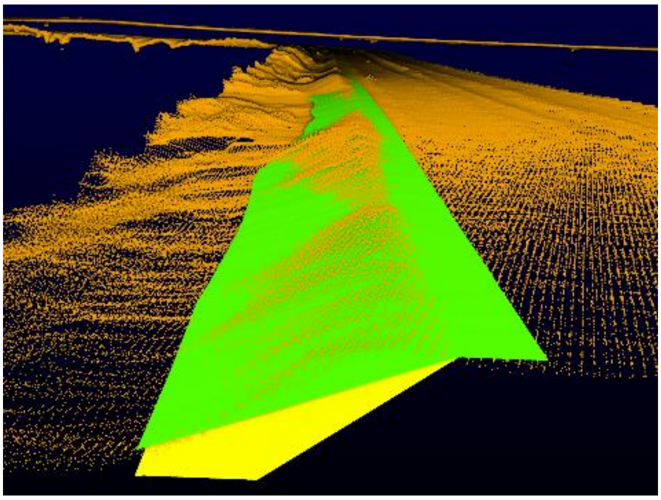
FP3-IAM4RAIL Work Package 9 - Railway Infrastructure

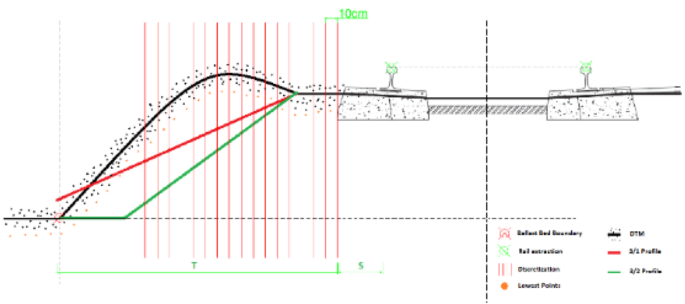
WP9 Railway Infrastructure develops cutting-edge solutions for the design, monitoring, and maintenance of railway infrastructure. Using wayside, onboard, and crowd-based sensing combined with advanced analytics, WP9 delivers practical anomaly detection solutions, predictive models, and guidance for future standards. These insights feed into digital decision-support tools for maintenance. Showcased through European prototypes, one of our primary objectives is to transform railway data into actionable intelligence, enabling advanced maintenance strategies that result in fewer disruptions, lower costs, higher safety, and more sustainable operations. This, in turn, paves the way for a resilient, digital, and efficient European railway network.

WP9 Meeting in Madrid – Museo del Ferrocarril

The project is supported by the Europe's Rail Joint Undertaking and its members.

Sensing Solutions for Superstructure Components and Railway Infrastructures: ***The Intelligent Sleeper (led by ADIF and INDRA)*** is an advanced technological solution that integrates sensors within a specially designed concrete sleeper, enabling real-time monitoring of railway infrastructure conditions. This sleeper incorporates various types of sensors: temperature sensors for both the rail and the surrounding environment, providing critical information, particularly under extreme thermal conditions; capacitive sensors to detect occlusion caused by water, mud or loose materials, enabling identification of abnormal situations such as landslides; accelerometers to record the accelerations and inclinations of the sleeper, providing data on structural deformations, abnormal vibrations or possible instabilities in the track; an ambient microphone to capture track sound for detecting irregularities through acoustic analysis; a humidity sensor, located at the base of the ballast, measures abnormal moisture levels and alerts possible water accumulations or the onset of flooding processes that could compromise the stability and safety of the infrastructure. The data collected by these sensors is processed using algorithms that correlate the different inputs to generate early warnings in cases of landslides, floods, track defects, or other conditions that may endanger railway traffic. At the same time, a second research line focuses on incorporating graphene into concrete sleepers. This innovation aims to enhance the mechanical properties of the material, increase its durability, and minimise its environmental impact, thereby promoting a more efficient and sustainable infrastructure. Both lines of research (sensing and material) converge in a smart sleeper, conceived as a more economical, sustainable, and functional solution, capable of providing key data for high-quality predictive maintenance and generating alerts under any condition that compromises the safety of the infrastructure or rolling stock.





