



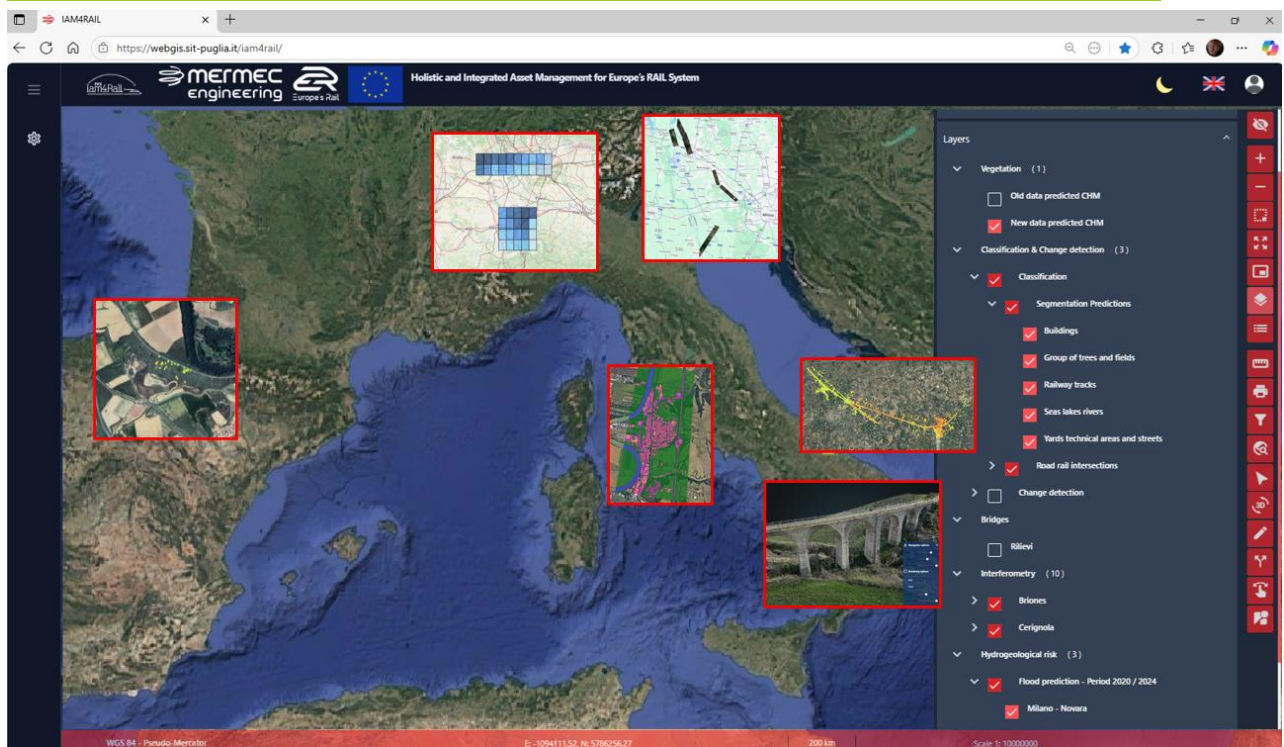
FP3-IAM4RAIL WP13 Implementation and Demonstration of Intelligent Maintenance Tools for Civil Engineering Asset Management



Work Package 13 Team, MerMec headquarters, Monopoli - Italy

WP13 Implements Intelligent Maintenance Tools for Civil Engineering Asset Management Railway Infrastructure.

Boasting more than ten demonstrators across five countries, WP13 promotes holistic asset management of civil infrastructures & surrounding areas by means of state-of-the-art technology. The teams of Italy, Spain, Norway, the Netherlands and France demonstrated monitoring technologies for bridges, slopes and tunnels. Utilising satellites, airplanes, ground and underground-based technologies, the team tackles problems related to subsidence, component fatigue, structural oscillations & failure and vegetation encroachment. WP13 consolidated the algorithm, and the measurement campaigns started with FP3-IAM4RAIL.



