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Deliverable D 2.7

Definition of Use Cases, including Innovation, Business Assessment, KPIs definition and roadmap (second Issue)

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1. Executive Summary

The Scope of the D2.7 is to define the second issue for the definition of FP3-IAM4RAIL project Use Cases (UC), including a description of innovation, an introduction to the business assessment. This first definition will cover how the proposed developments go beyond the state-of-the-art, including specific technical KPIs and the target baseline not only at WP level, but also at UC level.

The UC definition includes a chapter for Cluster, including a sub-chapter for each Use Case on the respective innovation management and synergies/risk of duplication of work. It includes, as well, a final catalogue per UC with tables with the UC and TRL level, including, when applicable, agreements reached with other FPs in the specific Work Packages or relevant System Pillar links.

Validation will be carried out by each UC through the corresponding Key Performance Indicators (KPIs) identified in Task 1.7 and how these KPIs are impacting all of Europe's Rail JU initiatives.
The work has started with the definition, for each WP with a demonstrator, of:

- The problem to be solved by the Infrastructure Managers in terms of Intelligent Asset Management, the baselines and the target multi-objectives to be optimised.
- The variables to be optimised, their correlations and the knowledge on the variables.
- The KPIs and how to compute them through measurable and non-measurable parameters describing the variables.

Each WP has initially focused on the proposition of KPIs and how to compute each one for the respective Use Cases and compare it with the previous baselines.
D1.5 for a report of Technical/Impact KPIs will cover the following points:

- full definition of KPIs model development;
- baseline for each KPI;
- formula for each KPI;
- link with GA KPIs, in particular, the contribution to the target set out to relate the FP3-IAM4RAIL project with Europe's Rail Multi Annual Work Programme and the project's pathways towards impact of FP3-IAM4RAIL GA;
- credible pathways from technical to societal KPIs.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
ABA	Axle Box Acceleration
ACCM	Central Computerized Multistation Apparatus
AI	Artificial Intelligence
BD	Bogie Diagnostic
BIM	Building Information Model
CAPEX	Capital Expenditure
CBM	Condition Based Maintenance
CCTV	Closed Circuit Television
CM	Corrective Maintenance
CMMS	Computerised Maintenance Management Systems
CoF	Coefficient of Friction
CTO	Combined Transport Operator
DDoS	Denial of Service
D&M	Diagnostics and Maintenance
DAS	Distributed Acoustic Sensing
DSS	Decision Support System
DT	Digital Twin
DTS	Distributed Temperature Sensing
ECN	Ethernet consist network
ERJU	Europe's Rail Joint Undertaking
ETB	Ethernet Train Backbone
FLG	Few-Layer Graphene
FMECA	Failure Mode, Effects, and Criticality Analysis
FP	Flagship Project
GA	Grant Agreement
GPR	General Purpose Relief
HABD	Hot Axle Box Detector
HMI	Human-Machine Interface
HVAC	heating, ventilation and air conditioning
IAMS	Intelligent Asset Management Systems
IM	Infrastructure Manager
IMR	Interest Maintenance Reserve
IoT	Internet of Things
IP	Internet Protocol
IXL	Interlocking
KPI	Key Performance Indicator
LCC	Life Cycle Costing
LDV	Laser Doppler Vibrometer
MAWP	Multi Annual Work Programme
MBTF	Mean Time Between Failures

ML	Machine Learning
OPEX	Operational Expenditure
PM	Preventive Maintenance
PSD	Power Spectral Density
RAMS	reliability, availability, maintainability and safety
RU	Railway Undertaking
SoA	State of the Art
SCCM	Multistation Command and Control System
S&C	Switches & Crossings
SMO	SIEMENS
TC	Track Circuits
TCR	Temporary Capacity Restrictions
TCU	Traction Control Unit
TCMS	Train Control Monitoring System
THI	Turnout Health Index
TMI	Turnout Maintenance Index
TMS	Train Management System
TRL	Technology Readiness Level
UC	Use Case
WP	Work Package

3. Background

The present document constitutes the Deliverable D2.7 “Definition of Use Cases, including Innovation, Business Assessment, KPIs definition and roadmap (second Issue)” in the framework of the Flagship Project FP3–IAM4RAIL as described in the EU-RAIL MAWP and contributes as well to the Flagship Project FP1–MOTIONAL and Flagship Project FP5–T RANS4M-R.

The FP3-IAM4RAIL flagship project aims to provide innovative technical requirements, methods, solutions and services - including technical requirements and standards for future developments - based on the latest cutting-edge technologies to minimise asset lifecycle costs and extend service life while meeting safety requirements and improving the reliability, availability and capacity of the railroad system. Both infrastructure and rolling stock are addressed.

The FP3-IAM4RAIL Flagship Project will research, develop and deliver solutions that will be demonstrated in different (relevant) scenarios across Europe, targeting up to TRL 6 as European common integrated solutions. Due consideration will be given to certification and validation of the new technologies and processes as part of those demonstrators, supported by a set of different Use Cases, integrating different technical enablers.

4. Objective/Aim

4.1. Scope of the document

This document has been prepared to provide, both internally to FP3–IAM4RAIL partners and externally to other FP members and other relevant part, a detailed description of the different Use Cases (UCs) defined by each WP.

The goal of this document is to describe each Use Case proposed by the different Clusters, including a description of innovation, an introduction to the business assessment, linking a general definition for socioeconomic objectives. This first definition will cover how the proposed developments go beyond the state-of-the-art, including specific technical KPIs and the target baseline not only at WP level, but also at UC level.

The document has been updated at M28, with aim to present the different technical objectives targeted by the WPs, the current position and the foreseen impact on the railway industry. Each UC defines a series of relevant technical problems, providing the context and necessary developments needed to solve them, also in terms of different KPIs that will be validated at the end of the project.

The definition of UCs and their context in the railway industry will be also useful to allow the definition of links with different ER – FPs that will be investigated during the course of the project and will serve as a base for the definition of future research activities within the Europe's Rail Programme.

4.2. Contextualisation of the document in the Europe's Rail JU framework

This document represents the results of the work described in Task2.2 and Task2.3 of the FP3–IAM4RAIL Grant Agreement to allow the interaction and alignment with the System Pillar and other ERJU Flagship Projects.

It also provides the definition of how the different Demonstrator Objectives defined in section 1.1.1.4 of the FP3–IAM4RAIL Grant Agreement are addressed by the different Use Cases.

5. Cluster B - Wayside Monitoring and Traffic Management System Link

The cluster focuses on the design, development, testing and validation of an Intelligent Asset Monitoring System capable of supporting the railway operators and infrastructure managers in maintaining smooth and uninterrupted operations. These activities are covered in WP3 and WP4 and 2 use cases will be developed (see Table 1).

UC ID	Title	Relevant WP/DO
3.1	Wayside and Infrastructure IAMS for TMS optimisation	WP3/DO1
3.2	Wayside monitoring in conventional and high-speed lines for TMS optimization	WP3/DO1

Table 1: Cluster B use cases

5.1. UC3.1: Wayside and Infrastructure IAMS for TMS optimisation

The objective of the "Wayside and Infrastructure monitoring system for TMS optimisation" is to provide a remote and centralised interface with the existing railway systems (Signalling, TMS, Wayside Monitoring Systems, etc), automatically collecting reports, functional parameters, logs, alarms and other diagnostic data.

Specifically, UC3.1 will develop a remote and non-intrusive data collection system to collect operational and diagnostic data from the IXL system, as well as dedicated interfaces with the TMS and ERP systems to acquire traffic and maintenance records.

The collected data is then processed, cleaned and stored in a database to provide easy access to the maintainer, enable correlation of different sources and serve as a starting point for the development of data analytics procedures.

The information that are derived from the collected data, that will range from statistics about some key operative indicators, prediction on assets status and of possible anomalies, will be exploited mainly to improve the maintenance activities to be performed and to optimise the scheduling of traffic. This will create therefor a link both with the Decision Support System and with the Traffic Management System.

5.1.1. Overall aim of the use case

5.1.1.1. Problem to be solved

The management of a route is currently carried out through a latest generation apparatus, called **Central Computesized Multistation Apparatus (ACCM),** which manages several stations from a central location ("Posto Centrale" or PC in Italian), located in the metropolitan area.

The PC concentrates *the functions and logic of all the controlled plants*, and *a series of Peripheral Sites (Posti Periferici or PP in Italian)* located in special buildings along the line, typically connected with long-distance fiber optic networks to allow the control of actuation cabinets placed even at a distance of hundreds of km. Within the PC, the supervision and regulation **of traffic are managed**

by the SCCM (Multistation Command and Control System) which performs the functions of *optimising railway traffic and supervising technological systems*. **A system composed of ACCM + SCCM normally manages a large area (typically regional), containing railway lines and Nodes,** from a PC where usually all the Traffic and Maintenance Operators are concentrated.

However, these systems are often the result of multiple revamping and integrate both new and legacy sub-systems. Additionally, the diagnostic information reports provided to the operator are generally poor and scarce (except for new systems that provide a dedicated diagnostic channel) and are often elaborated independently instead of merging them together to extract added value. Within the context of improving the infrastructure maintenance process, **the need to introduce predictive maintenance** (which uses data analysis and modelling to anticipate and avoid the occurrence of failures or malfunctions in equipment, adopting preventive measures that aim to reduce unplanned downtime and preserve the useful life of assets) **is of primary importance.**

It is also possible to study and implement **prescriptive algorithms for maintenance** that, building upon the prediction and insights provided by the analytics, also **suggest the actions and interventions to be performed** to solve unexpected problems and ensure the correct functioning of components and systems over time, **anticipating problems** and **planning the optimal timeslot to perform maintenance of the systems**.

Therefore, the Infrastructure Manager intends to pursue this ambitious objective by **collecting operational, diagnostic and maintenance data from both the wayside systems** (signals, switches & crossings, balise, track circuits, etc.) **and the infrastructural elements** (bridges, level crossings, etc.) along the line. Specifically on this last point, it is envisioned **to use the current monitoring systems and diagnostic vehicles** available, but also **to develop an obstacle detection system for the monitoring of railway level crossings,** based on the fusion of two different technologies: Lidar and Radar. This would allow the monitoring of singular points of the infrastructure where rail and car/pedestrian traffic intersect, increasing the safety of the system (traffic, workers, users) and reducing the requirements of slowdowns and the related management costs.

All this information will be used to create an **Intelligent Asset Management System (IAMS)**. This platform will implement **specific Analytics and algorithms for the detection of anomalies and decision support methodologies to support the TMS** (Train Management System) with diagnostic information of the assets and to improve railway management in terms of punctuality and regularity, reducing service interruptions, line unavailability and related management costs, improving the use of assets themselves.

5.1.1.2. Industry current position / baseline

As already mentioned in the previous paragraph, currently, the SCCM (Multistation Command and Control System) which is physically located at the central station, performs the functions of optimising railway traffic and supervising technological systems. The latter function is implemented through a specific subsystem dedicated to Diagnostics and Maintenance (D&M) connected, through a TLC/LD long-distance Data Transmission network, to peripheral stations along the line in order to monitor and diagnose security systems, auxiliary technological systems and equipment of the system itself.
The Diagnostics and Maintenance Subsystem is therefore used for the management, data

processing and display of diagnostic and maintenance information (on appropriate video units) of the technological systems (security, auxiliaries, etc.) of jurisdiction.
The functions of the Diagnostics and Maintenance subsystem allow to optimise the activities related to the monitoring and maintenance of systems and infrastructures by providing appropriate tools for the timely detection of faults and anomalies (in progress or expected) and for technical support for preventive, on-condition, or repair maintenance interventions.
The diagnostic functions allow the operator to identify, analyse and locate the situations of failure and failure that may occur in the system, obtained through the integration of the following basic functions:

- On-line diagnostics, obtained through the monitoring of events, the detection of faults or malfunctions in progress on the controlled systems.
- Predictive diagnostics, obtained by controlling the degradation of the system preceding the failure.

The maintenance management functions are implemented through "IN. RETE2000", which uses the information on the systems collected by the diagnostic functions to provide operators with operational support for the management of maintenance interventions. In general, the maintenance functions managed by IN. RETE2000 can be classified as follows:

- Corrective (or extraordinary) maintenance: aimed at restoring the full functional conditions of the monitored systems through the interpretation of alarms and intervention on faulty components.
- Preventive (or scheduled) maintenance: with the aim of increasing the Mean Time Between Failures (MBTF) of the individual components through the programming of maintenance interventions.
- Cyclical: based on pre-defined inspection time cycles.
- On condition: where the operating cycle is defined based on the final data on the operating conditions of the systems, and which allows to intervene before the failure occurs.

Also, the infrastructural maintenance management functions are implemented through the "IN. RETE2000" system, which uses the information on the systems collected by apposite diagnostic functions to provide operators with operational support for the management of maintenance interventions. In addition to the above, supplementary protection systems are put in place to monitor Level Crossings passage's clearance. By scanning the area between the level crossing barrier pairs, these systems check for the presence of obstacles that could collide with the passing trains, causing damages to the rolling stock and harming people. The systems do interface with the signalling system.