Smart sleeper (left) and results of LiDAR monitoring for ballast (right)

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The research about ***Onboard Monitoring LIDARs for Ballast (led by SNCF)*** relies on LiDAR (Light Detection and Ranging), which is a remote sensing technology widely used to map and analyse physical environments. The technology works by emitting rapid pulses of laser light and measuring the time it takes for the light to reflect off surfaces, allowing for the capture of the structure and objects in a scene as a 3D point cloud with high spatial accuracy and detail. Along with its maintenance efforts, operations teams at SNCF Réseau gather LiDAR data of train tracks across France, which can then be leveraged for asset monitoring applications. One application is ballast recycling and renewal. Ballast plays a crucial role in the stability of the track. To this day, ballast profile monitoring relies mainly on traditional methods conducted by field experts with minimal automation. Considering that ballast maintenance operations represent one of the most expensive operations, there is a real need for optimisation in terms of material resources used and the required maintenance workload. In IAM4RAIL, we aim to assess the conformity of on-site ballast profiles by comparing LiDAR acquisitions of tracks to the expected compliance levels. This is achieved through a combination of techniques, ranging from digital terrain modelling and 3D geometric computation to object identification and filtering. Initial runs have already been conducted, and the operations teams have validated the results. Further runs have been conducted and are currently being analysed, with additional runs planned for 2025 to refine performance further. We expect the developed algorithm to support the decision-making process and help reduce ballast waste.

Fibre optics with the WILD installation in Sweden

Fibre Optics Sensing (led by SNCF and TRV) is a breakthrough technology that measures various physical parameters (see the photo of a fibre optic sensor, the size of a hair). In IAMRAIL, we have been focusing on distributed acoustic sensing, a part of FOS that is primarily sensitive to vibrations, by utilising standard telecommunications fibre optic cables that are already installed. It is a low-cost, innovative initiative that focuses on enhancing safety and maintenance efficiency by using advanced monitoring technologies. Two developments are considered: rockfall detection and flat wheel detection. For rockfalls, a real operational railway line near Besançon, France, is being analysed along a 30km section of the line. The primary objective is to develop an automatic rockfall detection algorithm that minimises false positives, establishes key performance indicators, and leverages findings to update maintenance protocols. We are currently developing algorithms for event detection through 2025, followed by extensive data testing and rockfall characterisation. In a final stage, the focus will be on environmental modelling to improve detection capabilities. In the case of wheel flats, they are typically detected using specialised wayside monitoring systems at

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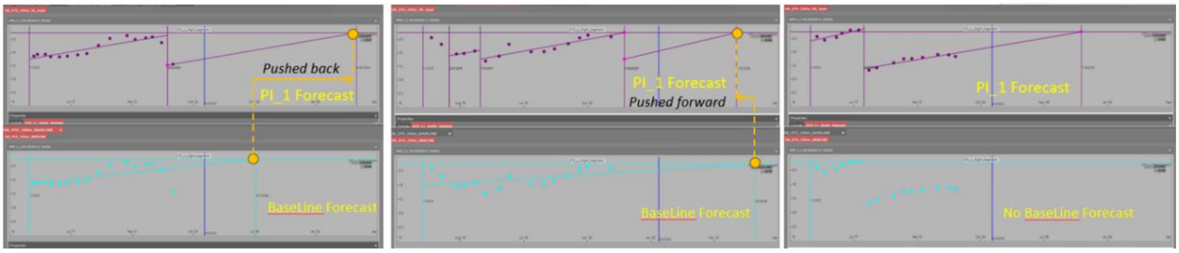
specific locations. To extend the wheel defect detection capability beyond these discrete locations, the potential of using fibre optics is explored. In the project, a fibre measurement system was installed along a heavy-haul railway line in northern Sweden, covering 39 km of railway track. To evaluate the fibre measurements for possible wheel flats, simultaneous wayside measurements were conducted using a wheel impact load detector (WILD) – see the photo. Detected wheel flats in the WILD system were compared with strain signals recorded in the fibre cable.

