The development of an information system to support and automate linear infrastructure management

João Morgado[1] and Emanuel Duarte[2]

Asset Management Directorate, Infraestruturas de Portugal, SA, Rua de Santa Apolónia, 65 · 1100-468 Lisboa · Portugal

[1]joao.gmorgado@infraestruturasdeportugal.pt (corresponding author)

[2]emanuel.duarte@infraestruturasdeportugal.pt

The condition and performance of the land transport infrastructure has a big societal and economic relevance. The available budgets tend to be allocated to maintenance interventions for existing road and rail networks and not for its expansion. Besides that, the aging condition of these networks will require more maintenance interventions, resulting in the need to optimise its performance.

Considering this context, the INFRALERT project (Linear Infrastructure Efficiency Improvement by Automated Learning and Optimised Predictive Maintenance Techniques) is being developed by 7 different partners from 6 European countries. It aims the development of an expert-based information system to support and automate linear infrastructure management from measurement to maintenance, focusing on road and rail. This includes the collection, storage and analysis of inspection data, the determination of maintenance tasks necessary to keep the performance of the infrastructure system in optimal condition, and the optimal planning of interventions.

The INFRALERT empirical developments and its demonstration are supported in two real-world pilots chosen for their potential for replication: a railway network in Sweden and a road network in Portugal. In both cases, extensive data from auscultation campaigns are available since several years ago. This paper describes in detail the objectives and the several project stages, as well as the presentation of the first achieved developments since its start in 2015.

Keywords: Maintenance and Rehabilitation Strategies, Monitoring and Inspection, Risk Management, Life Cycle Cost Analysis, Management software and tools

Introduction

The largest infrastructure network systems are those related to land transport, and in particular the linear asset systems in road and railway transport. The European motorway network alone enfolds about 69,500 km of road, while the European rail network comprises 213,600 km. The condition of infrastructure systems like road and rail has enormous societal and economic relevance, since constraints in infrastructure result in constraints in transportation. It is expected that in 2020 the long distance railway traffic will increase by 21% (Amadeus, 2013) up to 1359 million passengers in Europe (34 % in high speed trains). Meanwhile, road demand is not expected to diminish because the urban matrix remains still based on the road grid concept and the private car industry (ERTRAC, 2013). Briefly stated, the demand for surface transport will significantly increase in the next few years.

Given the existing budget restrictions, a substantial enlargement of the road or rail networks in the next decade is doubtful. Therefore, the only way to adapt capacity to the increased transportation demand is to optimise the performance of the existing infrastructure, which is the context of INFRALERT project (INFRALERT, 2016).

Objectives

INFRALERT aims to develop an expert-based information system to support and automate infrastructure management from measurement to maintenance. This includes the collection, storage and analysis of inspection data, the determination of maintenance tasks necessary to keep the performance of the infrastructure system in optimal condition, and the optimal planning of interventions. The major challenges of INFRALERT are:

- Developing the information technologies and standard procedures applicable to linear transport systems in general.
- Developing expert-based toolkits built on artificial intelligence and optimisation techniques to support decision making in maintenance planning, renewal and new construction
- Integrating all previous models and tools in a cloud-based framework compatible with existing asset management systems.

The main expected outcomes of INFRALERT are a way towards:

(1) Ensuring service reliability and safety by minimising incidences and failures of decaying assets
(2) Keeping and increasing the availability by optimising operational maintenance interventions and strategic long-term decisions on new construction
(3) Ensuring the operability under traffic disruptions due to interventions.

The INFRALERT developments will be demonstrated in two real-world pilots chosen for their potential for replication: a railway network in Sweden and a road network in Portugal. In both cases, extensive data from auscultation campaigns are available since several years ago. The empirical development of the whole project will be based on these pilot cases.

The consortium is composed by 7 partners from 6 different European Union countries: Germany, Hungary, Italy, Portugal, Spain and Sweden, encompassing different profiles: 3 technology SMEs (CEMOSA, Régens and DMA), 3 research organisations (Fraunhofer IVI, Universidad de Sevilla and Luleå Tekniska Universitetå) and one public infrastructure manager (Infraestruturas de Portugal).