5.1.1.3. Subproblem addressed by the use case and measurable objectives

<u>Wayside Signalling Equipment Monitoring System</u>
The Wayside Signalling Equipment Monitoring System will focus on the remote and non-intrusive collection of diagnostic and operational data coming from the wayside signalling assets monitored. It is the central use case of the Work Package since it enables the development of all the other features by providing access to the functional parameters, alarms and logs related to the different assets monitored.

Within the context of WP3, the development of a monitoring system is envisaged, which would allow the collection of data related to different wayside signalling assets (e.g., switch and crossings, signals, track circuits) from both the TMS and IXL. Additionally, data related to past maintenance procedures will also be collected, together with weather information. This would allow for an automated and reliable method for continuously collecting operation and diagnostic data that would feed the machine learning models and the DSS modules.

Infrastructure Monitoring System

Information related to the geometry of the track, structural health conditions of the bridges, exposure of the surrounding environment to hydrogeological risks and vegetation encroachment is essential to obtain a holistic view of the network status. The continuous update of this information defines a Real-Time Monitoring system that allows managers to set appropriate thresholds on each of the risk factors affecting the track and, therefore, enhance train circulation safety. Exceeding one or more thresholds can indicate the development of a serious risk to the infrastructure that requires actions to be taken such as train speed reductions and in some cases interruption on the railway circulation.

The possibility to constantly monitor these risk factors and store the collected measurements in a dedicated environment for further historical and statistical analysis represents not only a key asset for predictive maintenance but it also has a significant relevance for the TMS. Adopting an appropriate communication protocol, the derived actionable insight can be transmitted to the TMS to achieve a more efficient management of the rail traffic.

The target of this activity is to create a link with WP13, where additional data on infrastructure status are collected using diagnostic vehicles, in-situ sensors, drones, and satellites, and to develop efficient procedures for data pruning and threshold definition to automate and make the selection of information to be transmitted to the TMS more efficiently.

Level Crossing Monitoring System - Radar and Lidar Obstacle Detection System

Level crossing intersections are hazardous areas as several things can go wrong once the level crossing barriers get closed. For instance, vehicles or sensibly sized objects falling from vehicles could be located between barriers. Usage of obstacle detectors in proximity of level crossing is therefore pivotal to prevent damages to the rolling stock and save human lives.

Obstacle detection in the railway arena relies on various technologies. Lidar and Radar, adopting different wavelengths and implementing different algorithms, are certainly the most widespread technologies. However, to the best of our knowledge, these two technologies are not exploited simultaneously.

The development and test of a level crossing obstacle detector, banking simultaneously on Lidar and Radar sensors, is within the scope of this project. The double detection mechanism, scanning concurrently the same area, will rely on completely independent processing chains (electronic and algorithmic).

Finally, the two processing chains are logically merged, with passage clearance granted as soon as one of the detection chains indicates the availability of the passage. The hardware will allow stand-alone and simultaneous detection, allowing Lidar and Radar to be used individually or simultaneously.

The complementary of the 2 different approaches implemented will be analysed to determine

under which cases or conditions the joint use of the technologies enhance the performance of the detection system.

Asset Status Forecasting System

During WP3, the IM will be involved in the definition and description of the major and most critical issues that affect the operation and more specifically that are significant for the case study. Based on that information and the data collected by the previous sub-systems, several specific machine learning models will be developed and applied in order to solve the issues highlighted. For example, in the case of the monitoring of the Track Circuits, the objective will be to reduce false occupations instances, which can lead to service disruptions and line unavailability.

The goal will be to validate this prediction against the actual state of the assets monitored by cross-checking the number of maintenance interventions performed, in order to provide the operator with a health index of the asset and additional information on its criticality and remaining useful life.

This information will be then provided to the DSS module for the scheduling of maintenance procedures or to the TMS for the optimisation of operations.

Decision Support System for Automatic and Optimised Maintenance Scheduling

The DSS is aimed at suggesting possible alternative solutions in case of an interruption of the line due to planned maintenance interventions.

The suggested solutions consider the costs for the service manager and the users involved in the service interruption. The goal is to minimise the impacts due to maintenance interventions, increase the quality of the service and guarantee regular and seamless connections.

The following functionalities shall be implemented:

- Visualising the current assets state, highlighting any anomalies, and possibly providing assets status prediction.
- Visualising, in a single interface, the historical values of the assets monitored, events and alarms raised and environmental data of the track.
- In case of disruption, focus the attention of the operator on the key elements of the assets causing the disruption, possible root causes and mitigation actions.

Integration of Analytics with TMS

Information on the diagnostic status of the signalling devices, track and infrastructure can be fed back into the TMS in order to improve and optimise the scheduling on the line. Moreover, statistical information about track occupation, frequency of usage and mean time of transit can be extremely useful to allow the operator to make a more informed decision in the management of the service.

This use case, and more generally the whole work package, targets to provide this kind of inputs to the TMS and will contribute to both the specification of protocols to be implemented for the data exchange and the actual implementation of this process with real data coming from the field. In this context, an alignment with FP1-Motional has been established to define the scope of the interactive activity between the 2 FPs.

5.1.1.4. Influence of the proposed innovation on the IM/RU problem

The development of the IAMS platform will enable the capability to manage in a holistic and integrated way all assets involved, allowing for an optimised use of resources and an improvement of operations. Regarding the obstacle detection system, the double detection technology advantage lays in its inherent redundancy, as a failure of both Radar and Lidar is extremely unlikely. Tackling detection's correctness results in superior availability of the system, hence higher reliability for the signal to be transmitted to the signalling system. Compared with single detection technology systems, this double detection technology is less intrusive as weather conditions will not be flagged as dangers in correspondence of level crossings. In fact, single detector-based systems, often trigger false positive detections (rain or fog can mislead the detection). In such cases, the train must slow down approaching zero speed and a person from the personnel must conduct a visual inspection. Increasing availability and enforcing safety at the same time should reduce the IMs' hesitancy to adoption of level crossing detectors.

5.1.2. UC3.1: demonstrator's KPI

5.1.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #1: Asset Management and TMS and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO1 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
I	Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50 %, in specific use cases	High/direct
V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy improvement of 10%)	Little/indirect
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XI	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 2: UC3.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
3.1-1	Reduction of speed restrictions on trains due to deteriorating asset condition	10 %
3.1-2	Reduction of infrastructural data management time, useful for TMS connection	10 %
3.1-3	Providing alarms to TMS in case of obstacles on the level crossing area	NA
3.1-4	Corrective maintenance prediction	NA
3.1-5	Reduction of service disruption	10 %
3.1-6	Data processing time	< 10 s

Table 3: UC3.1 PIs

5.1.2.2. PI3.1-1 - Reduction of speed restrictions on trains due to deteriorating asset condition

Short description

Predictive maintenance can significantly influence the reduction of speed restrictions on rail infrastructure by enabling early detection of potential problems before they become critical failures that may have an impact on circulation.

In the Italian use case, real-time data processing tools, aided by sensors and analysis systems, will be used to collect information for the Integrated Asset Management System (IAMS).

By analysing this information, the predictive models to be developed will be able to detect patterns and anomalies that indicate potential problems before they become critical failures. This allows them to schedule maintenance before it is needed, helping to reduce unplanned downtime and improve the reliability and availability of rail infrastructure.

In short, predictive maintenance can help improve the reliability and availability of rail infrastructure, which can reduce the need for speed restrictions on railways and improve the passenger experience by reducing travel times and avoiding unnecessary delays.

How to compute PI 3.1-1

The number of speed restrictions due to deteriorating asset conditions will be quantified with the current corrective/preventive maintenance approach compared to the future predictive maintenance approach in which maintenance activities can be scheduled without affecting circulation. The time period will be determined based on the available data.

$$PI_{3.1-1}\ (\%\ \text{speed restrictions}) = \frac{TSRn}{TSRt} x\ 100$$

Where:

- *TSRn* is the number of total temporary speed restrictions in Line (the particular section examined) due to deteriorating asset conditions with the new maintenance strategy.
- *TSRt* is the number of total temporary speed restrictions in Line (the particular section examined) due to deteriorating asset conditions with the current maintenance strategy.

5.1.2.3. PI3.1-2 - Reduction of on infrastructural data management time, useful for TMS connection

Short description

The main objective of this PI is to verify whether the time (directly linked to the cost of operating personnel) necessary to decide which maintenance information relating to the state of conservation and maintenance of the railway infrastructure (bridges, tracks, ...) and of the surrounding environment, may affect rail traffic and, in this case, to be transmitted to the TMS, can be reduced in specific cases. For this aim, for the same activity, IM operators can jointly use data remotely acquired from satellites, drones, in-situ measurements and ancillary data as support for infrastructure and surrounding monitoring, without the need to interrupt the railway traffic.
This factor is also directly related to a correct preventive maintenance, by knowing the state of health of the infrastructure in a faster time. This allows infrastructure managers to detect any critical area along the infrastructure and take appropriate actions if necessary, including high resolution data gathering, detection of threshold values for activation of emergency procedures and mitigation actions.

How to compute PI3.1-2

For the calculation of PI3.1-2, it is possible to estimate the time (man/hour) necessary for the management and selection of the data collected along the infrastructure (bridges, tracks, ...) and the surrounding area before and after the application of a holistic monitoring approach (new methodology), comparing it with the current one (traditional/conventional methodology).
For this KPI evaluation, we can use the following formula:

$$PI_{3.1-2}\ (\%\ time\ savings) = \frac{Time_{traditional_method} - Estimated\ time_{new_method}}{Time_{traditional_method}} \times 100$$

Where:

- $Time_{traditional_method}$ is the time required to perform conventional data management.
- $Estimated\ time_{new_method}$ is the time required to manage data after the application of the new approach.

If PI3.1-2 is positive, it indicates that the estimated time for the new method is less than the time required for the traditional method. In this case, a positive value indicates a time saving or a reduction in the time required to complete the task. However, if PI3.1-2 is negative, it indicates that the estimated time for the new method is greater than the time required for the traditional method. In this case, a negative value indicates that the new method would require more time compared to the traditional method.

Therefore, the cost of personnel is indicated below:

$$PI_{3.1-2}\ (\%\ cost\ savings)\ = \frac{Cost\ _{traditional_method} - Estimated\ Cost_{new_method}}{Cost_{traditional_method}} \times 100$$

Where:

- $Cost_{traditional_method}$ is the cost required to perform the conventional data collection.
- $Estimated\ Cost_{new_method}$ is the cost required to manage data after the application of the new monitoring approach.

If PI3.1-2 is positive, it indicates that the **estimated** cost for the new method is less than the time required for the traditional method. In this case, a positive value indicates a time saving or a reduction in the cost required to complete the task. However, if I3.1-P2 is negative, it indicates that the estimated cost for the new method is greater than the cost required for the traditional method. In this case, a negative value indicates that the new method would require more cost compared to the traditional method.

5.1.2.4. PI3.1-3 - Providing alarms to TMS, via ILX, in case of obstacles on the level crossing area

Short description

The obstacle detector shall provide an alarm to TMS, by means of interlocking (IXL), in case of detection of an obstacle. In a specific application, this alarm is sent to the interlocking (IXL), which will make the subsequent decision regarding the specific logic implemented from the IM.

How to compute PI3.1-3

The obstacle detector will be tested on a trial site, in a representative environment and in different scenarios, with different types of obstacles. For each situation, the overall system shall provide, on a dedicated output, the alarm to be read from the IXL.

The system will be tested simulating faults on the single technology too, checking the capability of the system to work with just one technology. This will demonstrate the higher availability of the combined solution.

The calculation of this PI is trivial. In fact, when comparing the level crossing clearance assessment by visual inspection with its automated counterpart operated by the obstacle detector, it is clear how the adoption of the obstacle detector results in a reduction of time communicating the line status to the TMS (more than 50% as per PI). Equally, there would be a reduction of human intervention as visual inspection will be less demanded (more than 10% as per PI).

5.1.2.5. PI3.1-4 - Corrective maintenance prediction

Short description

This PI refers to the algorithm precision in the evaluation and detection of anomalies for a specific asset fault mode. One example is the prediction of the Track Circuits (TCs) behaviour that can lead to a False Occupancy and, therefore, to a Corrective Maintenance (CM) intervention. However, the PI can be extended also to other fault modes if coherently described.

How to compute PI3.1-4

The evaluation of the PI is based on the formula of the "balanced accuracy" which is a metric used to evaluate how good a binary classifier is, taking also into account the possible imbalance between the two classes analysed. The formula is defined as the mean value of the "Sensitivity" and the "Specificity" indexes of the algorithm.

$$PI3.1-4 = \frac{Sensitivity + Specificity}{2}$$

Where:

$$Sensitivity = \frac{Number\ of\ correct\ CM\ prediction}{Number\ of\ correct\ CM\ prediction + n°\ of\ missed\ CM\ prediction}$$

$$Specificity = \frac{Number\ of\ correct\ healthy\ prediction}{Number\ of\ correct\ healthy\ prediction + n°\ of\ wrong\ CM\ prediction}$$

5.1.2.6. PI3.1-5 - Reduction of service disruption

Short description

This PI shows, for a specific time horizon, the average percentage of corrective interventions that can be transferred into predictive interventions and can be planned more efficiently in the longer term. The computation of this PI is dependent on the availability of maintenance intervention planned and implemented to be used as a reference.