Advanced Interpretable Analytics for track, including S&Cs: In the research about ***Plain Track Geometry Impact Analysis and Resurfacing Work Cycle Detection (led by MERMEC),*** we are developing AI-based methods to automatically detect maintenance works and outliers using infrastructure, track condition, and work history data. To ensure robust results, we have analysed challenges around data quality and availability, with a focus on handling incomplete data and identifying gaps that influence predictive accuracy. Our approach combines traditional linear analytics with machine learning to link short-term and long-term predictions. 1) Defect-level: ML-driven fingerprint recognition and time-series tracking of individual geometry defects to support short-term maintenance decisions. 2) Segment-level: modelling track geometry variability per 200 m section and using maintenance logs to train ML models that identify tamping cycles, improve KPI prediction, and forecast long-term interventions. A key innovation is the automatic detection of maintenance cycles, which enhances prediction accuracy and supports the optimisation of preventive maintenance strategies. This work is being validated with data from DB, SNCF, and ADIF, ensuring applicability across different infrastructure contexts.



Results on forecasts and baselines for track geometry analysis

Regarding ***Health and Maintenance Indicators for S&Cs (led by MERMEC),*** we are developing a Turnout Health Index (THI)—a machine learning–based criticality metric designed to quantify turnout condition and guide maintenance prioritisation. The THI is derived from inspection scores and is being validated using data from eight high-speed turnouts on ADIF's network. Core innovations of the approach include: 1) Inspection-Based Ground Truth: Training ML models directly on inspection scores from ADIF experts to embed quantitative assessment criteria. 2) Automated Criticality Scoring: Producing a continuous THI with prioritisation logic based on proximity to maintenance thresholds, enabling nuanced decision-making. 3) Feature Impact & Explainability: analysing how turnout geometry, component condition, and tamping frequency influence health outcomes to generate actionable insights. 4) Integration with Linear Asset Management (LAM): aligning metadata, inspection data, and tamping records to provide contextualised inputs for machine learning. This positions the Turnout Health Index as an explainable, data-driven tool that enhances both the automation and reliability of turnout maintenance planning.

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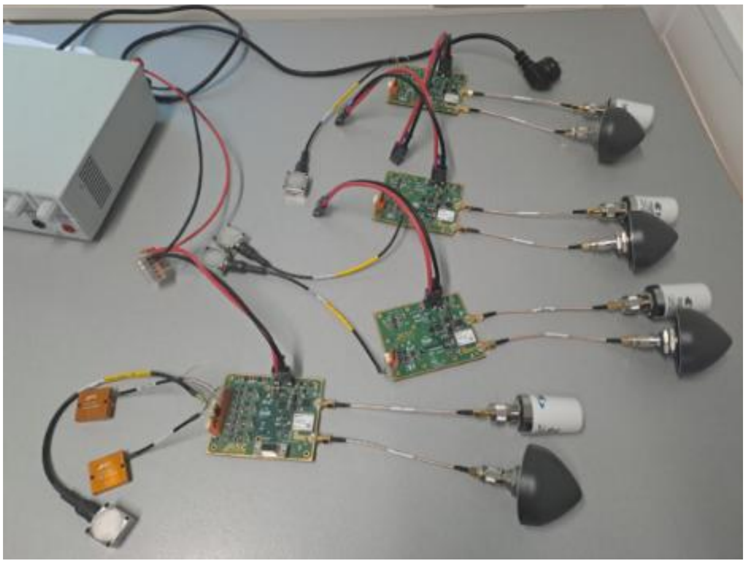
The research about ***Wireless Continuous Track Monitoring (CTM) (led by DB)*** aims to design a system that reduces the effort involved in installing CTM measurement systems in existing vehicles, regarding vehicle engineering, approval, and documentation. Wireless Continuous Track Monitoring is currently being developed. This new concept reduces the effort required to integrate measurement systems into existing vehicles, making the temporary use of the CTM measurement system possible. The custom-built sensor hardware has arrived and is now ready for testing. The sensor boxes shown in the picture take highly synchronised measurements and send the values to the computing box. The following steps will be to test the communication and prepare the received values for transfer over the mobile network. When the boards are placed in their housing and the batteries are connected, field tests can be prepared.