Work Plan

The project is structured and divided into 10 Work Packages (WPs). The main scientific and technical work will be conducted in WPs 2-7. Besides those, the requirements will be identified in WP1 and the whole INFRALERT system will be demonstrated in WP8. Finally, these technical WPS are completed by two general WPs named WP9 and WP10, regarding dissemination and exploitation, as well as the project management (see Figure 1).

In WP1 the basis for the development of the INFRALERT expert-based Infrastructure Management System (eIMS) will be laid. The weak points of current IT tools for infrastructure management and maintenance will be identified, while an evaluation framework based on Key Performance Indicators (KPIs) will be established to ensure that these drawbacks are overcome and the expected impacts are properly achieved.

In WP2 the currently existing databases for measurements from the field are adapted and extended for multi-purpose asset management. The Data Farm to be built is holistic to the extent of including all types of data in a consistent architecture. The field data are maintained in the most efficient way, preserving the "measurement campaign" concept. This will prevent from losing useful information and will allow the reprocessing of raw data if any error occurs. Also, preserving the original data structure as delivered by the instrumentation allows extracting more information from the data, in case new methods are developed.

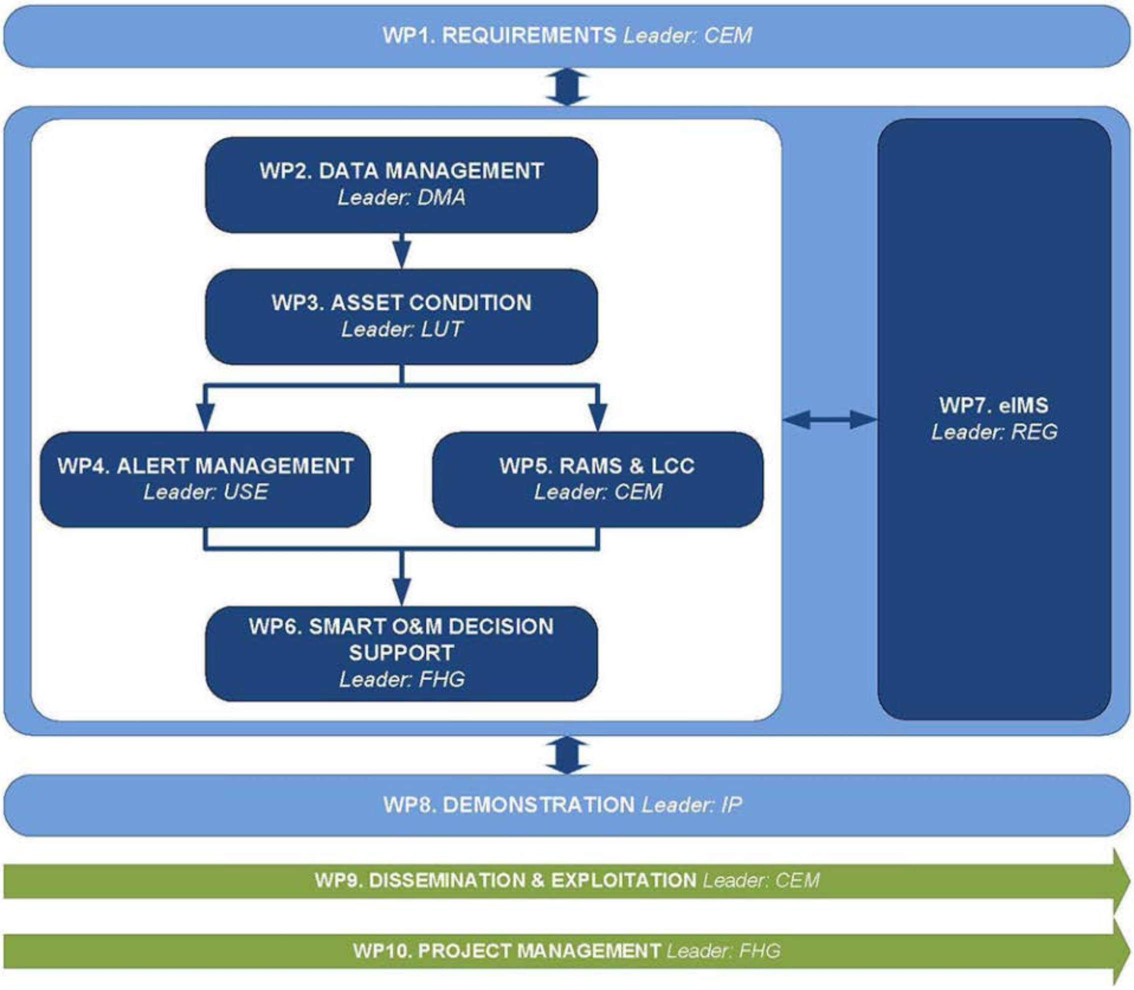


Figure 1. Project structure in terms of Work Packages

In WP3 the assessment of the current condition of the assets and the prediction of the future development will be carried out based on the ontologies created in WP2 and further data collection. The information generated has a twofold objective: the current asset condition will be useful for operation and traffic management; the forecasting of the asset condition will be relevant for the smart decision support tools, which follow a condition- and risk-based approach.

In WP4 a methodology for generating maintenance alerts of infrastructure network assets will be developed based on asset conditions development (WP3) and prior expert-knowledge on maintenance interventions. The research innovation builds upon machine learning techniques to characterise true positive alerts using statistical and probabilistic approaches. The practical technological development is based on creating alert-severity-intervention and alert-time-probability spaces to prioritise maintenance alerts. These results will be fed to the smart decision support in interventions planning (WP6).

