railway industry, in order to be able to demonstrate the following technological developments:

- Railway infrastructure management smart control to deliver decision support services to railway managers.
- Centralized control and co-optimization across the European railway infrastructure for more effective and cost efficient planning.

The mentioned actions have led to obtain a technological progress that will help to increase infrastructure availability, ensure security and improve EU competitiveness.

This project has developed a conceptual design for next generation of decision support tools to manage and coordinate cross-border railway infrastructure maintenance operations. Thus, the deliverables provided within the project will allow the railway industry to take concrete steps in replicating the integration of the new tool with lower risk and less warranty issues.

Finally, by providing to industry and researchers tools (open code) to work with, the consortium has contributed to the appearance of new players with innovative ideas that could be used by the main Railway companies and operators, looking for new ideas and opportunities of becoming better without major investments and risks.

DISSEMINATION PLAN

OPTIRAIL project elaborated a Dissemination Plan at the beginning of the project, collected in Deliverable 7.1. This deliverable has been updated every six months. In addition, in order to monitor and evaluate the dissemination activities, several monitoring tables has been used for summarizing events, publications, etc. In particular, the following table shows a summary of all the dissemination activities carried out by each partner during the project:

TABLE 3. SUMMARY OF DISSEMINATION ACTIVITIES CURRENTLY DONE BY THE PARTNERS.

DISSEMI-NATION ACTIVITIES	VIAS	CARTIF	LTU	UGR	OSTFALIA	SINTEF	MERMEC	EVOLEO	ADIF
Peer reviewed publications		Information Sciences			Communications in statistic				
Participation in Scientific & Technological Conferences	EIA-AIE 2013 & TRA 2014 & eMaintenance 2014 (3)	EIA-AIE 2013 & TRA 2014 (2)	PHM2013 & eMaintenance 2014 & MPMM 2014 (3)	EIA-AIE2013 (1)	FuzzIEEE2013 & WILF2013 (2)	ESREL2013 & RAMS2014 (2)	WCRR2013 & Rail Conferences 2015 (2)		
Assist to National and International Workshops	PTEC2013 & Poland2013 & 7º Forum PTEC 2014 & IX-IHSEC (4)	PTEC2013 (1)	CM/MFPT 2013 (1)				LCM2013 (1)	Smart Rail Europe (1)	
Organization of national or international workshops	OPTIRAIL Mid Term & Final Worksho	OPTIRAIL Mid Term & Final Worksho	ICRESH - ARMS 2015 (1)					Workshop REFER/ UP 2015 (1)	

	p (2)	p (2)							
Newsletters	✓ (7)	✓ (1)	✓ (1)						
News in local media	✓ (11)	✓ (4)		✓ (4)					✓ (11)

Finally, it should be highlighted that detailed information about all dissemination activities carried out within the project is provided in **¡Error! No se encuentra el origen de la referencia.¡Error! No se encuentra el origen de la referencia.**.

ELABORATION OF A PROJECT WEB SITE

First of all, the OPTIRAIL web site (www.optirail.eu) was elaborated in the first three months of the project: the public area of the web site was launched on 20/12/2012, the private area web site was launched on 08/03/2013 and the Advisory Board area web site was launched on 11/06/2013. Finally, in order that everybody will be able to download the OPTIRAIL open source tool, a special web page inside Deliverables & Publications area was launched on 25/09/2015. In general terms, it can be said that the information contained in the web site has been updated every two months.

In order to monitor the impact of the website, several statistics related with web access have been analysed every six months. The following table shows the accumulated data from OPTIRAIL web site accesses since the date on which the website was made available online, 10th February 2013.

TABLE 4. OPTIRAIL WEB ACCESS FROM 2013-02-10 TO 2015-09-30.