Wireless continuous track monitoring development

With the ***acceleration measurements using Smartphones (led by SNCF)***, accelerations on board commercial trains are measured using specialised equipment by trained staff, for purposes such as maintenance and to validate line speeds for new tracks (or after major maintenance). The current measurement system is costly and requires in-depth knowledge of its operation. Could smartphones replace the current measurement equipment? In this use case, an application has been developed to utilise smartphones in commercial trains as track monitoring systems, leveraging the geolocated accelerations provided by their sensors. Acceleration on board commercial trains can thus be accurately measured. This offers greater flexibility in terms of training, and such an application is user-friendly, making it easier to organise and manage. This application will be used by maintenance teams, in addition to geometry measurements, to observe the behaviour of rolling stock on the track. How does it work? The maintenance agent sits in the cab of a passenger train, places his smartphone on the ground or the console, and measures accelerations. Variations in track geometry cause movements and accelerations, which are calculated by the smartphone. These measurements are geo-localised with a kilometric estimation over the track and speed estimation. The data is then sent to an online platform for analysis, and maintenance agents can access it directly when they return to the office. This ensures the safety and comfort of users. Following a 6-month test phase in 2024 with conclusive results, the application's use is now being extended to all French regions.

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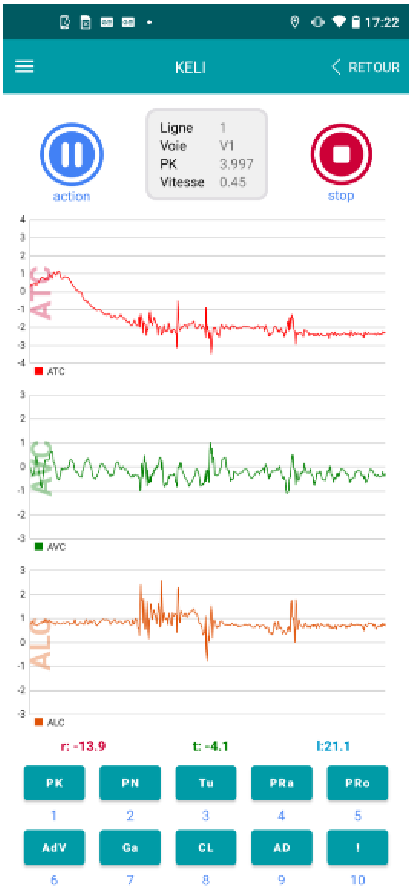
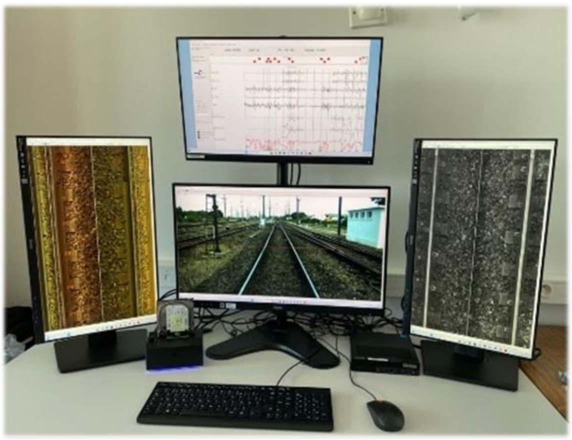
Switches and crossing monitoring using infrared cameras (led by SNCF), unlike plain track, the monitoring of switches and crossings is currently performed by inspectors who must travel to these locations to conduct visual inspections, with frequencies ranging from 2 to 12 weeks. During the inspection, they must place themselves on the track, which comes with the danger of being hit by a passing train. For over a decade, inspection trains have covered almost the entire French rail network, but only on plain tracks, which replace a portion of the visual inspections (although visual inspections are still maintained, albeit less frequently). The Switch monitoring project, utilising infrared cameras, enables the use of data recorded when the 3 French Track inspection trains pass by, including photos taken by the cameras and information on track geometry. This data is made available to the Maintenance Unit, enabling an agent in the office to view the images on a screen station. He can then detect any anomalies and analyse the track geometry data via an image display module, coupled with a graphic analysis module. This enables the inspection of part of the switch and crossings without having to go out into the field, thereby eliminating risks associated with rail and road operations. The system provides the maintainer with a visual display of anomalies related to the various components of the turnout, featuring synchronised images and turnout geometry data. This means that any anomaly identified in the office can be corrected on the machine. A six-month test phase has just begun with future users. The goal of this phase is to compare several infrared camera inspections with the same field test on foot, and also to test the ergonomics of the proposed system.