In WP5 novel RAMS&LCC models will be developed. Based on European Standards, these methodologies will use the probabilistic information provided by the eIMS to perform holistic and more realistic analyses. Once programmed, this expert toolkit will provide the decision support system with the inputs and targets necessary for the optimisation (WP6) leading to a more reliable, available, maintainable, safe and cost-efficient infrastructure.

In WP6 the eIMS's intelligence for smart decision support in interventions planning will be developed. The work focusses on the mathematical modelling of maintenance planning on the tactical and operational level, and in particular on modelling of uncertainties to be dealt with in the dynamic planning process. The design of a condition- and risk-based interventions planning concept is another key objective of this WP, since it constitutes the basics of the smart decision support framework to be applied within the eIMS. Link with the RAMS & LCC models from WP5 will be established also by the compilation of a strategic assessment tool.

In WP7 the expert-based IMS will be finally built that exploits the data management developed in WP2 and integrates the expertise and artificial intelligence tools to be developed by WP3, WP4, WP5 and WP6 (see Figure 2). Innovative methods and algorithms provided by WP3-6 will be implemented within this WP and integrated into the cloud-based eIMS platform. In order to provide interoperability between eIMS and existing IMS systems, the platform will also contain an integration gateway that will serve as an interface to external data sources. For the stakeholders interested in infrastructure management, the platform will provide an internet-based presentation layer to access INFRALERT services.

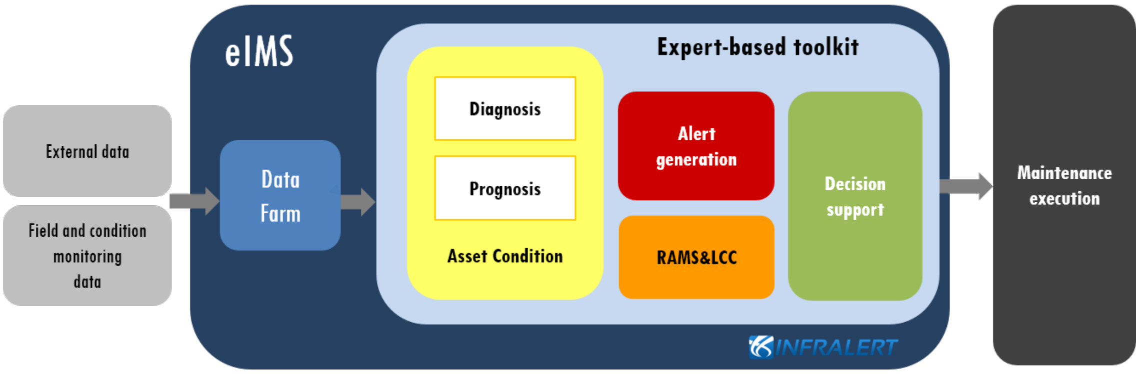


Figure 2. Expert-based Infrastructure Management System architecture

In WP8 the eIMS prototype resulting from the previous WPs will be demonstrated in real-world pilots for both road and rail infrastructures. These use cases support the empirical development of the project as well as its validation within a real context. Besides data collection for the selected scenarios in terms of asset condition, also operational, budget and other resource-related constraints will be identified. The results evaluation and overall impact analysis will be based on KPIs (defined in WP1), allowing a clear quantification of INFRALERT benefits.