Mermec Engineering Web Platform for multiscale monitoring of civil assets

Multiscale monitoring of civil assets (Italy)

The MERMEC Group and Ferrovie dello Stato Italiane (FSI) demonstrated six technologies in multiple locations:

- ☆ The defects of a 19th-century bridge near Potenza were inspected using drones and cameras. This data, along with that from many other Italian bridges, serves as the basis for Artificial Intelligence (AI) training for defect classification purposes. This technology will reduce bridge inspection time & costs, resulting in less traffic disruption.

- ☆ Part of the Roman railway was classified by a Neural Network (NN) trained with orthophotos from several areas of Italy. This trained NN enabled change detection near the Milan area, close to a newly built structure. This technology will help monitoring the emergence of unauthorised works.

- ☆ Vegetation height measurements between Lombardia and Piemonte, obtained via expensive airplane-borne LiDAR data, were used to train a NN. After training, the AI could recognise vegetation height from inexpensive satellite orthophotos. This will help monitor dangerous situations around the railway's corridor.

- ☆ The hydrogeological risk of a vast area in northern Italy was assessed using AI, based on historical precipitation data. In this work, FSI collaborated with CEMOSA (a Spanish company offering engineering and quality control services in the construction sector), applying custom-made methodologies to forecast precipitation for Milan, Tortona, Novara and Voghera, thus addressing climate change-related issues.

- ☆ Pronounced land subsidence near Foggia was inspected using InSAR technology, with data spanning over ten years, revealing issues along the train line. The same technique was applied to a

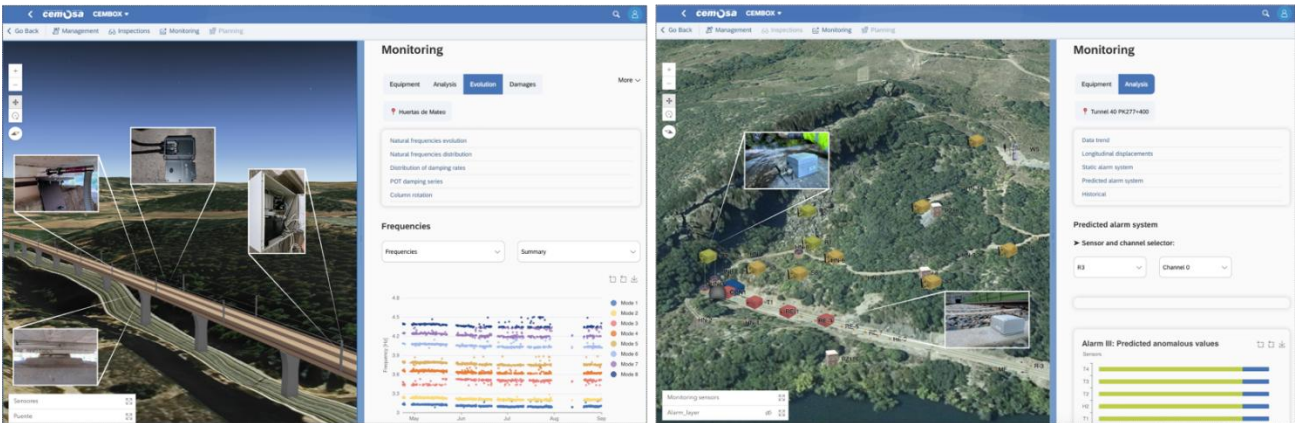
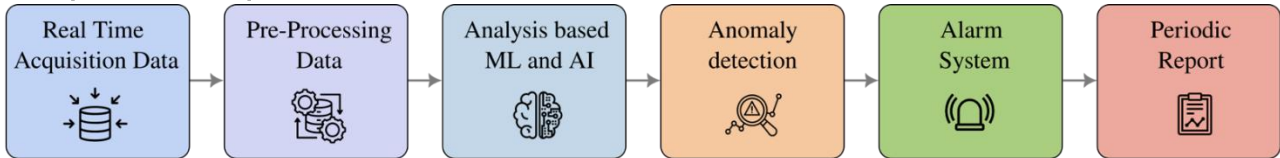


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slope next to the railway in Spain for ADIF (Spanish Railway Infrastructure Administrator), further demonstrating the transversal nature of these approaches.