How to compute PI3-1-5

This KPI shows the percentage of avoided corrective interventions that can be identified through prior data analysis.

KPI 5 can be computed with the following formula

$$PI_{3.1-5}\ [\%] = \left(\sum_{t=1}^{W} \frac{(Number\ corrective_before_t - \ Number\ corrective_after_t)}{Number\ corrective_before_t}\right) * \frac{100}{W}$$

Where:

- *W* defines the number of considered weeks
- The fraction's numerator describes the number of corrective interventions that can be avoided due to the data analysis in week t
- The fraction's denominator defines the number of corrective interventions that occurred before the planning tool was used in week t.

5.1.2.7. PI3.1-6 - Data processing time

Short description

Time required by the whole data processing, starting from the raw data acquisition from the field or the source system to the availability of the data on the platform and the visualisation of the HMI.

How to compute PI 3.1-6

Several input data coming from the different assets monitored is processed, analysed and visualised in the HMI. Different data sources are matched by different data processing techniques, so each data source is considered separately for the computation of the KPI and finally the average is calculated.

$$PI_{3.1-6} = time\ of\ single\ datapoint\ processing < 10\ s$$

5.2. UC3.2: Wayside monitoring in conventional and high-speed lines for TMS optimisation

The objective of the "Wayside monitoring in conventional and high-speed lines for TMS optimisation" system is to develop monitoring solutions and sensors to enable the remote monitoring of point machines and level crossing barriers along the line and to collect diagnostic information needed for the development of anomaly detection models.

The different monitoring solutions are then interfaced with a common IAMS application for the centralisation of alarms and HMIs that can support the operator in the management of the line.

The information that are derived from the collected data, that will range from statistics about some key operative indicators, prediction on assets status and of possible anomalies, will be exploited mainly to improve the maintenance activities to be performed and to optimise the scheduling of traffic. This will create therefor a link both with the Decision Support System and with the Traffic Management System.

5.2.1. Overall aim of the use case

The goal of this use case, which involves collaboration among three technology companies (ENYSE, GTS and INDRA) and the main Spanish infrastructure manager (ADIF), is to develop asset monitoring technologies for railway infrastructure. The aim is to achieve predictive maintenance for critical assets such as level crossing barriers and point machines, enabling informed decision-making related to traffic management activities.

In this way, the use case consists of an **integrated demonstrator installed by three technology companies across four different locations** within the Spanish railway network:

- **LOCATION 1:** ENYSE's level crossing barrier monitoring system in conventional line in Lláscares (Asturias)
- **LOCATION 2A:** GTS' point machine monitoring sensors in Bifurcación Torrejón Velasco (Madrid-Seville high-speed line)
- **LOCATION 2B:** GTS' point machine Smart Wayside Object Controller (SWOC) in Medina del Campo-Olmedo line (former high-speed railway line currently out of operation)
- **LOCATION 3**: INDRA's point machine monitoring system in Santa Cruz de la Zarza (Madrid-Valencia high-speed line)

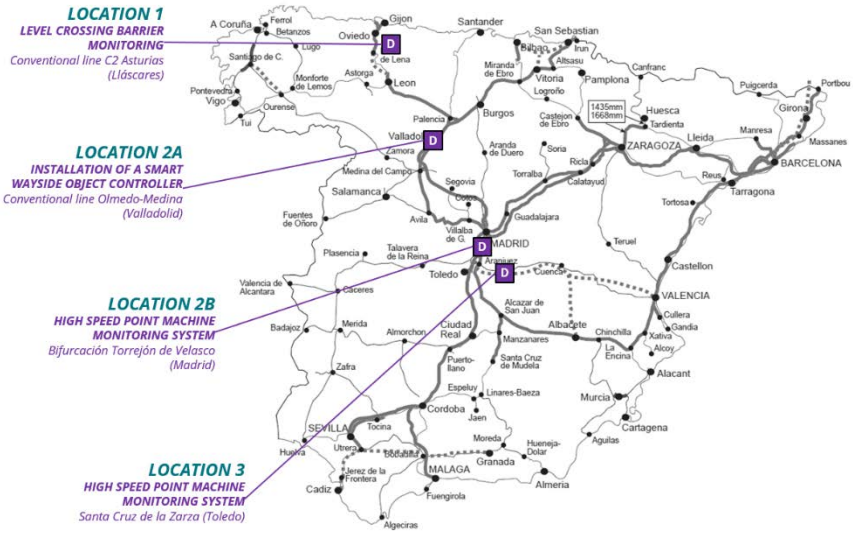

Figure 1: Map with locations on the Spanish railway network

The locations for the installation of the systems were selected as significant conflict points for ADIF in collaboration with all technology companies. The reasons for this selection are detailed in the document "FP3-IAM4RAIL MS04: Preliminary Field Installations Report of Milestone Achievement." Nonetheless, this chapter introduces the motivations behind the chosen locations.

The **architecture** selected for the Spanish use case will be integrated into the IAMS for each company's specific use. This will result in three IAMS for processing asset data, which will be integrated into a common database and common HMI.

Each company will have access to the information from each asset in the common database, facilitating integration between the different companies. The processed data can be observed on a common dashboard that integrates each asset's own dashboard, which will be developed by ENYSE and GTS.

Also, an interactive map or interface will be developed by ADIF in WP4, which will incorporate all the demonstrators in which ADIF is working in ERJU. It will consist of a map of the Spanish railway network that will show the different locations and will permit easy access to the dashboard by clicking on them. This will facilitate greater integration and near real-time knowledge of all the

demonstrators in which ADIF is working in ERJU.

5.2.1.1. Problem to be solved

Switches and crossings are sensitive components of the railway infrastructure since the exchange of forces between the wheel and the rails at these points is greater than that generated on the rails in the rest of the track. It is the weakest point of the railway superstructure since there are important discontinuities in them for the support of the wheel that cause strong unwanted wheel load impacts. In the same way, level crossing barriers are elements that are part of the railway interlocking and can experience mechanical issues under adverse weather conditions, vandalism, etc., which can lead to a significant problem on the track.

Currently, in the Spanish network managed by ADIF, there are more than 15,000 switches and crossings and thousands of level crossing barriers, so their correct maintenance is essential given their high number and importance in safety. A failure in crossings and level crossing barriers can have major effects on the safety and operation of the railway network. For this reason, they require more expensive and specialised conservation, which makes them elements on which maintenance attention must be concentrated to ensure their functionality and reliability.

These assets, highly linked to signalling, are located and controlled from ADIF traffic control centres, where they determine the itineraries that the train must follow. At present, these assets (switches and crossings and level crossings) send an alarm to the control centres signalling a "check" or "no check", which indicates whether it works correctly or, on the contrary, a defect has been found in its operation. In the event that it does not work, the control centre gives the order for the trains to stop running. However, no other information is given to indicate what the exact problem is, nor is information collected on the status of the asset.

Given the critical importance of maintenance for safety and its significant scalability, ADIF recognises the necessity of monitoring devices to anticipate potential incidents using predictive maintenance techniques. This approach enables the identification of potential failures in infrastructure elements before they occur. Therefore, it is essential to adopt innovative technological solutions that facilitate a predictive maintenance strategy for switches, crossings, and level crossings, allowing for the early detection of structural damage. Implementing predictive maintenance would yield several advantages, including:

- Improved maintenance planning
- Reduced downtime
- Optimised maintenance costs
- Extended asset lifespan
- Enhanced utilisation of work intervals

The implementation of this predictive maintenance in the assets is expected from this project and, that said, information will be able to be sent to the signalling assets in order to be more agile when it comes to managing rail traffic.

5.2.1.2. Industry current position / baseline

Currently, asset assessments are primarily conducted through preventive maintenance—periodic inspections—rather than predictive approaches that anticipate potential failures. Currently, maintenance of switches and crossings is performed through visual and geometric inspections, as well as ultrasonic testing to identify internal defects on a regular basis. For level crossings, the functionality and setup of mobile elements are also verified.

The inspections carried out to control the condition of the high-speed switches and crossings, which are the focus of study in this project, are regulated by the Technical Instruction for Inspection and Surveillance of track devices Adif IT-301-001-VÍA-28 and the General Criteria for preventive maintenance of infrastructure and track Adif-PE-301-001-005-SC-524-A-06. Furthermore, since they do not have fixed-point frogs, they avoid discontinuities in the rolling, and the data from the geometry monitoring trains are valid, so through their analysis, it is possible to continuously control the geometry of the track devices. Also, ultrasonics auscultations are carried out annually. The most common incidents in these assets are caused by problems in the mechanical safety installations and the lack of testing of the motors since the rolling continuity in the moving-point frogs prevents impacts on them.

ADIF implements a preventive maintenance program for level crossing barriers that focuses on inspecting and lubricating mechanical components and electrical systems. This program includes thorough visual inspections to identify any signs of wear or damage, the application of lubricant to moving parts to ensure smooth operation and reduce wear, and checks of electrical circuits, sensors and control systems to confirm proper functionality. Functional tests are also conducted to ensure that barriers close and open correctly and that warning lights are operational. All inspections and maintenance activities are documented to maintain a detailed record, which helps prevent failures and accidents, thereby ensuring the safety of users and the efficiency of the railway system.

Implementing predictive maintenance is essential for achieving significant cost savings. This approach allows for targeted replacements based on actual need rather than relying on periodic replacements or addressing issues only after failures occur. Responding to railway asset failures can disrupt rail traffic, highlighting the importance of developing an effective and economical maintenance strategy. Additionally, traffic control centres typically receive limited information about asset status, only indicating whether it is operational. This lack of detailed insights can extend work intervals and delay response times.

5.2.1.3. Subproblem addressed by the use case and measurable objectives

Signalling data Acquisition - Level crossing monitoring system

A level crossing is an intersection where a railway line crosses a road or path, or in rare situations, an airport runway, at the same level. In them, trains usually have priority because their inertia prevents them from stopping easily. Level crossings use mechanisms such as barriers or traffic

lights to warn those who intend to cross them when the train is in proximity.

Level crossings are safety devices that have a great impact on the operation since a failure can cause the stoppage of the trains. Therefore, the availability of this equipment is very important to reduce possible delays in railway traffic.

A problem in the mechanical system is the most common failure of this type of equipment due to the environmental conditions in which they are working (vibrations, adverse weather conditions, vandalism, ...). In addition, it provokes the trains to stop, causing serious delays in train operation.

As indicated previously, the inspections of level crossing barriers are not carried out predictively to anticipate the possibility of asset failures, but rather preventive maintenance (periodic inspections), as well as corrective maintenance, if the asset has already failed.

Therefore, to carry out predictive maintenance to reduce the number of incidents produced in operations, a level crossing barrier diagnostic system will be implemented. This diagnostic system will also allow data to be sent to the TMS when a failure forecast is made. The TMS will be able to make modifications in normal operation to adapt them to different scenarios.

Unmanned System Data Acquisition - Switches monitoring system

The goal is to design and implement an unmanned, unsupervised data acquisition system. A complete monitoring system will utilise advanced, cost-effective inspection technologies based on sensors, IoT and external data collection. This will enable unmanned and self-diagnostic asset assessments for condition monitoring of wayside solutions.

Specifically, for switches—critical components that significantly affect operation, safety and investment—the focus is on early detection and prediction of defects and damage (structural issues, obstacles, etc.) that may hinder normal operation. This approach aims to enhance availability while optimising maintenance and extending lifespan.

Common failures in high-speed lines include the breaking of lock bars in point machines due to vibrations and movement, as well as slack in the locking mechanisms.

For the Train Management System (TMS), the availability of switches is crucial due to its high impact on train operations. As part of the condition analysis, it will be evaluated whether additional parameters provided by the TMS are relevant.

Asset Status Forecasting System

The implementation of sensitisation through SWOC capabilities and integration via EULYNX (SDI-P) enables standardised integration of new measures into the platform. This framework allows for the integration and processing of new information for self-diagnostics, facilitating data analysis in collaboration with T4.1 and supporting TMS exchange for comprehensive asset decision-making.

By leveraging AI technologies, the data acquired from sensors and stored in the IAMS will be

analysed to identify anomalous operating patterns and predict potential issues. This proactive approach will enable effective maintenance planning and operational adjustments, minimising the impact of problems before they arise.

Decision Support System for Optimised Maintenance Scheduling
Utilising data from sensor networks stored in IAMS, along with information from the TMS, the AI system will analyse and process this information to assess the condition of the elements. This will enable the extraction of relevant insights that can provide the maintenance team with a clearer understanding of asset status.

Integration of Analytics with TMS
With data from the TMS and sensor networks stored in the IAMS, the AI system will analyse and process this information to assess the condition of the elements. This will enable the extraction of relevant insights to assist maintenance efforts and provide additional status updates to the TMS.