Achieved Developments

This section briefly describes the first achieved developments since its start in 2015. These are focused on the conclusion of WP1 (Requirements), having as key results the definition of the functional framework of the system to be developed as well as the necessary requirements. Additionally, the road and rail case studies were selected, support the subsequent validation of the system in real cases.

Framework and Requirements

First, the state of the art of existing infrastructure management systems have been analysed and the drawbacks that shall be overcome by the INFRALERT system have been identified. This review includes the perspective of the members from the External Advisory Board (EAB), who are relevant actors in the road and rail sectors with real-world experience in the use of asset management systems.

Second, the functional and technical requirements of the INFRALERT subsystems have been defined to achieve a useful tool able to provide a step enhancement of maintenance management capabilities of existing systems. These requirements have been defined for every expert-based toolkit, as well as for the whole system.

Based on the aforementioned results, the drawbacks of existing tools and the features required for the INFRALERT system have been analysed from external and internal perspective, identifying the positive and negative aspects. The SWOT methodology has been applied to identify the strengths, weaknesses, opportunities and threats of the INFRALERT system, as well as a preliminary strategy for development and exploitation. The outcome of this analysis is the SWOT matrix of the INFRALERT project, presented in the Table 1.

Table 1. SWOT matrix of the INFRALERT project

	Positive	Negative
Internal	Strengths • Effective data management • Able to evolve and adapt to changing inputs and requirements • AI techniques for data analytics • Integrated RAMS&LCC optimisation • Risk-based maintenance planning • Cloud-based, easy to implement • Compatible with existing asset management solutions	Weaknesses • Needs large amounts of data to run the algorithms and probabilistic analysis • Results from data analytics are not trivial. The user has not chance to check them using manual methods • Security issues in cloud-based service • Very technical interface, needs external GIS and asset management software for reporting
External	Opportunities • Asset owners from several countries are joining the rail and road management in the same company. It will boost the use of generic linear asset management solutions. • New sensing technologies are more and more data producers • Wide variety of data formats (from different sensor manufacturers) require standardization before feeding the management system • Big data and cloud computing have recently achieved good performance at low cost • Rapid spread of PPP contracts were the builder has to manage (and maintain) the infrastructure for many years. It will increase the importance of risk-based decisions	Threats • Another software solution for maintenance planning • Difficult implementation in large companies • Lack of confidence on automated decision making • Not useful for simple corridors (e.g. road concessions)

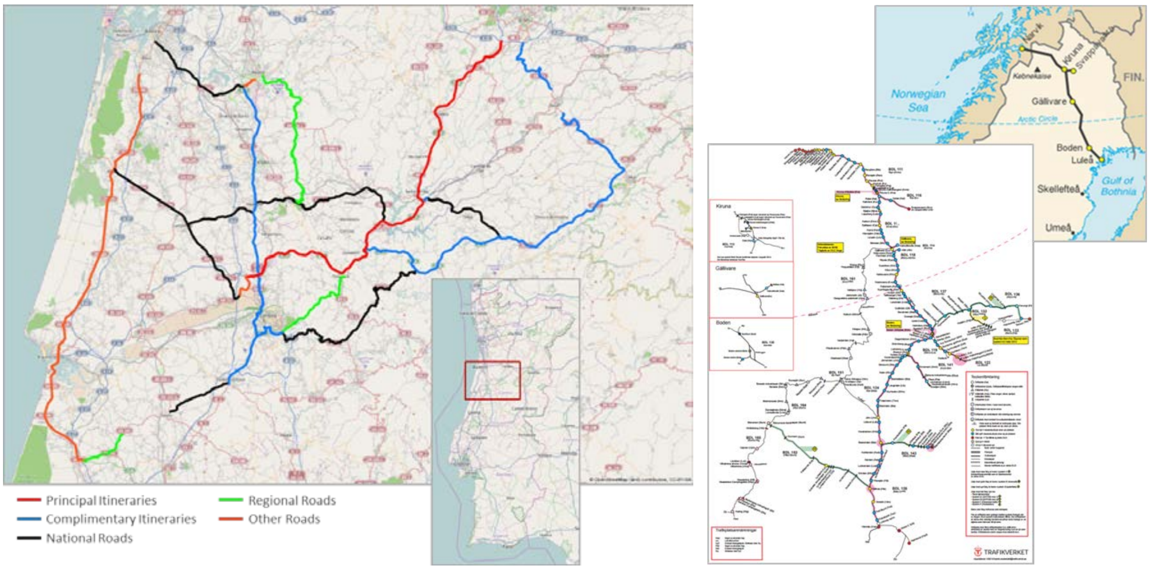
Finally, in order to provide a common framework for the quality assessment of the infrastructure, the main quality parameters considered by the international regulations in rail and road sectors have been analysed. The system shall keep the infrastructure condition between the thresholds in order to fulfil the existing regulation, but it shall be also flexible enough to shift these values when there are sufficient arguments. With the aim of enabling the future implementation of generic parameters for any type of linear infrastructure, the quality parameters have been grouped into functional quality and structural quality categories.