⇒ Finally, the data from these technologies has been uploaded to a custom-made web platform, thus demonstrating the realm of the holistic approaches to infrastructure management by means of intelligent technologies.



Digital Twin (DT) construction workflow and CEMBOX platform views for the Huertas de Mateo Viaduct and Vilar de Silva slope case studies.

Bridges and earthworks asset management aided by geotechnics (Spain):

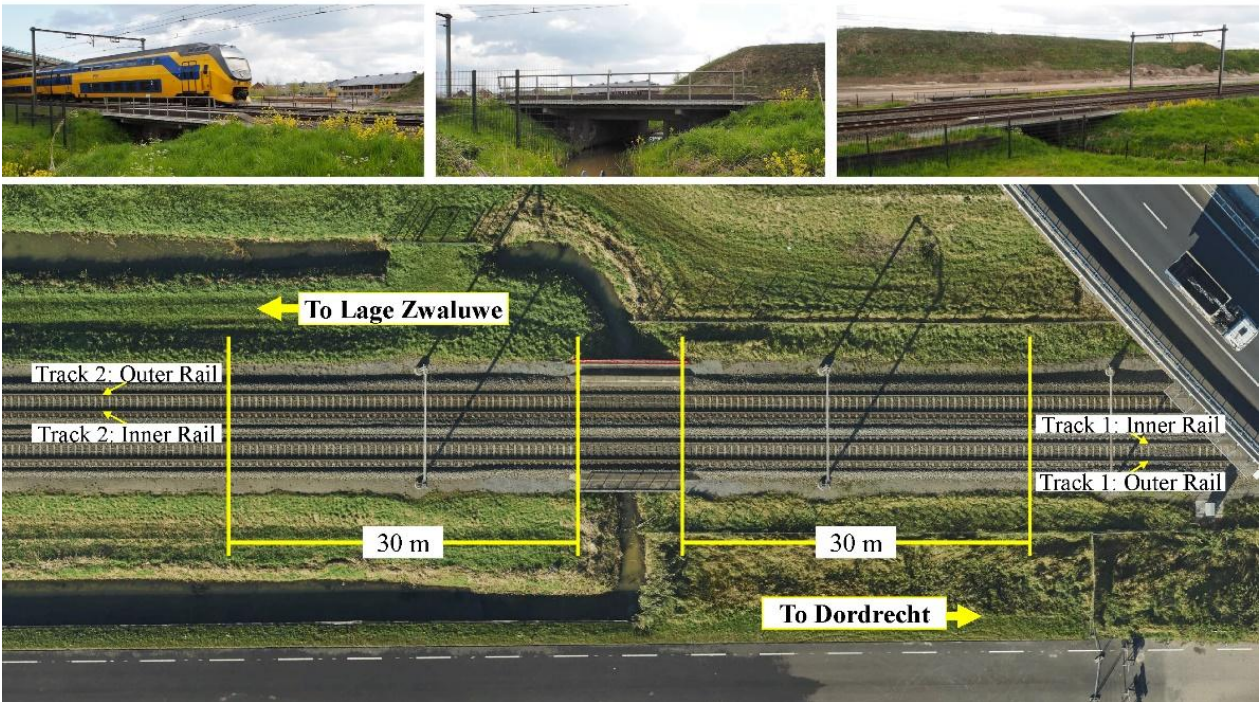
Through the collaboration of ADIF, CEMOSA, INECO (Transport Engineering and Economics) and CEDEX (Spanish Centre for Public Works Studies and Experimentation), case studies have been carried out to develop Digital Twins (DTs) for the intelligent management and monitoring of critical infrastructures in Spain. The projects focus on the Huertas de Mateo railway viaduct, notable for its POT bearings and its considerable length without expansion joints, and the slopes of Vilar de Silva and Briones, areas highly susceptible to ground movements. Advanced monitoring systems have been deployed to enable early warning mechanisms, combining real-time sensor data with Machine Learning (ML) and predictive analytics to detect and anticipate anomalies. For the viaduct, Operational Modal Analysis (OMA) is used to extract dynamic frequency series in real time, which are then integrated into a Structural Digital Twin based on a finite element model continuously updated using AI and validated against real damage scenarios. By correlating dynamic responses with POT bearing displacements, the system can automatically detect anomalies, locate potential structural issues and anticipate maintenance needs before they develop into critical problems. For the slopes, real-time monitoring of ground movement is combined with rainfall data, sensor-based alarm systems and predictive models, including LSTM (Long Short-Term Memory) neural networks, to anticipate high-risk situations during heavy precipitation, supporting timely interventions to prevent failures. Each DT also incorporates on-site inspection data, enabling the correlation of visual observations with sensor measurements and providing valuable insights into degradation patterns, structural behaviour and long-term performance. These case studies demonstrate how the