5.2.1.4. Influence of the proposed innovation on the IM/RU problem

Level crossing monitoring system
The diagnostic system for level crossing barriers will have a direct impact on the operation, reducing the number of traffic delays due to failures in more than 1000 level crossings on the Spanish railway network alone.

Such an innovative system allows predictive maintenance and the detection of damages at early stages, providing new and additional information, to increase the asset lifecycle, to reduce maintenance costs and optimising the operation (TMS).

Unmanned System Data Acquisition for point machines
The unmanned system has a direct influence on the more than 15.000 switches of the railway network in Spain, as sensitive components in the operation and destination of high investments, for maintenance.

Such an innovative system allows predictive maintenance and the detection of damages in the early stages, providing new and additional information for the optimisation of the operation (TMS), the optimisation of the maintenance and the extension of the asset lifetime.

5.2.2. UC3.2: demonstrator's KPI

5.2.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the IAM4RAIL Demonstrator #1: Asset Management and TMS and the related KPIs.

Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO1 with the following Key Performance Indicators:

KPI	Description	Impact
I	Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50 %, in specific use cases	High/direct
V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy improvement of 10%)	Little/indirect
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XI	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 4: UC3.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
3.2-1	Reduction of delayed trains due to asset condition.	< 10 %
3.2-2	Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown.	< 20 %
3.2-3	Reduction of normalisation time in case of the monitoring of the point machine slack in the “locks” to closure.	30 %

Table 5: UC3.2 PIs

5.2.2.2. PI3.2-1 - Reduction of delayed trains due to asset condition

Short description

By integrating predictive maintenance techniques into asset management practices, it's possible to foresee and address potential issues before they lead to delays, thus reducing delay minutes per train caused by asset condition problems.

The train operator typically records and, in most cases, provides to the signalling maintainer the delayed trains and delay time per train for each failure. This is essential for effective traffic management and planning, as well as for delivering satisfactory service to passengers. Signalling failures can cause significant delays, as they require staff to physically access to investigate, analyse and repair the faulty component, which takes time and very often more than one visit on-site.

We will compare the data obtained for the assets under study with the data for the same assets in previous years. Ultimately, the aim is to optimise asset management strategies, prevent service interruptions and enhance the overall performance and reliability of the transportation or operational system.

How to compute PI 3.2-1

In order to compute the proposed PI, the number of train delays in the period prior to the project (2022-2024) will be compared to the same parameter computed in the period 2025-2026. The proposed formula for the evaluation is the following:

$$PI_{3.2-1} = \left(\frac{n_c - n_n}{n_c}\right) \cdot 100 \geq 10\ \%$$

Where:

n_c: current number of delayed circulation due to a problem of an asset.
n_n: new number of delay circulation due to a problem of an asset.

Delay minutes will be measured at all available measuring points. Of those trains with measured delay minutes that exceed a specific threshold, a delay event is counted. The threshold will vary depending on the line type and the category of the train involved: for example, in a high-speed scenario, a train delay event is counted if the delay exceeds 5 minutes for passenger services and 15 minutes for freight services.
No train delay event is counted if these thresholds are not exceeded at any measuring point.

5.2.2.3. PI3.2-2 - Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown

Short description

The solution for monitoring a level crossing barrier shall provide a warning or alarm in the event of detection of a possible breakdown of the electric motor. This degradation data is sent to the IAMS which will make the subsequent decision, based on thresholds and algorithms to produce a warning or alarm, depending on the scenario provided to the LX/OC/TMS.

How to compute PI 3.2-2

Electric motor degradation detection will be tested on a trial site in a representative environment. For each situation, the overall system shall provide a dedicated output, the warning and/or alarm to be read on the IAMS HMI and to be read from the operation system (LX/OC/TMS).
For the calculation of the PI: the time required to diagnose a broken electric motor using the conventional diagnostic method shall be compared to the automated solution. The time shall be counted from the moment the problem occurs until the maintenance staff knows the reason for the problem. The PI will be met when:

$$PI_{3.2-1} = \left(\frac{\overline{tcv} - \overline{tnw}}{\overline{tcv}}\right) \cdot 100 \geq 20\ \%$$

Being:

$$\overline{tcv} = \frac{\sum_{i=1}^{n} tcv_i}{n} \qquad \overline{tnw} = \frac{\sum_{i=1}^{n} tnw_i}{n}$$

Where:

- $\overline{tcv}$: average conventional diagnosis time.
- $\overline{tnw}$: average diagnosis time with the new automated system.
- tcv: time of conventional diagnosis.
- tnw: diagnosis time with the new automated system.
- n: number of delayed circulations / trains due to a problem of a level crossing barrier.
- i: incremental number.

5.2.2.4. PI3.2-3 - Reduction of normalisation time in case of the monitoring of the point machine slack in the "locks" to closure

Short description

The monitorisation solution of the point machine shall provide a warning or alarm in case of detection of the slack in the "locks" to closure. In a specific application, the slack parameter is monitored and sent to IAMS which will make the subsequent decision, based on thresholds and algorithms to produce a warning or alarm, depending on the scenario to be provided to the IXL/OC/TMS.

One of the measures usually considered is the total normalisation time for an incident, typically involving communication time plus the intervention time of the maintainer. In many cases, this time is very low, but usually in switch points faults, in incidents due to mechanical adjustment, the maintainer makes several inspections and on-site visits before resolving, this results in a time between the occurrence of the fault and the effective normalisation time.

How to compute PI 3.2-3

The slack detection will be tested on a trial site in a representative environment. For each situation, the overall system shall provide on a dedicated output, the warning and/or alarm to be read on the IAMS HMI and to be read from the operation system (IXL/OC/TMS).

$$\text{Average normalisation time per failure } = \frac{SUM(normalisation\ times)}{Total\ failures}$$

For the calculation of the PI: we sum up all reporting times of all faults related to switch setting faults and divide by the total number of faults.

When comparing the values on the same point machine in the years before the demonstrator is set up (2021-2023) and after (2024-2026), the improvement will be the ratio between the average in previous 2 years and the average in the 2 years of the demonstration.

When comparing the assessment of the slack in the "locks" to closure by visual inspection (same point machine in previous years, i.e. 2021-2024) with its automated counterpart operated by the IAMS (2024-2025), it is clear how adoption of the automated solution results in a reduction of time

for communicating the status to the maintenance (IAMS) and to the operator (IXL/OC/TMS). Equally, there would be a reduction of human intervention as regular visual inspection will be less demanded.
The improvement is computed as the ratio of the 2 normalisations.

$$PI_{3.2-2} = \frac{Avg\ norm.\ time\ before\ demo - Avg\ norm.\ time\ after\ demo}{Avg\ norm.\ time\ before\ demo} x100$$

For the point machine use case, we propose an improvement threshold of at least 30%.

6. Cluster C - Rolling Stock Asset Management: On-board and Wayside Technologies

This cluster addresses both on-board (WP5 and WP6) and wayside (WP7) monitoring technologies for the design, testing and validation of intelligent rolling stock asset management solutions.
The 18 Cluster C use cases (UC) are listed in Table 6:

UC ID	Title	Relevant WP/DO
5.1	Bogie Monitoring System (on-board)	WP5/WP6/DO2
5.2	Health Monitoring & Analytics of HVAC & Brakes systems (ES)	WP5/WP6/DO2
5.3	Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)	WP5/WP6/DO2
5.4	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries & Brakes (ES)	WP5/WP6/DO2
5.5	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)	WP5/WP6/DO2
6.1	Development of next generation Traction control unit hardware and gate drive communication link	WP6/DO2
6.2	Traction Component Health Monitoring & predictive Maintenance	WP6/DO2
6.3	Set up of adaptive wireless telecom network between train elements	WP6/DO2
6.4	Adhesion estimation for management	WP6/DO2
6.5	Wayside signalling equipment monitoring system	WP6/DO2
6.6	On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany	WP6/DO2
6.7	Digital twin for energy	WP6/DO2
6.8	Smart maintenance scheduling tool	WP6/DO2
7.1	Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)	WP7/DO2
7.2	Pantograph Monitoring System (wayside – video and 2D-3D images)	WP7/DO2
7.3	General physical anomaly detection Monitoring System (wayside – video and 2D- 3D images)	WP7/DO2
7.4	Data path diagram use case	WP7/DO2
7.5	CBM algorithms for freight	WP7/DO2

Table 6: Cluster C use cases

6.1. UC5.1: Bogie monitoring system (on-board)

This use case spans Tasks 5.1 “Monitoring of Rolling Stock using bogie mounted sensors”, 6.2 “Demonstration and validation of Rolling Stock (on-board) inspection and monitoring systems” and subtask 6.3.1 “Estimation of component health status and analytics”.

6.1.1. Overall aim of the use case

6.1.1.1. Problem to be solved

The overall aim is to deliver information about the health status of the bogie components to enable condition-based maintenance (CBM), reduce maintenance cost and achieve high availability.
Based on existing experiences, the idea of this use case is to develop a new generation of bogie & track monitoring systems with the associated assessment routines.
The targets can be described as follows:

- Extension of the monitoring range by also applying other types of sensors, other than accelerometers (e.g.: on-board acoustics).
- Identifying potentials for combining different sensor signals (e.g. sensor fusion).
- Achieving more economical monitoring technologies (e.g., on-board and wayside acoustics).

6.1.1.2. Industry current position / baseline

The current practise in the rail industry is to perform the maintenance of the bogie components based on fixed intervals that can be time and/or mileage dependent. The current practise is not economically optimised because the components are exchanged/replaced before the end of their lifetime. As an additional risk, the component failure may happen between two pre-defined maintenance slots.

6.1.1.3. Subproblem addressed by the use case and measurable objectives

Therefore, the UC aims to measure, acquire, collect, pre-process, transmit and store data in networks and ecosystems from on-board digital and analogue variables together with the system alarms and other non-vehicle-based data sources.

- Identify monitoring strategies by simulation that define physical parameters suitable to detect wear/defects on the main bogie components.
- Identify the most promising monitoring technologies during roller rig tests, focussing mainly on the powertrain (engine and gearbox) by equipping a bogie with pre-defined damages/failures or worn components.
- Test the most feasible monitoring technologies identified during the roller tig tests under real service conditions in the field.

6.1.1.4. Influence of the proposed innovation on the IM/RU problem

The application of condition-monitoring to railway vehicles provides a possibility to get information on the current health status of different train components under real operating conditions. Such information can facilitate the implementation of CBM for railway vehicles. Compared to Preventive Maintenance (PVM), it can be shown that CBM will not only bring higher reliability but also more cost-efficient maintenance to the rail sector.
Using the available sequence of data points extracted/measured at a specific time intervals, it is possible to predict the future health status of components by applying advanced analytics, e.g.: regression analysis. In such a way, maintenance activities can be planned based on a more precise estimation. This type of maintenance is called Predictive Maintenance (PDM) which can be considered as an extension of CBM.

The Work Package 5 (WP5) foresees a bench test with the target to detect defects on drive with different sensor technologies. The Work Package 6 (WP6) builds on WP5 with on-track tests to check the technologies which proved their feasibility on bench under operational conditions on track. During the on-track tests, the sensors will detect or measure more noise in the signals due to the dynamic movements of the train.
The defects and sensors (on the axle bearings, motor bearings and on the gearbox bearings) will be the same for both WP5&WP6. Additionally, the wayside microphone array from Work Package 7 (WP7) will be included for the bench and the on-track tests.

Hence, the bench tests are a first step:

- to check the capacity of each technology
- to check the limits of each sensor
- to rule out the sensors which are not capable of detecting the defects
- to learn about the signatures of the different defects
- to prepare the test on train by using the experiences of the bench tests

The on-track test is a second step with a higher difficulty level, compared to the bench tests:

- to check the recorded data in a real train and track environment
- to choose the most feasible technology

6.1.2. UC5.1: Demonstrator's KPI

6.1.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect

Table 7: UC5.1 KPIs on a FP level from the Grant Agreement

The use case aims to contribute to the three overarching goals by reducing material and labour costs, providing accurate information about the condition and decreasing the downtimes. These improvements enable higher reliability and availability of the bogies.
Since the use case only covers one test vehicle, the correlation to the KPIs will be analytical and predictive in nature rather than statistical.

6.1.2.2. List of own PIs

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
5.1-1	Number of components / assets that could be monitored with each sensor	≥ 2
5.1-2	Average accuracy (all technologies) of detecting faulty components	70 %
5.1-3	Reduction of in-service failures	25 %

Table 8: UC5.1 PIs

6.1.2.3. PI5.1-1 – Number of components that could be monitored with each sensor

Short description
This PI is used to measure the number of components monitored per sensor. Nowadays, for the monitoring of bogie components, at least one sensor per component is normally needed. This leads to a high number of sensors and consequently high costs, both in procurement and maintenance. Each additional sensor not only increases material costs but also adds to the system's complexity and the effort required for installation and calibration.
The aim of this work package is to find ways to reduce the number of sensors so that a single sensor can monitor multiple components simultaneously. Through innovative technologies and approaches, the efficiency of the sensor system should be maximised without compromising the

quality and reliability of monitoring. In the long term, these improvements will result in significant cost savings and simplification of the overall system, ultimately enhancing ease of maintenance and operational safety.