Case Studies

The developments of the INFRALERT project will be demonstrated both in a rail and road systems, with the aim of proving the transversal approach of the system to linear assets in general.

The road demo case is a meshed road network in Portugal under the management of Infraestruturas de Portugal (see Figure 3). The selected road sub-network comprises several roads in the Coimbra region in centre of Portugal, including roads from Aveiro, Coimbra, Guarda, Leiria and Viseu districts, totalling 539 km. The selected sub-network does not include motorways. It includes Principal Itineraries (IP), Complimentary Itineraries (IC), National Roads (EN), Regional Roads (ER) and Other Roads (EM), which are under IP jurisdiction. Considering traffic levels, it is also found heterogeneity among the chosen sub-network. Besides freight transport, the selected road-subnetwork links several important urban areas at a national and regional scale, such as the municipalities of Coimbra (143.396 inhabitants), Aveiro (78.450 inhabitants) and Viseu (99.274 inhabitants).

The railway demo case is a rail corridor in Sweden under the management of Trafikverket: the Iron Ore Line (Malmbanan), in northern Sweden (see Figure 3). It starts in Luleå and ends in Narvik in Norway. The traffic on the Line consists of both passenger and freight trains. The freight traffic consists primarily of heavy haul trains with axle loads of 22,5 tonnes and more. Running heavy-haul railway traffic in a mountainous area north of the Arctic Circle is a challenging task. The trains operate in harsh climate conditions, including snow in the winter and extreme temperatures ranging from -45ºC to +25ºC.



(a) (b)

Figure 3. Location of case studies for road (a) and rail (b)

The relevant database in the selected road and railway demo cases have been make available for the INFRALERT partners in order to enable the technical developments in WP2 to WP7.

With the aim of evaluating the impact of the INFRALERT system in capacity, cost-efficiency and performance, a set of Key Performance Indicators have been defined. This evaluation framework is structured as follows:

- External level, where the KPIs are set by the Infrastructure Manager (general targets)
- Internal level, where the KPIs are pre-defined and auto-adjusted by the INFRALERT system to meet the general project targets (capacity, cost efficiency, performance).

The evaluation framework set out in the INFRALERT project will not replace the KPIs in existing Asset Management System, but it will be focused on those parameters that the project aims to improve (capacity, cost efficiency, performance).

Moreover, INFRALERT will only focus on those KPIs which the INFRALERT system will be directly able to assess which will be mainly derived from the infrastructure auscultation data and maintenance actions.

Final remarks

This paper presented the main goals of the INFRALERT project, work plan, as well as the key development already achieved since the project's start in 2015. Given the current context of constrained budgets regarding the investment on land transport networks, it is vital to pursue its performance optimisation, not compromising the mobility of people and goods all across the European zone. It is then expected that the INFRALERT system can be directly applied by road and rail infrastructure managers, on the topics of smart maintenance and strategic planning, assuring the complementarity with existing management systems, minimising the implementation costs.

Acknowledgements

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