Results of the KELI system by SNCF and testing (left and right up photos) and S&C monitoring using infrared cameras (right down photo)

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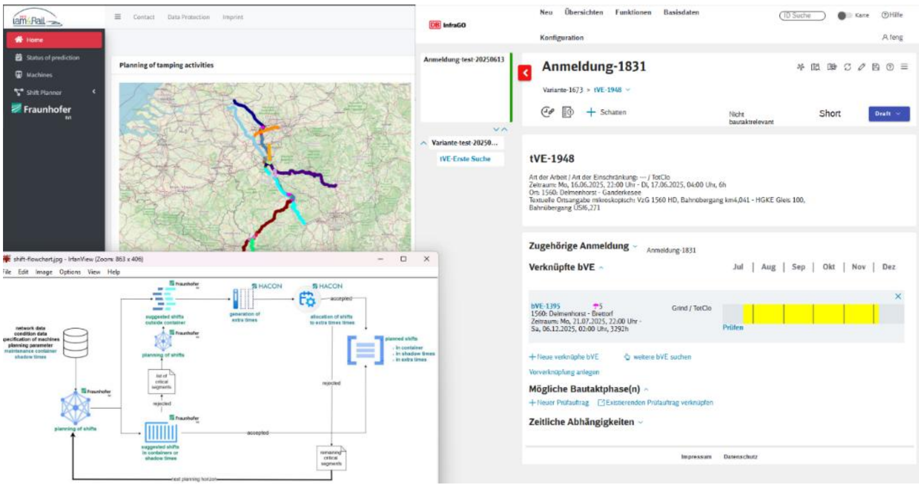
Prescriptive Maintenance of Railway Infrastructures: In the research about ***Prescriptive Maintenance Approach from Measurement to Maintenance Shift Planning (by DB InfraGO and HACON)***, a pilot achievement in the planning procedures of prescriptive maintenance is being developed. On 3rd June, the planning tool for prescriptive maintenance was released. Comprising prediction of track geometry, maintenance shift planning, and maintenance coordination planning, this tool represents the prescriptive approach of DB InfraGO for the cumbersome planning tasks of track maintenance. Based on the prediction of track geometry and the regional railway network prepared in Task 9.4, DB InfraGO has been developing the shift planning tool for the maintenance works. The tool identifies the connections between dedicated maintenance works, combining and prioritising them to achieve a paradigm shift from defect-driven planning to data-driven and prescriptive approaches. In this release, the current “maintenance container” of DB InfraGO has been implemented, allowing shifts to be planned in accordance with real maintenance practices. They are then processed by the coordination planning tool, set up in collaboration with Hacon and DB InfraGO, and highly integrated in the real planning procedure. Various maintenance conditions are being configured and tested with the new release of the planning tool. Preliminary results would be presented in the final demonstrator.