How to compute PI5.1-1

Therefore, we define the PI in the following way: Number N of components that can be monitored by 1 sensor.

$$PI_{5.1-1} = N$$

6.1.2.4. PI5.1-2 – Average accuracy

Short description

This PI is used to assess the combined average accuracy of all the developed sensing technologies. Fault detection in bogie components is essentially a binary classification problem, where it must be determined whether a component is faulty or not. Accuracy is a crucial metric for evaluating classification models, as it indicates the proportion of correctly diagnosed cases (both faulty and fault-free components) out of the total number of cases.

High accuracy is desirable and necessary, as it ensures that the monitoring system operates reliably and minimises the likelihood of false alarms or overlooked faults. This is particularly important to ensure the safety and availability of the entire system and to reduce maintenance costs through precise and timely fault detection.

How to compute PI5.1-2

For binary classification, average accuracy can be calculated using the following formula:

$$\mathrm{PI}_{5.1-2}\ \mathrm{Accuracy}_{\mathrm{Average}} = \frac{\sum_{i=1}^{n} \frac{(\mathrm{TP_i} + \mathrm{TN_i})}{(\mathrm{TP_i} + \mathrm{TN_i} + \mathrm{FP_i} + \mathrm{FN_i})} * 100}{n}$$

Where:

- TP: True Positive
- TN: True Negative
- FP: False Positive
- FN: False Negative
- i: i-th sensor technology
- n: number of sensing technologies

6.1.2.5. PI5.1-3 – Reduction of in-service failures

Short description

Without condition monitoring, there is a risk that in-service failures occurring leads to the situation

that the affected trains have to be towed from the tracks. By applying condition monitoring, the number of critical failures can be reduced.
This PI5.1-3 relates to the availability and the reliability of the assets in scope. By measuring improvements in these values, the reduction of in-service failures can be quantified. Since availability is calculated for the entire train and is subject to numerous factors, this PI focuses on the reliability of each individual system.

How to compute PI5.1-3

$$PI_{5.1-3} = \frac{Number\ of\ failures_{without\ sensors} - Number\ of\ failures_{with\ sensors}}{Number\ of\ failures_{without\ sensors}} \times 100$$

Where:

- $Number\ of\ failures_{without\ sensors}$ is the number of failures in service in the current maintenance strategy without sensors.
- $Number\ of\ failures_{with\ sensors}$ is the number of failures in service in the new maintenance strategy with sensors.

6.2. UC5.2: Health Monitoring & Analytics of HVAC & Brake systems (ES)

This use case spans Tasks 5.3 “Onboard systems monitoring of trains in Spanish railway sections”, 6.2 “Demonstration and validation of Rolling Stock (on-board) inspection and monitoring systems” and subtask 6.3.2 “Onboard systems predictive analytics using data available for trains operating in the Spanish network”.

6.2.1. Overall aim of the use case

6.2.1.1. Problem to be solved

The overall aim is to enable an improved maintenance regime and enhance performance of selected subsystems by increasing the amount and quality of available data. By providing detailed information about the subsystem performance, the goal is to allow for better use of component life and also allow for more cost-efficient maintenance activities.

6.2.1.2. Industry current position / baseline

Current maintenance activities of the RU are largely based on fixed maintenance intervals, as is common in PVM and corrective maintenance. There is usually insufficient real-time information available regarding the different assets to support informed decisions about interventions and CBM or PDM.

Due to this situation, there is significant potential in providing additional data about critical parameters.

6.2.1.3. Subproblem addressed by the use case and measurable objectives

The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures,* using additional data to gain new insights about performance of the systems. The demonstrator for this use case is the S106 fleet operated by RENFE and manufactured by TALGO.

Additional sensors will be installed for selected systems in order to provide new data signals currently not available on the train bus. This will provide additional information and allow improved analytics (proof of concept will be performed with one test vehicle). The data will be transferred over a separate transmission system to avoid homologation requirements.

After alignment among the partners, the following systems have been selected:

- HVAC: filter lifetime analysis, compressor lifetime analysis, refrigerant level monitoring.
- Brakes: compressor lifetime and status, process brake data monitoring.

The selected systems play a significant role in contributing to maintenance efforts of the RU. The additional sensors cover several different failure modes which are currently not monitored. This data will be transferred to a cloud storage and used for analysis, monitoring and anomaly detection.

For the vehicles and subsystems in scope, the goal is to implement the entire value chain of:

1. Data Generation & Processing on the vehicle.
2. Transfer Data off-board to a cloud.
3. Analyse data and derive actionable information.
4. Feed the results in a workflow to generate measurable outcome.

The goal of achieving TRL5/6 is to concentrate on realising the entire chain fundamentally.

6.2.1.4. Influence of the proposed innovation on the IM/RU problem

This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.
By providing more exact information about the state of the asset, it is also possible to optimise the replacement of components, thereby reducing the costs of spare parts.
In addition, collecting data regarding the assets will allow for better timing of repairs. This can be done through anomaly detection and completing replacement and correcting activities before failures occur during service.

6.2.2. UC5.2: Demonstrator's KPI

6.2.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct

Table 9: UC5.2 KPIs on a FP level from the Grant Agreement

The use case aims at contributing to both important over-arching goals, by reducing the costs of materials and labour as well as providing accurate information about the assets, allowing for improved reliability and availability of the systems.

Since the use case only covers one test vehicle, the correlation to the KPIs will be analytical and predictive in nature rather than statistical.

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
5.2-1	Reduction of maintenance costs	10%
5.2-2	Reduction of in-service failures	25%

Table 10: UC5.2 PIs

6.2.2.2. PI5.2-1 – Reduction of maintenance cost

Short description
This PI sums up the relevant cost factors related to maintenance cycles overall and the execution of maintenance itself. This includes the main factors of material costs and labour costs.
This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.

How to compute PI5.2-1

The PI5.2-1 is mainly computed by measuring and adding the following factors:

- Reduction of cost of spare parts (PI 5.2-1A)
- Reduction in cost of working hours (PI 5.2-1B)

The calculations can be done as follows:

$$PI_{5.2-1A}\ (\%\ material\ savings) = \frac{Material\ cost_{\ current_method} - Estimated\ Material\ Cost_{new_method}}{Material\ Cost_{current_method}} \times 100$$

Where:

- $Material\ cost_{\ current_method}$ is the cost associated with the current material needed.
- $Estimated\ Material\ Cost_{new_method}$ is the cost associated with predicted material needed with the new monitoring and data analysis.

$$PI_{5.2-1B}\ (\%\ time\ savings) = \frac{Time_{current_method} - Estimated\ time_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Time_{current_method}$ is the time required to perform the conventional maintenance activities.
- $Estimated\ time_{new_method}$ is the time required to perform maintenance activities with the new monitoring and data analysis.

In the short to mid-term run, most savings will be in the form of reduced labour hours. The more mature the models become, the more possibilities will arise to extend the useful life of components, through condition monitoring and efficient maintenance scheduling.

6.2.2.3. PI5.2-2 – Reduction of in-service failures

Short description

In-service failures are very costly for operators and maintainers and have significant impact on customer experience and the ability to provide the main intended service of transportation. This PI refers to the availability and reliability of the assets in scope. By measuring improvements in these values, we can quantify the reduction of in-service failures. Since the availability is calculated on the whole train and is subject to a high number of factors, this KPI focuses on reliability of each system.

How to compute PI5.2-2A

The ideal way to estimate this PI, would be to measure the actual number of in-service failures. However, this requires a large amount of data to be statistically significant, since there are a lot of uncontrolled variables and not many failures and the data for this use case does not cover a whole fleet. Therefore, the in-service failures can only be estimated.

$$PI_{5.2-2A}\ (in\ \%) = \frac{Estimated\ in-service\ failures_{\ current\ method} - Estimated\ in-service\ failures_{new\ method}}{Estimated\ in-service\ failures_{\ current\ method}} \times 100$$

Where:

- $Estimated\ in-service\ failures_{\ current\ method}$ is the estimated disruptive failures based on an FMECA using the current maintenance strategy.
- $Estimated\ in-service\ failures_{new\ method}$ is the estimated disruptive failures based on an FMECA analysis of the fleet using the new maintenance strategy highlighting the predicted failures as not occurring in-service.

On a system level, this PI can be assessed by looking at the reliability of the system. Reliability quantifies the likelihood of equipment to operate as intended without disruptions or downtime. In other words, reliability can be seen as the probability of success and the dependability of an asset to continuously be operational, without failures, for a period of time, which covers the probability of in service failures.

The improvement of these aspects can, in general terms, be measured as follows:

$$PI_{5.2-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current_method} - Estimated\ Reliability_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Reliability_{current_method}$ is the cost associated with current maintenance strategy.
- $Estimated\ Reliability_{new_method}$ is the reliability expected with the new monitoring and data analysis.

Another way of predicting reliability would be to look at the number of monitored failure modes in the FMECA of the system. Since we can use monitoring of failure modes to avoid in-service failures through early detection (instead of reactive), reliability of the system will improve, and more failure modes are monitored. In this case, the PI could be measured as the increase in monitored failure modes.

$$PI_{5.2-2C}\ (\%\ Monitored\ failure) = \frac{Monitored\ Failure_{\ current_method} - Monitored\ Failure_{\ new_method}}{Monitored\ Failure_{\ current_method}} \times 100$$

These general PIs will be used in different ways across the different systems covered within this use case, depending on the method of monitoring and the amount of data gathered throughout the project.

6.3. UC5.3: Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)

This use case spans Tasks 5.4 “Onboard systems monitoring of trains in The Netherlands sections”, 6.2 “Demonstration and validation of Rolling Stock (on-board) inspection and monitoring systems” and subtask 6.3.3 “Monitoring and predictive analytics using data available on The Netherlands railway type sections. Onboard systems”.

6.3.1. Overall aim of the use case

6.3.1.1. Problem to be solved

The overall problem to be solved is to enable an improved maintenance regime and enhance performance of selected subsystems by increasing the amount and quality of available data.

6.3.1.2. Industry current position / baseline

Current maintenance activities of the RU are largely based on fixed maintenance intervals and corrective maintenance. There is usually little real time information available regarding the different assets to support informed decisions about interventions and PDM.

Due to this situation, there is significant potential in providing additional data about critical parameters.

6.3.1.3. Subproblem addressed by the use case and measurable objectives

The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures,* using additional data to gain new insights about performance of the systems. The demonstrator for this use case is the Sprinter New Generation (SNG) operated by NS and manufactured by CAF.

Additional sensors will be installed for selected systems in order to provide new data signals currently not available on the train bus. This will provide additional information and allow improved analytics (one test vehicle for proof of concept). The data will be transferred over a separate transmission system to avoid homologation requirements.

After alignment among the partners, the following systems have been selected for each approach:

- HVAC: filter lifetime analysis, compressor lifetime analysis, refrigerant level monitoring.
- Sanitary Equipment: Pressure curve analysis, water level analysis (no new sensors, only available data).
- Magnetic Track Brakes: Status Monitoring, Automatic test validation.

The selected systems play a significant role in contributing to maintenance efforts of the RU. The additional sensors cover several different failure modes which are currently not monitored. This data will be transferred to a cloud and used for analysis, monitoring and anomaly detection.

For the vehicles in subsystems in scope, the goal is to implement the entire value chain of:

1. Data Generation & Processing on the vehicle.
2. Transfer Data off-board to a cloud.
3. Analyse data and derive actionable information.
4. Feed the results in a workflow to generate measurable outcome.

The goal of achieving TRL5/6 is to concentrate on realising the entire chain fundamentally.

6.3.1.4. Influence of the proposed innovation on the IM/RU problem

This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.
By providing more exact information about the state of the asset, it is also possible to optimise the replacement of components, thereby reducing the costs of spare parts.
In addition, collecting data regarding the assets, will allow for better timing of repairs. This can be done through anomaly detection and completing replacement and correcting activities before failures occur during service.

6.3.2. UC5.3: Demonstrator's KPI

6.3.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct

Table 11: UC5.3 KPIs on a FP level from the Grant Agreement

The use case aims at contributing to these both important over-arching goals, by reducing costs of materials and labour as well as providing accurate information about the assets, allowing for improved reliability and availability of the systems.

Since the use case only covers one test vehicle, the correlation to the KPIs will be analytical and predictive in nature rather than statistical.

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
5.3-1	Reduction of maintenance costs	10%
5.3-2	Reduction of in-service failures	25%

Table 12: UC5.3 PIs

6.3.2.2. PI5.3-1 – Reduction of maintenance cost

Short description

This PI sums up the relevant cost factors related to maintenance cycles overall and the execution of maintenance itself. This includes the main factors of material costs and labour costs.

This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.