STATISTICS OPTIRAIL			
BY VISITS			
Number of unique visitors	11251		
Number of visits	30261		
Number of pages	122295		
Number of hits	2116464		
Mean time on site (seconds)	311		
Traffic (MB)	37414,97		
BY COUNTRIES (TOP 5)			
	Number of pages	Number of hits	Traffic (MB)
Germany	14433	19700	3257,98
Spain	13365	104400	4480,68

Italy	2069	6498	343,38
Portugal	1650	15851	362,54
Sweden	1547	8043	537,32
*Others**	89231	1961972	28435,46

Others include: other countries, of unknown origin, and network, non-profit

organizations & commercial origin

FIGURE 11 shows the biannual statistics by countries. Germany and Spain are the countries with more accumulated visited pages, followed by Italy, Portugal and Sweden. In any case the rest of the countries outside the top five have together a lot of visited pages and web traffic.
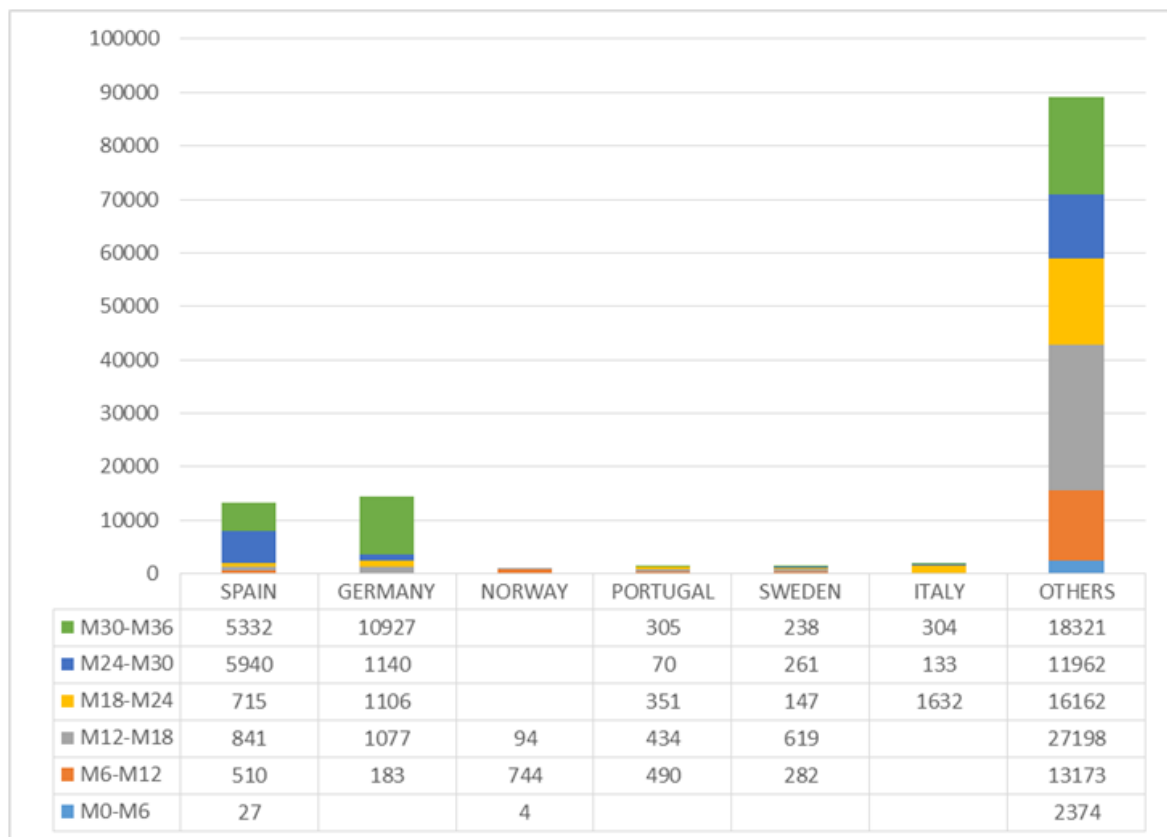

	SPAIN	GERMANY	NORWAY	PORTUGAL	SWEDEN	ITALY	OTHERS
■ M30-M36	5332	10927		305	238	304	18321
■ M24-M30	5940	1140		70	261	133	11962
■ M18-M24	715	1106		351	147	1632	16162
■ M12-M18	841	1077	94	434	619		27198
■ M6-M12	510	183	744	490	282		13173
■ M0-M6	27		4				2374

FIGURE 11. TOP 5 COUNTRIES: NUMBER OF VISITED PAGES.