Planning tool development by DB

Regarding the progress in the topic ***rail anomaly detection by means of an eddy current sensing technology system (led by TRV and ALSTOM),*** the mounting bracket design is complete and successfully installed in the vehicle after several reviews and test fit phases in Germany. Field testing is planned at Kleve station, with a pre-test visual inspection scheduled to take place. Insulation joint detection has already proven successful on trolley data. Resources (personnel, rolling stock, and track availability) are being secured for 11–15 September 2025, with minimal impact on the overall programme. In the research on ***On-board monitoring using LDV and its integration (led by PRORAIL)***, we aim to answer the question “how can we leverage in-service trains to efficiently and frequently monitor our rail infrastructures?” In our latest paper, published in IEEE Transactions on Industrial Informatics, we explore a solution. We combine a train-borne laser Doppler vibrometer (LDV) and axle box accelerometers (ABAs) to enable synchronised measurements of train-track vibrations under operational conditions. By incorporating a GPS antenna and video camera, we obtain the train's position and speed, and then fuse these multiple signals to extract key indices of train-track interactions, enabling interpretable anomaly detection. We test this technology on

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an operational railway line in the Netherlands under different conditions and demonstrate its capability to detect, locate, and quantify both surface and support anomalies in the railway track—open access link: https://doi.org/10.1109/TII.2024.3485764.

Lindometer (up) and LDV measurements (down) campaigns

In the ***monitoring of lipping as an indicator of degradation of common crossings (led by PRORAIL)***, we aim to integrate the degradation of common crossing geometry into asset management systems. Between the 7th of February and the 29th of June 2023, 8555 common crossing point clouds were measured of almost all remotely operable turnouts in the Netherlands. All these point clouds have been assessed by an algorithm that compares the designed geometry with the degraded (measured) geometry. Additionally, all these assessments have been manually checked for the detection of plastic deformation (lipping). This has resulted in 1) a large and validated dataset of lipping, 2) a set of labelled incidents like breakouts, and 3) improvements of the detection algorithm, which is now compatible with all crossing types at ProRail track. The photo shows the first experiment with the grinding of a crossing, where the algorithm detected lipping. The crossing assessments were shared with ProRail's track inspectors and with the maintenance contractors to experiment with the use of this data in operations. Based on feedback from the inspectors and contractors, the delivery of later measurements was improved in such a way that it was better tailored to the recipients

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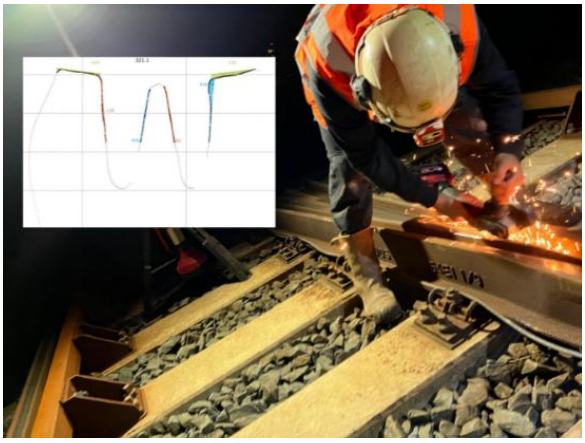
(with ways to prioritise inspection/maintenance resources more easily). The pilot for delivering crossing assessments to inspectors and contractors will continue at least until the summer of 2025. Discussions are already underway to secure the deliveries after that period. On the scientific side, the lipping data was analysed in various ways. This has yielded insights into the prevalence of lipping at various crossing types and locations, as well as the reasons behind this phenomenon. A first draft of a journal paper was completed in February 2025 and is now undergoing a review and improvement cycle.