How to compute PI5.3-1

The PI5.3-1 is mainly computed by measuring and adding the following factors:

- Reduction of cost of spare parts (PI 5.3-1A)
- Reduction in cost of working hours (PI 5.3-1B)

The calculations can be done as follows:

$$PI_{5.3-1A}\ (\%\ material\ savings) = \frac{Material\ cost_{\ current_method} - Estimated\ Material\ Cost_{new_method}}{Material\ Cost_{current_method}} \times 100$$

Where:

- $Material\ cost_{\ current_method}$ is the cost associated with the current material needed.
- $Estimated\ Material\ Cost_{new_method}$ is the cost associated with the predicted material needed with the new monitoring and data analysis.

$$PI_{5.3-1B}\ (\%\ time\ savings) = \frac{Time_{current_method} - Estimated\ time_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Time_{current_method}$ is the time required to perform the conventional maintenance activities.
- $Estimated\ time_{new_method}$ is the time required to perform maintenance activities with the new monitoring and data analysis.

6.3.2.3. PI5.3-2 – Reduction of in-service failures

Short description

In-service failures are very costly for operators and maintainers and also have significant impact on customer experience and the ability to provide the main intended service of transportation. This PI refers to the availability and reliability of the assets in scope. By measuring improvements in these values, we can quantify the reduction of in-service failures. Since the availability is calculated on the whole train and is subject to a high number of factors, this PI focuses on reliability of each system.

How to compute PI5.3-2

The ideal way to estimate this PI, would be to measure the actual number of in-service failures. However, this requires a large amount of data in order to be statistically significant, since there are a lot of uncontrolled variables and not many failures. Therefore, the in-service failures can only be estimated.

$$PI_{5.3-2A}(in\ \%) = \frac{Estimated\ in{-}service\ failures_{\ current\ method} - Estimated\ in{-}service\ failures_{new\ method}}{Estimated\ in{-}service\ failures_{\ current\ method}} \times 100$$

Where:

- $Estimated\ in-service\ failures_{\ current\ method}$ is the estimated disruptive failures based on an FMECA using the current maintenance strategy
- $Estimated\ in-service\ failures_{new\ method}$ is the estimated disruptive failures based on an FMECA analysis of the fleet using the new maintenance strategy, highlighting the predicted failures as not occurring in-service

On a system level, this PI can be assessed by looking at the reliability of the system. Reliability quantifies the likelihood of equipment to operate as intended without disruptions or downtime. In other words, reliability can be seen as the probability of success and the dependability of an asset to continuously be operational, without failures, for a period of time, which covers the probability of in service failures.

The improvement of these aspects can, in general terms, be measured as follows:

$$PI_{5.3-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current_method} - Estimated\ Reliability_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Reliability_{current_method}$ is the cost associated with current maintenance strategy.

- $Estimated\ Reliability_{new_method}$ is the reliability expected with the new monitoring and data analysis.

Another way of predicting reliability would be to look at the number of monitored failure modes in the FMECA of the system. Since we can use monitoring of failure modes to avoid in-service failures through early detection (instead of reactive), reliability of the system will improve, and more failure modes are monitored. In this case, the PI could be measured as the increase in monitored failure modes.

$$PI_{5.3-2C}\ (\%\ Monitored\ failure\ modes) = \frac{Monitored\ Failure\ Modes_{current_method} - Monitored\ Failure\ Modes_{new_method}}{Monitored\ Failure\ Modes_{current_method}} \times 100$$

These general PIs will be used in different ways across the different systems covered within this use case, depending on the method of monitoring and the amount of data gathered throughout the project.

6.4. UC5.4: Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes, (ES, CAF fleet)

This use case spans Tasks 5.3 “Onboard systems monitoring of trains in Spanish railway sections”, 6.2 “Demonstration and validation of Rolling Stock (on-board) inspection and monitoring systems” and subtask 6.3.2 “Onboard systems predictive analytics using data available for trains operating in the Spanish network”.

6.4.1. Overall aim of the Use Case

6.4.1.1. Problem to be solved

This use case aims at contributing to the improvement of the overall availability of the railway fleet by implementing new maintenance **strategies**. To achieve this, the work done will focus on retrieving additional data to the one currently collected from CAF in the Euskotren fleet, specifically from the systems HVAC, doors and brake. This new data, added to the one already available for these systems, and also batteries, traction and auxiliars, will enable further analysis and algorithm development.

6.4.1.2. Industry current position / baseline

Presently, maintenance activities rely mostly on fixed maintenance intervals, so called PVM, and post failure intervention, called corrective maintenance. Typically, there is minimal real-time information available to support informed decision-making regarding various assets and their requirements for PDM.

6.4.1.3. Subproblem addressed by the use case and measurable objectives

In order to achieve the previously indicated target, the sub-problems to achieve the target are:

1. Data generation on the vehicle.
2. Data transmission to cloud storage.
3. Data processing and preparation on cloud.
4. Exploratory data analysis and analytics building.
5. Implementing maintenance optimisation workflow starting from the built analytics.

As the use case starts from a low TRL level (TRL1), the aim is to achieve a TRL level 5. A higher level of TRL can be addressed in the following calls of the project.

6.4.1.4. Influence of the proposed innovation on the IM/RU problem

The influence of the proposed innovation lies in the provision of accurate data regarding the condition of assets, leading to reduced train inspection times. This could translate to extended intervals between inspections and faster execution of the inspections carried out. More specific information about failures will also enable better-targeted maintenance interventions. By providing more exact information about the state of the asset, it becomes possible to optimise component replacement, thereby reducing spare parts' costs. Moreover, the collection of data about assets enables better timing of repairs through anomaly detection. This allows for the completion of replacement and correction activities before failures occur during service. Ultimately, PDM optimises the use of resources, increases efficiency and enhances safety while reducing costs.

The work was focused on developing indicators to monitor the health of the HVAC, brake and door systems. Therefore, these algorithms can be used, for example, to detect friction issues in the door systems, identify degradation of braking performance or assess heating and cooling capacities for the HVAC units.

It is important to highlight that the targeted fleet currently lacks any implementation of PDM algorithms dedicated to reporting on the health status of the HVAC, brake and door systems. Implementing PDM algorithms for these fleets would signify a significant shift in the maintenance strategy used to maintain this fleet. Furthermore, the PDM algorithms will be developed with the aim of complete reusability, enabling their use on other fleets equipped with identical systems.

6.4.2. UC5.4: Demonstrator's KPI

6.4.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct

Table 13: UC5.4 KPIs on a FP level from the Grant Agreement

Those KPIs are related together as the in-service failure contributes to the maintenance cost and both have been detailed. However, it is important to clarify that during the solution evaluation process, only one of them will be considered.

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
5.4-1	Reduction of maintenance costs	10%
5.4-2	Reduction of in-service failures	25%

Table 14: UC5.4 PIs

6.4.2.2. PI5.4-1 – Reduction of maintenance cost

Short description

The maintenance cost for this is mainly composed of the sum of two components. The first one is the so-called materials cost, reflecting the cost of the materials needed to perform the maintenance tasks, such as spare parts, consumables and others. The second component is labour cost, which mainly shows the maintenance crew's needed time to perform the tasks, multiplied by the hourly rate. Usually, maintenance costs are expressed in euros per kilometre.

How to compute PI5.4-1

$$KPI_{5.4-1}\ (in\ \%) = \frac{Maintenance\ cost_{current\ maintenacne\ strategy} - Estimated\ Maintenance\ cost_{new\ maintenance\ strategy}}{Maintenance\ cost_{current\ maintenacne\ strategy}} \times 100$$

Where:

- $Maintenance\ cost_{current\ maintenacne\ strategy}$: is the sum of the material and labour costs of the current maintenance strategy
- $Estimated\ Maintenance\ cost_{new\ maintenance\ strategy}$ is the estimated sum of the material and labour costs of the new maintenance strategy

6.4.2.3. PI5.4-2 – Reduction of in-service failures

Short description

In-service failure refers to the failure of a rolling stock or its systems while it is being used or during its service life. This may result in trip delays or cancellation. In-service failures can be caused by a variety of factors including wear and tear of components or environmental factors. To report an impact on in-service failures, the level of in-service failures before and after the change of the maintenance strategy can be compared, relative to the level of in-service failures before the change of the maintenance strategy.

How to compute PI5.4-2

$$KPI_{5.4-2}\ (in\ \%) = \frac{Estimated\ in-service\ failures_{\ current\ maintenance\ strategy} - Estimated\ in-service\ failures_{new\ maintenance\ strategy}}{Estimated\ in-service\ failures_{\ current\ maintenance\ strategy}} \times 100$$

Where:

- $Estimated\ in-service\ failure_{\ current\ maintenance\ strategy}$ are the estimated disruptive failures based on an FMECA using the current maintenance strategy.
- $Estimated\ in-service\ failures_{new\ maintenance\ strategy}$ are the estimated disruptive failures based on an FMECA analysis of the fleet using the new maintenance strategy highlighting the predicted failures as not occurring in service.

6.5. UC5.5: Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)

This use case spans Tasks 5.4 “Onboard systems monitoring of trains in The Netherlands sections” and subtask 6.3.3 “Monitoring and predictive analytics using data available on The Netherlands railway type sections. Onboard systems”.

6.5.1. Overall aim of the use case

6.5.1.1. Problem to be solved

The overall problem to be solved is to enable an improved maintenance regime and enhance performance of selected subsystems by increasing the amount and quality of available data.

6.5.1.2. Industry current position / baseline

Current maintenance activities of the RU are largely based on fixed maintenance intervals and corrective maintenance. There is usually little real time information available regarding the different assets to support informed decisions about interventions and PDM.

Due to this situation, there is significant potential in providing additional data about critical parameters.

6.5.1.3. Subproblem addressed by the use case and measurable objectives

The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures,* using additional data to gain new insights about performance of the systems. The demonstrator for this use case is the Fleet "Sprinter New Generation (SNG)" operated by NS and manufactured by CAF.
The cornerstone of the work done here will be the data stream generated for this purpose, adding cybersecurity while letting the data available. Signals that are currently available on the train bus system but are currently not being transmitted to the wayside, and therefore not being used to conduct analytical monitoring and predictive assessments, will be made available by implementing a new data transmission chain (fleet wide).

After alignment among the partners, the following systems have been selected for each approach:

Fleet wide data transmission:

- Development of ML CBM Model for HVAC.
- Development of ML CBM Model for Doors.
- Development of ML CBM Model for Brakes – (Air compressors).
- Development of ML CBM Model for Batteries.
- Development of ML CBM Model for Traction.
- Development of ML CBM Model for Auxiliars.

The selected systems play a significant role in contributing to maintain efforts of the RU.

For the vehicles in subsystems in scope, the goal is to implement the entire value chain of:

1. Data Generation & Processing on the vehicle.
2. Transfer Data off-board to a cloud.
3. Analyse data and derive actionable information.
4. Feed the results in a workflow to generate measurable outcome.

The goal of achieving TRL5/6 is to concentrate on realising the entire chain fundamentally.

6.5.1.4. Influence of the proposed innovation on the IM/RU problem

This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.
By providing more exact information about the state of the asset, it is also possible to optimise the replacement of components, thereby reducing the costs of spare parts and warehouse costs.

In addition, collecting data regarding the assets, will allow for better timing of repairs. This can be done through anomaly detection, completing replacement and correcting activities before failures occur during service.

6.5.2. UC5.5: Demonstrator's KPI

6.5.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct

Table 15: UC5.5 KPIs on a FP level from the Grant Agreement

The use case aims at contributing to these both important over-arching goals, by reducing costs of materials and labour as well as providing accurate information about the assets, allowing for improved reliability and availability of the systems.

Since some parts of the use case only cover one test vehicle, the correlation to the KPIs will in some cases be analytical and predictive in nature rather than statistical.

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
5.5-1	Reduction of maintenance costs	10%
5.5-2	Reduction of in-service failures	25%

Table 16: UC5.5 PIs

6.5.2.2. PI5.5-1 – Reduction of maintenance cost

Short description

This PI sums up the relevant cost factors related to maintenance cycles overall and the execution of maintenance itself. This includes the main factors of material costs and labour costs.

This use case intends to provide accurate data about the condition of the assets, which in turn allows for reduced inspection times on the train. This can include extended intervals between inspections, as well as faster execution of the inspections carried out. By providing more specific information about failures, it will also allow for more targeted maintenance interventions.

How to compute PI5.5-1

The PI5.5-1 is mainly computed by measuring and adding the following factors:

- Reduction of cost of spare parts (PI5.5-1A).
- Reduction in cost of working hours (PI5.5-1B).

The calculations can be done as follows:

$$PI_{5.5-1A}\ (\%\ material\ savings)\ = \frac{Material\ cost\ _{current_method} - Estimated\ Material\ Cost_{new_method}}{Material\ Cost_{current_method}} \times 100$$

Where:

- $Material\ cost\ _{current_method}$ is the cost associated with the current material needed.
- $Estimated\ Material\ Cost_{new_method}$ is the cost associated with the predicted material needed with the new monitoring and data analysis.

$$PI_{5.5-1B}\ (\%\ time\ savings)\ = \frac{Time_{current_method} - Estimated\ time_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Time_{current_method}$ is the time required to perform the conventional maintenance activities.
- $Estimated\ time_{new_method}$ is the time required to perform maintenance activities with the new monitoring and data analysis.