FIGURE 12 shows how statistics have evolved monthly. Related to these statistics it is possible to observe that they are increasing month by month, while the mean time on site has a decreasing tendency.
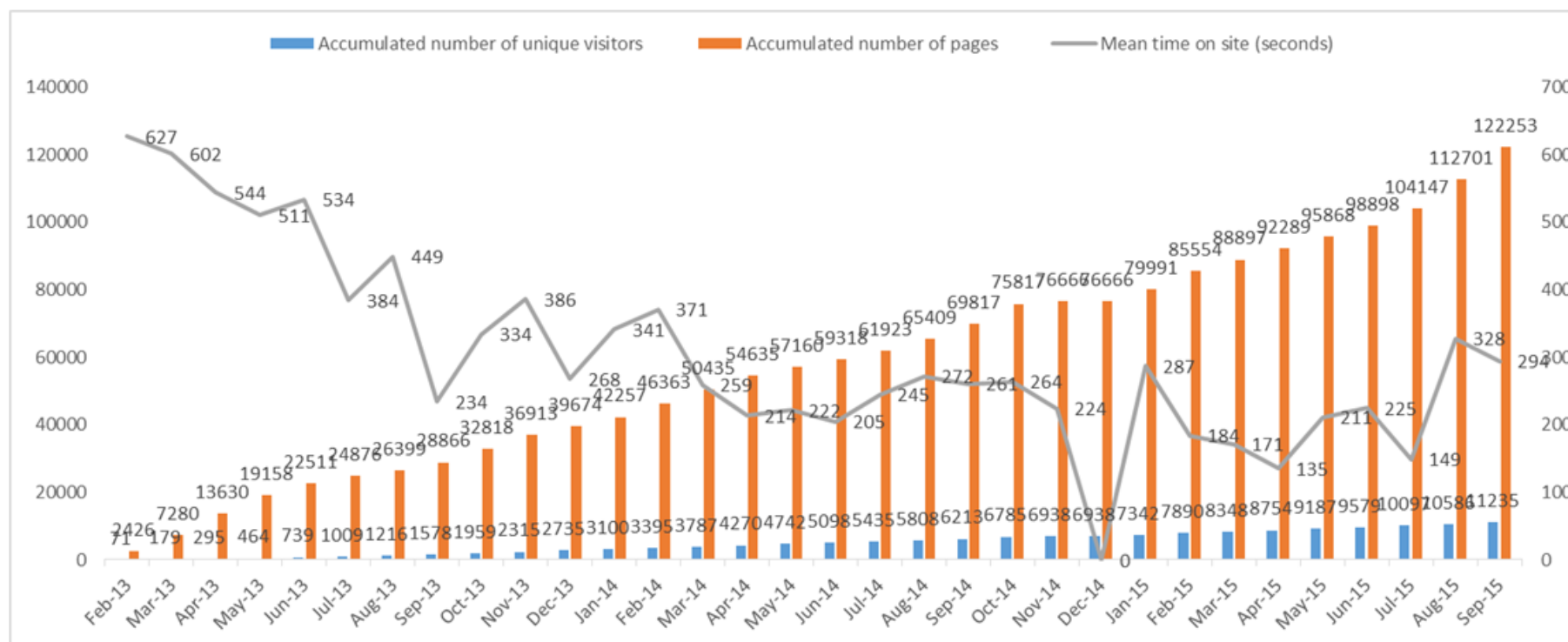
FIGURE 12. OPTIRAIL WEB SITE MONTHLY STATISTICS

WORKSHOPS AND PUBLICATIONS

Altogether OPTIRAIL project has participated in 11 scientific and technological conferences, 7 national and international workshops, 2 peer reviewed publications, 9 newsletters in corporate magazines and 25 news in local media. Also 4 workshop had been organized by the consortium, being the most important the technical workshops about the project that took place in Brussels (Belgium) 2014, the 23rd of October and in Madrid (Spain) on 2015, 25th of September. All details about the dissemination activities are included in Section 3.3 of Deliverable 7.1.