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integration of DTs, ML, AI, LSTM models, and continuous real-time monitoring can transform infrastructure management by enabling data-driven, proactive and resilient decision-making for both bridges and earthworks, ultimately enhancing safety, reliability and operational efficiency. All of this is managed through the CEMBOX (a software by CEMOSA) platform, which centralises data, analysis and alerts, providing an integrated and user-friendly environment for monitoring and decision support.



Transition zones studied using TG, ABA and InSar – in line between Lage Zwaluwe and Dordrecht in the Netherlands.

Analysis of Railway Transition Zones Using Multiple Data Sources (the Netherlands)

In FP3-IAM4RAIL, we have investigated the relationships between dynamic train loading (by axle box acceleration - ABA) and the rate of change of track geometry (derived from track geometry measurements - TG) to provide insights into the stability of embankments in those locations with excessive deformations. Transition zones are the locations that reported the most significant deformations, so we have focused on them. In this latest study, we proposed an approach for more frequent evaluation of transition zone health by integrating it with interferometric synthetic aperture radar (InSAR). As railway infrastructure continues to age, such tools are vital for enhancing safety and optimising maintenance. Some of the key highlights of the study: 1) Developed a hybrid neural network model that fuses multiple data sources (track geometry, InSAR, and ABA) for comprehensive transition zone health assessment. 2) Introduced a novel Key Performance Indicator (KPI) that supports more frequent evaluations to support proactive and targeted maintenance planning. 3) Validated using real-world field data from transition zones on a Dutch railway bridge,





demonstrating its practical effectiveness. You can find more information about this study in the following link: <https://doi.org/10.1109/TIM.2025.3575986>

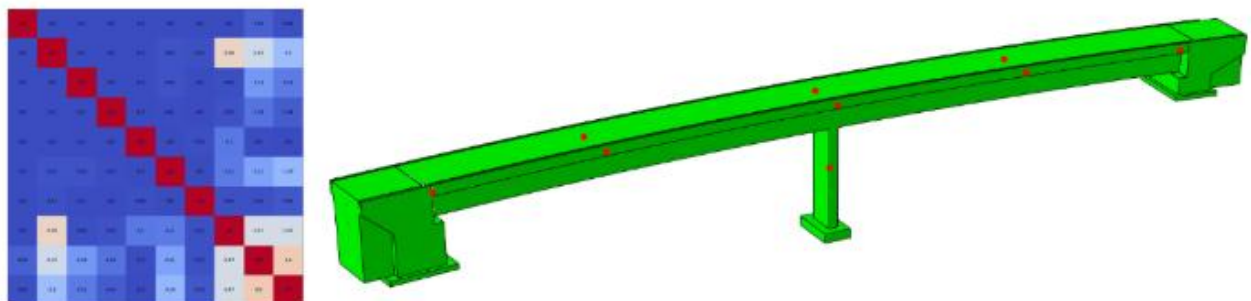


Søsterbekk bridges 1 (single span) and 2 (2-span) in Norway, with details about the accelerometers mounted on the sleepers in the transition zones and the inclinometers mounted along the bridge side.