First experiments with the grinding of a crossing where lipping was detected

The task in IAM4RAIL about ***Adapting and Shaping Standards for Future Track Maintenance (led by Siemens Mobility)*** drives the evolution of standards, rules, and regulations (SR&R) to enable modern, data-driven track maintenance strategies. It combines two key efforts, defining transformation paths for existing SR&R and developing pre-standardisation for Distributed Acoustic Sensing (DAS). The first subtask focuses on identifying regulatory gaps and proposing practical updates to integrate advanced monitoring solutions, such as axle box acceleration-based defect detection. An initial draft of an adjustment proposal was created by Siemens and refined collaboratively with DB, ProRail, SNCF and TUDelft. Siemens led the review and consolidation of comments. A face-to-face “ABA Workshop” aligned perspectives on ABA-based monitoring and its regulatory implications. The project and subtask plan were presented to the CEN SC1 WG28 (EN 13848) to ensure alignment with standardisation goals, and discussions were initiated regarding the provision of a text proposal for an Annexe to EN 13848-1. The objective is to define clear, consensus-based transformation paths for integrating advanced monitoring into the EN 13848 framework. In parallel, the second subtask, related to DAS work, aims to establish recommendations for using optical fibre as a vibration sensor, ensuring compliance with international standards while addressing railway-specific needs. In future versions, these recommendations aim to be as exhaustive as possible, covering aspects throughout the entire value chain of the technology, including hardware, data formats, signal processing, AI and other relevant areas. Together, these two initiatives ensure that innovation is not only technically feasible but also supported by harmonised regulations. The ultimate goal is to establish a consistent and interoperable framework that accelerates the adoption of predictive maintenance across Europe.

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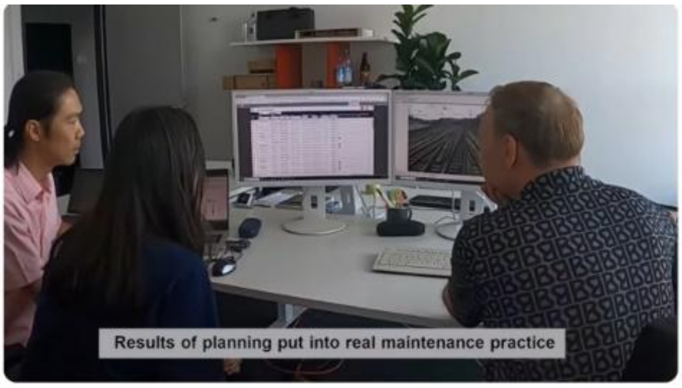
Videos Europe's Rail Joint Undertaking YouTube Channel:

DB Prescriptive Maintenance – Approach From Measurement to Maintenance Shift Planning: DB is transitioning from reactive to prescriptive maintenance, utilising track geometry predictions to plan shifts in a timely manner and achieve higher efficiency and reliability. Supported by monitoring technology and new eddy current sensors, we are performing root cause analysis. Our FP3-IAM4Rail shift planning tool, linked with DB's Maintenance tools and coordination system, enables data-driven and hands-on testing within DB's real maintenance planning processes. https://www.youtube.com/watch?v=oafevA2sLUA



Prescriptive maintenance – Approach from measurement to maintenance shift planning

Video YouTube Prescriptive Maintenance

ProRail Demonstrator LDV in The Netherlands: our FP3-IAM4Rail project successfully tested Laser Doppler Vibrometer (LDV) technology on TU Delft's V-track and onboard trains. This non-contact, high-precision method monitors vibrations in motion, marking a key step toward predictive maintenance and intelligent rail infrastructure, now enabling input-output measurements of track components! https://www.youtube.com/watch?v=ZlHIXIG2cD8

Flagship Project 3 IAM4RAIL - Demonstrator LDV in The Netherlands

Video YouTube LDV in The Netherlands

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Founding Members

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