During the project some dissemination materials have been created: videos, brochures, leaflets, posters, photos, notebooks and USB memories. OPTIRAIL web site stores this kind of materials (http://www.optirail.eu/optirail/?q=mediacentre).

Related to the Advisory board, its constitution and first meeting took place during the Second technical committee held in Boecillo (Spain) in November 2013. The members of this group have been:

- **JERNBANEVERKET (JBV):** Norwegian government's agency for railway services (Norway)
- **TRAFIKVERKET:** The Swedish Transport Administration (Sweden)
- **REFER:** National railway network infrastructure manager (Portugal)
- **INSTYTUT KOLEJNICTWA (IK):** Railway Institute (Poland)
- **NETWORK RAIL:** Authority responsible for the United Kingdom's railway network (United Kingdom)

ASSET MANAGEMENT CLUB

Finally, it should be highlighted that the Asset Management Club was constituted during the final OPTIRAIL workshop in Madrid, whose initial members are the partners of the project and advisory board participants. Inside this group more dissemination activities will be carried out, such as participations in Transport Research Arena 2016 (VIAS, CARTIF, UGR) and World Congress on Railway Research 2016 (SINTEF).

1.4.3 EXPLOITATION OF RESULTS

In a context of wide use of transport, it is necessary to increase efficiency of the different transport modes as well as their interaction. To that effect, rail transport will play an important role in the

future by increasing its capacity and serviciality. Thus, it would be necessary to strength the competitiveness of railway ensuring a sustainable, efficient and safe service.

Within this framework, and for the last three years, OPTIRAIL project has developed a **Smart Framework for maintenance management** to facilitate making **effective and efficient decision** in **maintenance of railway networks within corridors across Europe**. A new knowledge based tool focused on Fuzzy and Computational Intelligence techniques has been developed and validated in two case studies.

Main remarkable outputs and **exploitable results** of **OPTIRAIL project** are the following:

▸ **Depth-in revision** of the maintenance railway domain under European context and policies have been done, comparing actual reality versus expectations.

▸ An **open smart framework** based on knowledge regarding to railway maintenance: the know-how, in way of expert knowledge and data from monitoring systems, were modelled in order to take advantage of these organizational assets, and, on the other hand, to preserve these rewarding assets. This is an open concept that is ready to new cases, new technologies, new ICT systems, etc.

▸ **First foundations for a harmonized framework** for a **railway** condition based maintenance have been done along cross-border corridors.

▸ A **methodology** for **infrastructure deterioration modelling** has been developed, going beyond the current state of the art. Also a methodology for modelling maintenance decisions from current railway inspections was developed, which can be done data-driven and/or with expert knowledge.

▸ An **Open Source demo** has been developed and implemented in under GPL–v3 license. This demo is available at http://www.optirail.eu/optirail/?q=downloadsourcedemo.

▸ Some **promotional video** was produced by the OPTIRAIL consortium to highlight the major advances and the results of the project. Now these video are available at http://www.optirail.eu/optirail/?q=videos.

Finally, OPTIRAIL project has shown that **Computational Intelligence based railway maintenance is possible**. First steps have been done and now, in order to continue the constantly performance improvement of the OPTIRAIL smart framework by high quality data, expert knowledge and, in general, know-how about the domain, the **Asset Management Club (AMC)** has been constituted at

the end of the project. In addition, anyone interested within OPTIRAIL can join to this AMC sending their contact details to optirail@vias.es and/or optirail@cartif.es.