6.5.2.3. PI5.5-2 – Reduction of in-service failures

Short description

In-service failures are very costly for operators and maintainers and have significant impact on customer experience and the ability to provide the main intended service of transportation. This PI refers to the availability and reliability of the assets in scope. By measuring improvements in these values, we can quantify the reduction of in-service failures. Since the availability is calculated on the whole train and is subject to a high number of factors, this PI focuses on reliability of each system.

How to compute PI5.5-2

The ideal way to estimate this PI, would be to measure the actual number of in-service failures. However, this requires a large amount of data in order to be statistically significant, since there

are a lot of uncontrolled variables and not many failures. Therefore, the in-service failures can only be estimated.

$$PI_{5.5-2A}\ (in\ \%) = \frac{Estimated\ in{-}service\ failures_{\ current\ method} - Estimated\ in{-}service\ failures_{new\ method}}{Estimated\ in{-}service\ failures_{\ current\ method}} \times 100$$

Where:

- $Estimated\ in-service\ failures_{\ current\ method}$ is the estimated disruptive failures based on an FMECA using the current maintenance strategy.
- $Estimated\ in-service\ failures_{new\ method}$ is the estimated disruptive failures based on an FMECA analysis of the fleet using the new maintenance strategy highlighting the predicted failures as not occurring in service.

On a system level, this PI can be assessed by looking at the Reliability of the system. Reliability quantifies the likelihood of equipment to operate as intended without disruptions or downtime. In other words, reliability can be seen as the probability of success and the dependability of an asset to continuously be operational, without failures, for a period of time, which covers the probability of in service failures.

The improvement of these aspects can, in general terms, be measured as follows:

$$PI_{5.5-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current_method} - Estimated\ Reliability_{new_method}}{Time_{current_method}} \times 100$$

Where:

- $Reliability_{current_method}$ is the cost associated with current maintenance strategy.
- $Estimated\ Reliability_{new_method}$ is the reliability expected with the new monitoring and data analysis.

Another way of predicting reliability would be to look at the number of monitored failure modes in the FMECA of the system. Since we can use monitoring of failure modes to avoid in-service failures through early detection (instead of reactive), reliability of the system will improve, and more failure modes are monitored. In this case, the PI could be measured as the increase in monitored failure modes.

$$PI_{5.5-2C}\ (\%\ Monitored\ failure) = \frac{Monitored\ Failure_{current_method} - Monitored\ Failure_{new_method}}{Monitored\ Failure_{current_method}} \times 100$$

These general PIs will be used in different ways across the different systems covered within this use case, depending on the method of monitoring and the amount of data gathered throughout the project.

6.6. UC6.1: Development of next generation Traction control unit hardware and gate drive communication link

This use case spans Task 6.4 “Development of hardware improving Rolling Stock’s future lifecycle and maintenance” and subtask 6.4.3 “Traction hardware enabling predictive maintenance strategies”.

6.6.1. Overall aim of the use case

The final goal of this use case is to enable the customer trains to provide self-health diagnostics with the aim to reduce maintenance costs reduction of the rolling stock. In addition, the target is to be able to predict traction failures as far as possible before they occur. The aim is to increase service availability.

This use case spans task 6.4 “Onboard systems monitoring of trains in Spanish railway sections”, and subtask 6.4.3 “Traction hardware enabling predictive maintenance strategies”.

6.6.1.1. Problem to be solved

Tomorrow's powertrains should leverage PDM data to reduce total costs of ownership by optimising the number of maintenance operations on customer side and minimise equipment redundancies during design on manufacturer side – which could reduce procurement cost for the customer.
For traction side, the most significant maintenance operations are focused on power converter semiconductors, traction components circuit breaker, contactors, cooling systems and bearings. Our target is to be able to calculate on board and health indicator of cooling system (clogging level of cooling system heat exchangers) and bearings using traction case sensors and send this information to the customer for its train maintenance plan.
All these functions need additional data which requires that each one has its own wiring. At the end of the day, it entails a very expensive product to allow this high level of data acquisition. To allow data driven operation for smart maintenance purpose with cheaper costs, we need to rebuild the traction control hardware architecture in a better way.

6.6.1.2. Industry current position / baseline

The current situation is that if we need, for example, to compare semiconductor junction temperature measurement with theoretical embedded model for health monitoring, it is not possible to physically connect each semiconductor temperature sensor to the Traction Control Unit (TCU). Indeed, a TCU can drive more than 30 semiconductors. If we need to connect each of them with insulation protection, this leads to an excessive wiring system inside the traction cubicle. Moreover, this kind of solution highly increases the unit price of a traction case (more than 10%) because it leads to multiply the number of TCU to install inside the traction cubicle to be able to read all measurements.

6.6.1.3. Subproblem addressed by the use case and measurable objectives

The use case target is to increase semiconductor monitoring capability. Indeed, we need to define if with our new architecture we can drive semiconductors for traction purposes at the same time we monitor them for traction component health management.

For semiconductors, the state of the art of PDM requires the use of a measurement and/or an estimation of the semiconductor's internal temperature (e.g.: junction temperature) and the evolution of the conductivity in the ON state (i.e. when the semiconductor is conducting the current). Only an estimation of the semiconductor temperature will be provided by semiconductor manufacturers within the next years.

The first call consists of using an estimator for semiconductor junction temperature throughout an embedded algorithm using available traction signal (cf. task 5.2 "Traction component health monitoring" & sub-task 6.3.1 "Estimation of component health status and analytics"). This work would be the basis for the next step planned to be developed in further projects,

For the next projects to allow this information (semiconductor manufacturer junction temperature measurement sensing) to be used by traction smart maintenance algorithms (located in traction control electronics), it is necessary to be able to connect the semiconductor thermal sensors to the traction control electronic with a minimal of costs impact (i.e..., without multiplying wire connections between power converter and traction control electronics). To do so, our proposition is to create a merged digital channel in which semiconductors switching orders (generated by the traction control electronics), electrical sensors signal (current and voltage measurement) and smart data (junction temperature measurements, switched and conducted current statistics for each semiconductor and all other relevant information) could be exchanged.

To finally reach this target, it is necessary to make deep hardware changes in the control electronics to make it compatible with this Big Data strategy (this is the concern of WP6). These deep hardware changes are the concern of the UC6.1.

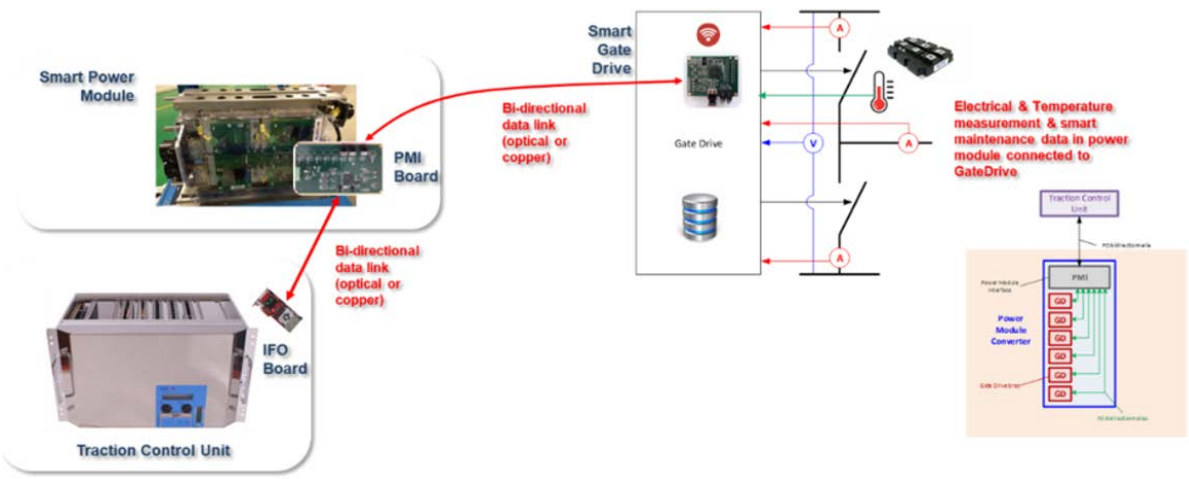

Figure 2: Traction control unit hardware and gate drive communication link

6.6.1.4. Influence of the proposed innovation on the IM/RU problem

Thanks to this innovation proposed within FP3-IAM4RAIL, the rolling stock owner would be able to reduce its maintenance costs by only execute maintenance operations when it is necessary (instead of doing it arbitrarily at fixed steps time). Besides it will also allow the RU to anticipate failures in operation: the direct consequence is a more reliable service seen from the end-customer. This will help the RU to build its train fleet maintenance plan according to the traction purposes.

6.6.2. UC6.1: Demonstrator's KPI

6.6.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
I	Qualitative and prompt integration of information, including reducing time to transfer asset condition stats to TMS (Reducing time to transfer asset condition status to TMS)	Little/indirect
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct

Table 17: UC6.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
6.1-1	Increase the number of monitored subsystems and physical quantities	NA

Table 18: UC6.1 PIs

These technologies allow to add semiconductors to the train component monitoring table (junction temperature, ON state resistance of semiconductor, derating, statistic of switched current…).

6.6.2.2. PI6.1-1 – Increase the number of monitored subsystems

Short description

For predictive maintenance, the more subsystems monitored, the better the failure prediction. The increase of the monitored subsystem number is simply the number of new measured signals dedicated to smart maintenance.

How to compute PI6.1-1

To compute this PI the formula to use is the following one:

$$PI_{6.1-1} = Nw - No$$

Where:

- N_w: total number of variables measured for smart maintenance of traction component with implementation of the solution.
- N_o: total number of variables measured for smart maintenance of traction component without implementation of the solution.

6.7. UC6.2: Traction Component, Health Monitoring & predictive Maintenance

This use case spans Tasks 5.2 “Traction component health monitoring”, 6.2 “Demonstration and validation of Rolling Stock”, 6.3 “Data analytics. Development of predictive and prescriptive workflows for maintenance actions based on component health status and capability of decision making” and subtasks 6.3.1 “Estimation of component health status and analytics” and 6.3.5 “Adhesion estimation for management”.

6.7.1. Overall aim of the use case

The final goal of this use case is to enable the customer trains to provide self-health diagnostics with the aim to reduce maintenance costs of the rolling stock. In addition to that, the target of this use case is to be able to predict traction failures as far as possible before they occur, hence, increasing service availability.

6.7.1.1. Problem to be solved

Tomorrow's powertrains should leverage PDM data to reduce total costs of ownership by optimising the number of maintenance operations on customer side and minimise equipment redundancies during design on manufacturer side – which could reduce procurement cost for the customer.

From traction side, the most significant maintenance operations are focused on power converter semiconductors, traction components circuit breaker, contactors, cooling systems and bearings. Our target is to be able to calculate on board and health indicator of cooling system (clogging level of cooling system heat exchangers) and bearings using traction case sensors and send theses

information to the customer for its train maintenance plan.

6.7.1.2. Industry current position / baseline

The current situation is that rolling stock owner must follow the train manufacturer recommendations for the maintenance route. For example, for the traction case cooling system, the train manufacturer could advise to clean the heat exchanger every 6 months, even if the RU observes that concretely even after 6 months of commercial operation the heat exchanger is clean. This implies that there are much more maintenance operations executed in comparison with what it is really needed.

6.7.1.3. Subproblem addressed by the use case and measurable objectives

For semiconductors, the state of the art of PDM requires the use of a measurement and/or an estimation of the semiconductor's internal temperature (i.e. junction temperature). This information will be provided by the semiconductor manufacturers in the next years.
The first step consists of using an estimator for the semiconductor junction temperature throughout an embedded algorithm using available traction signal. This work would be the basis for the next step planned in further projects.
For the next projects, to allow this information (semiconductor manufacturer junction temperature measurement sensing) to be used by traction smart maintenance algorithms (located in traction control electronics), it is necessary to be able to connect the semiconductor thermal sensors to the traction control electronic with a minimal of costs impact (i.e., without multiplying wire connections between power converter and traction control electronics). To do so, our proposition is to create a merged digital channel (similar to a bus system) in which semiconductors switching orders (generated by the traction control electronics), electrical sensors signal (current and voltage measurement), and smart data (junction temperature measurements, switched and conducted current statistics for each semiconductor and all other relevant information) could be exchanged.
To finally reach this target, it is necessary to accomplish deep hardware changes in the control electronics to make it compatible with this Big Data strategy (this is the concern of WP6-Sub-Task 6.4.3 "Traction hardware enabling predictive maintenance strategies").

Figure 3: Estimator for semiconductor junction temperature.