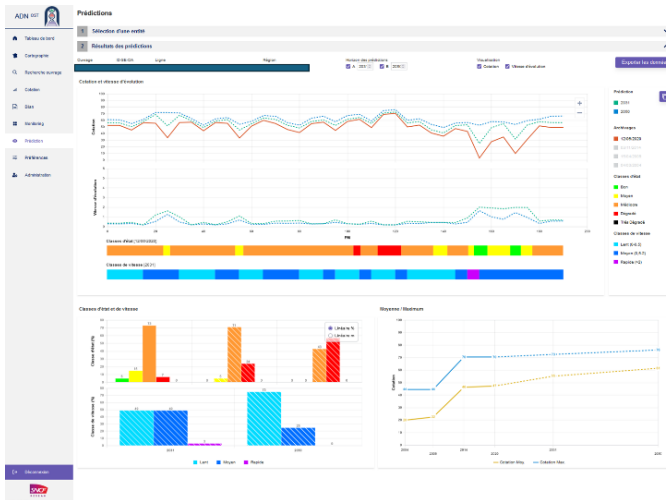
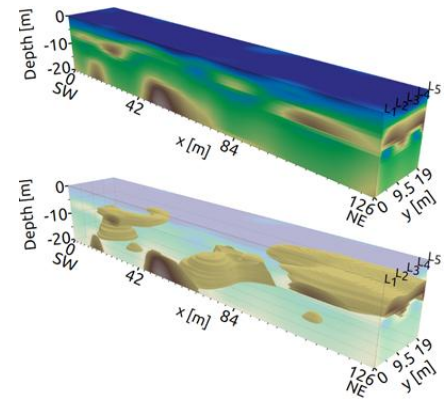
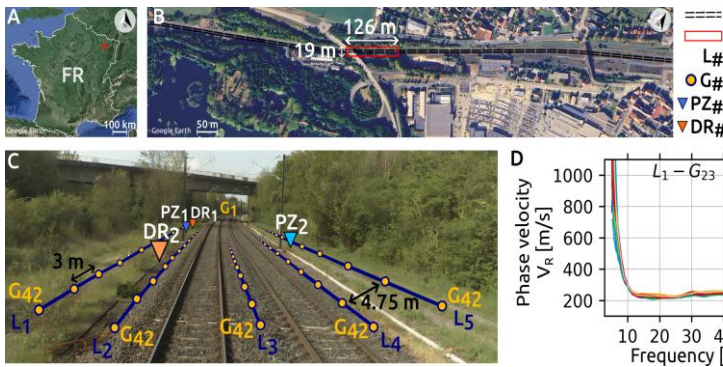
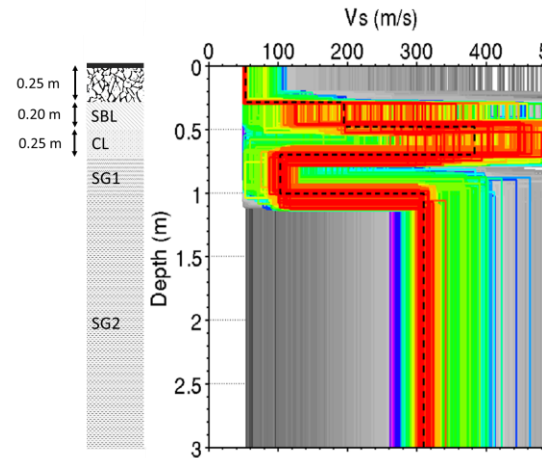
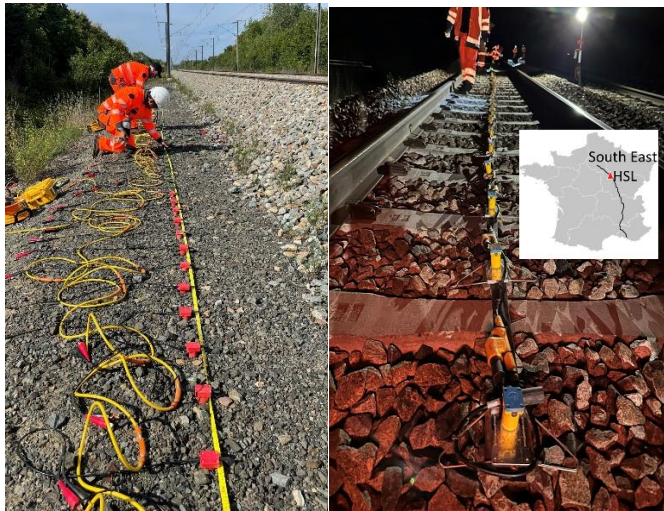
Analysis of Structural Condition Monitoring techniques – civil structures and works (Norway)

In FP3-IAM4RAIL, we designed a monitoring system for the monitoring of two concrete bridges situated on an active heavy haul railway line at a higher latitude than the polar circle. The data from the measurement system is going to be used to validate a digital model of both bridges with the relative transition zones, with the scope of predicting the behaviour of the bridges in the future, regardless of the operating conditions. Plans are ongoing to further increase the axle load on the line, which will require an accurate analysis of the infrastructure before starting operations with heavier trains. The data analysis techniques and numerical models will be a key part of these analyses, in addition to providing a tool for predicting the appearance of defects typical of prestressed concrete bridges during their life cycle.

The measurement system has been installed and the model has been built. Now, the activities are focused on the use of the data both for validation and for health assessment of the bridges.



Finite Element model of Søsterbekk bridge 2



Seismic measurement on the path and in the track axis using the “landstreamer” system (on the top), seismic monitoring on a 2-track platform (in the middle), and the associated results. Presentation of the decision-making tool (ADN OST) for predictive maintenance of tunnels and instrumentation of a disused tunnel (at the bottom).





Geophysical diagnostic and monitoring of sub-ballast layers and earthworks & inspection and monitoring of tunnels (France)

In FP3-IAM4RAIL, SNCF Réseau (French National Railway Company) conducted studies that confirmed the robustness and reliability of the seismic technique for detecting variations in shear wave velocity within the sub-ballast layers and underlying subsoil. This validation phase was essential to establish a solid reference framework before implementing more advanced techniques of acquisition, processing, inversion and interpretation in a future toolbox. The developments carried out concern: 1) the deployment of the "landstreamer" system, which allows rapid and reliable acquisition, adapted to railway constraints, with data quality comparable to conventional methods, 2) the automation of the extraction of dispersion curves using AI, which requires improvements for noisy data, 3) the exploitation of Bayesian inversion to estimate soil parameters and quantify uncertainties, identifying critical areas, 4) the mapping of water tables and the correlation between seismic velocities and soil resistance, optimising railway structures.

SNCF Réseau's rail tunnel monitoring system has been modernised with the implementation of the RADIS application to standardise the deterioration measurements carried out in recent years. An automatic rating system (0-100) was implemented to identify critical tunnel sections based on the RADIS application. This step was essential for providing predictive modelling of tunnel deterioration. The development of the ADN OST decision support tool for inspectors will now make it possible to anticipate deterioration and optimise regeneration investments, despite certain limitations in the face of unforeseen events. For tunnel monitoring, high-efficiency inspection technologies (photography, lidar and infrared thermography) have been tested to obtain high-definition 2D/3D representations of tunnels. The most significant benefit of combining these three tools is the automatic detection of changes/disorders. Tests of detection algorithms (imaging, 3D) have shown limitations due to material variability and numerous false positives on masonry. The approach remains promising, thanks to the automatic comparison of successive surveys, which precisely identifies changes and material losses.





Founding Members



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