6.7.1.4. Influence of the proposed innovation on the IM/RU problem

Thanks to this innovation proposed within FP3-IAM4RAIL, the rolling stock owner would be able to reduce its maintenance costs by only execute maintenance operations when necessary (instead of doing it arbitrarily at a fixed given time). Besides, it will also allow the RU to anticipate failures in operation: the direct consequence is a more reliable service seen from the end-customer. This will help the customer to build their train fleet maintenance plan according to the traction purposes.

6.7.2. UC6.2: Demonstrator's KPI

6.7.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct

Table 19: UC6.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
6.2-1	Maintenance costs reduction	NA
6.2-2	Increase service availability	NA
6.2-3	Increase the number of monitored subsystems	NA

Table 20: UC6.2 PIs

Calculating maintenance cost reduction allows us to predict a maintenance path. It will reduce maintenance operations to the "just right" level (which means fewer unnecessary operations). Moreover, since failures in the operation will be more predictable, they can be avoided, resulting

in increased service availability. In addition, these technologies make it possible to add semiconductors to the tracking table of train components: semiconductors, switches, bearings and heat exchangers.

6.7.2.2. PI6.2-1 – Maintenance costs reduction

Short description

The maintenance costs reduction PI is an estimation of the savings due to the optimisation of the number of maintenance operations to be done for each traction component studied at train (and fleet) level. The estimation of the savings on maintenance costs must be done for:

- Main transformer heat exchanger.
- Power module heat exchanger.
- Traction motor bearings.
- Semiconductors (FP4 - task 6.2).
- Switchgears (main circuit breaker & contactor).

How to compute PI6.2-1

The estimate of maintenance cost savings must be made for each of the components listed above. These savings are the price difference between the PVM costs and the predictive maintenance costs. It can be calculated by evaluating the difference between the number of maintenance operations to be done on the overall train lifetime according to the PVM plan, and the number of maintenance operations to be done on the overall train lifetime calculated by the predicted maintenance algorithm for several degradation profile of each component.
This could be summarised with the following formula:

$$PI_{6.2-1}\eta = (N_p - N_d)c_p$$

Where:

- N_p : number of preventive maintenance operation over train lifetime.
- N_d : number of predictive maintenance operation over train lifetime.
- c_p : unit cost of preventive maintenance operation.

6.7.2.3. PI62.-2 – Increase of service availability

Short description.

Service availability is considered as the ratio between the time during which the train operates at 100% of its traction capacity – which means without any traction power limitation or with a reduced number of tractions drive available due to inhibition for component failure – and the total train operating time over its lifetime.

How to compute PI6.2-2

This PI can be calculated according to the following formula:

$$PI_{6.2-2}\eta = \frac{\tau_f}{\tau_0}$$

Where:

- τ_f : time during which the train operates at 100% of its traction capacity – which means without any traction power limitation or with a reduced number of tractions drive available due to inhibition for component failure.
- τ_0 : total train operating time over its lifetime.

6.7.2.4. PI6.2-3 – Increase the number of monitored subsystems

Short description

For PDM, the more subsystems monitored, the better the failure prediction. The increase of monitored subsystem number is simply the number of new measured signals dedicated for smart maintenance.

How to compute PI6.2-3

To compute this KPI the formula to use is the following one:

$$PI_{6.2-3} = Nw - No$$

Where:

- N_w: total number of variables measured for smart maintenance of the traction component with the implementation of the solution.
- N_o: total number of variables measured for smart maintenance of the traction component without the implementation of the solution.

6.8. UC6.3: Set up of adaptive wireless telecom network between train elements

This use case spans Task 6.4 “Development of hardware improving Rolling Stock’s future lifecycle and maintenance” and subtask 6.4.1 “Multi-purpose resilient adaptative on-board telecom network”.

6.8.1. Overall aim of the use case

The global aim of the use case is to define an adaptive wireless telecom network that could be used between the train elements (inter-consist & inter-carriage coupling) that can be changed during a journey. By using virtualisation and isolation techniques, the single physical

communication infrastructure will be split into three virtual infrastructures to support three service types (Train Control and Management System (TCMS)), Operator Oriented Services (OOS) and Customer Oriented Services (COS)) to meet the adequate level of quality-of-service and security/safety requirements. This single infrastructure will be flexible to dynamically adapt to the composition of the train which can evolve along the journey (coupling/uncoupling). Cybersecurity requirements will be considered. This communication infrastructure will be used to transmit the data defined in FA2 activity "TE On-board Communications".

In the TCMS area, we found the following functionalities/systems:

- Main command
- Train radio
- Air conditioner
- Drive
- Brakes
- Electricity
- Bathroom
- Lighting
- Support systems
- Passenger announcement system
- Exterior & interior doors
- ETCS (European Train Control System)
- ATP (Automatic Train Protection)
- ODDRS (Onboard Driving Data Recording System)
- Passenger alarm system

In the OOS area, we found the following functionalities/systems:

- CCTV: protection video, in-cab track monitoring, rear vision
- Infotainment onboard train devices
- Automatic passenger counting
- Vehicle positioning-service (also exists in TCMS domain)
- Fare management or ticketing
- Driving assistance system
- E-schedule (schedule for the driver)
- Diagnostic systems and CBM (condition-based maintenance). Service exists in the TCMS domain as well
- Passenger Information System (PIS): Automatic Announcement

The COS functions/systems are as follows:

- User equipment access (example Wi-Fi hotspots).
- Public internet access

6.8.1.1. Problem to be solved

The telecom infrastructure deployed on board is currently wired and suffers from maintenance issues due to the mechanical stresses placed on the cables and connectors at the intercarrier and interconsistent level.
Several projects were conducted around wireless TCMS and one common bus. We can mention, for example, ROLL2RAIL, CONNECTA and SAFE4RAIL. The projects were focusing mainly on the specification of such a system.
The difference with these projects lies in: considering on-the-fly interconsistent virtual coupling at a speed around 100 km/h and considering one common bus concept (extended to the wireless part of the network). The different technical challenges foreseen for the embedded network are listed below:

- To be able to operate “on the fly” coupling (speed ~100km/h);
- To maintain high speed coupling (from 120 km/h at minimum up to 320 km/h);
- To be able to define train composition;
- To avoid coupling with compounds that should not be coupled;
- To avoid interferences between trains on adjacent tracks;
- To be resilient to interferences;
- To demonstrate a complete isolation of traffic flow between the different on-board networks (generation of overflow on one of the service types on the embedded network doesn’t impact the higher safety level service types of the on-board network);
- To consider the constraints of the propagation channel (mobility, multi-paths, multi-users (trains(trains/wagon)) or the different technologies foreseen (ITS-G5, UWB, LTE, 5G, mm waves).

6.8.1.2. Industry current position / baseline

In the 90’s IEC-61375 TCN standard was proposed. At this time, the Train Control and Monitoring System (TCMS) was based on the networks multifunction (vehicle bus-MVB and Wire Train Bus-WTB). But due to the increase of information volumes and the limitation capacities of the links, it was replaced by the Ethernet based networks (Ethernet consist network- ECN and Ethernet Train Backbone - ETB).

However, despite the performance increase and cost reduction, some major issues remain, such as TCMS complexity, consumption times (subsystem integration, commissioning, maintenance).

6.8.1.3. Subproblem addressed by the use case and measurable objectives

The use case had been defined to reduce cabling costs and ease the insertion of the WTCMS in existing fleet where the installation/de-installation of wiring is human & time consuming, while maintaining the same performance and security levels than on ECN/ETB network.

6.8.1.4. Influence of the proposed innovation on the IM/RU problem

The objective of the use case is to provide a solution for coupling (interconsist and inter-carriage coupling) that could be available for each train subsystem whatever the train type and its working environment. This use case has for objective to serve as a starting point for development of products by fixing some key elements (as telecom technology).

6.8.2. UC6.3: Demonstrator's KPI

6.8.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
I	Qualitative and prompt integration of information, including reducing time to transfer asset condition stats to TMS (Reducing time to transfer asset condition status to TMS)	Little/indirect
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect

Table 21: UC6.3 KPIs on a FP level from the Grant Agreement

To contribute and justify the choice of the telecom technology for this use case, the below PIs are proposed.

PI	Description	Target
6.3-1	Coupling Time & distance	NA
6.3-2	Usual IP Metrics	NA

Table 22: UC6.3 PIs

6.8.2.2. PI6.3-1 – Coupling time & distance

Short description

The main objective of this PI is to evaluate the time and the distance (directly linked to the time consuming for human operations) necessary to couple two identical train elements in their working environment.

Coupling time & distance:

> Average time & distance to couple two identical consists and comprises the time (and distance) between the beginning of the manoeuvre and the full availability of the coupled consists.

How to compute PI6.3-1

There is currently no formula for this PI as the coupling, as of today, is only performed while trains are initially stopped.

This PI can be measured in laboratory tests or in real environments, considering different factors:

- The time required to establish communication between two train elements using each radio technology, including the time required for exchange data (the identification of consists, message validation).
- The time required for coupling, encompassing the starting and the end of the manoeuvre (as a function of travel speed of consists).
- The time required to validate the operation depending on distance.
- The maximum distance at which communication can be established: depends on the range of each technology and the propagation channel.

6.8.2.3. PI6.3-2 – Usual IP metrics

Short description.

Usual IP metrics represent all the metrics allowing the analysis of IP interface network and the comparison between different technologies.

We consider the following metrics as usual IP Metrics:

- Throughputs
- E2E Delay
- Jitter
- PER (Packet Error Rate)

Throughputs: actual averages amount of data that can be exchanged through a network at IP layer In both directions. from the point A to the point B (and vice versa).

E2E Delay: end-to-end delay measured from the moment the packet leaves the source to the moment the same packet arrives at the destination at the application layer.

Jitter: variation of delay to exchange data packets through a network.

PER (Packet Error Rate): number of incorrectly received data packets divided by the total number of received packets.

How to compute PI6.3-2

Theses PIs can be measured in laboratory tests or in real environments, considering different factors:

- Traffic profiles (packet length, periodicity, etc.) & service criticality for the 3 domains (safe TCMS, TCMS, OMTS)
- Rolling stock (Types & their specifications)
- Flow types (TCP, UDP...)
- …

6.9. UC6.4: Adhesion estimation for management

This use case spans Task 6.3 "Data analytics. Development of predictive and prescriptive workflows for maintenance actions based on component health status and capability of decision making" and subtask 6.3.5 "Adhesion estimation for management".

6.9.1. Overall aim of the use case

The use case adhesion estimation for management aims to design methods to estimate/measure the Coefficient of Friction (COF) in real time under real operation conditions to determine at a certain time window, e.g., safe braking distance and, if necessary, the (strategy for) control of COF by friction modification (using sanding, lubrication, etc.). This will contribute (among other things) to increasing service availability and optimal capacity. In the use case, we focus on the modelling of the traction drive system, using electro-mechanical physical approaches and data-based methods to estimate COF.

6.9.1.1. Problem to be solved

Properly estimating the value of the COF is critically important for traction and braking and the minimisation of wear, deformation and rolling contact fatigue of rail and wheel. The increasing importance of rail transport in a CO_2-neutral society demands an increase in railway capacity, requiring faster, heavier and more frequent trains with short distances between trains. In this case, real-time measurement of COF from operational trains is needed to guarantee a safe operation. The railway infrastructure is an open system where the COF at the wheel-rail interface changes with humidity, contamination/lubrication, roughness and stress in the contact area, among other factors.

6.9.1.2. Industry current position / baseline

The Dutch railway (ProRail and NS) is a densely used infrastructure with a strong need for the accurate real-time measurement of COF. Train-borne COF measurement was developed, e.g., in the 1970-1980s by the British Rail. With the technological development of the last 50 years in the

understanding and quantification of wheel-rail frictional rolling contact and detection, data processing, identification, control and actuation, more advanced methods of COF measurement can be applied on board the train. Currently, there is no COF measurement system available that considers the real wheel-rail contact force, which can amount to several tons. The existing portable tribometer measures friction with low contact pressure, typically around 3 kg in weight. As a result, the measured coefficient of friction differs significantly compared to the actual weight of a train. In this use case, the baseline will consider scenarios under which no online information about COF at the wheel-rail interface is available, with different levels of uncertainties under different times and different track locations. The approach is simulation-based, and we will test different scenarios.

6.9.1.3. Subproblem addressed by the use case and measurable objectives

In the FP3-IAM4RAIL, the basis of a new train-borne COF measurement method will be envisaged by incorporating in the motor control an estimator of the adhesion level from the relation between the motor current and its corresponding rotor speed. We also require the estimation of the creepage of the wheel-rail rolling contact. Then, by controlling the traction/braking force through the electricity input to/output from the traction motor and estimating the operational location of the wheel-rail contact in the creepage-creep force curves, the COF could be estimated.

The method will be first demonstrated in a simulation environment using parameters available in the literature. Then, an electromechanical system is built by including the complex dynamics involving both the electrical and the mechanical subsystems. Within the framework of the ERJU, the target is to develop the method on trains in collaboration with rolling stock manufacturers. This will make it possible in the future to actually deploy the method as part of a holistic asset management system, with an accurate online (time-varying) estimation of the COF across the whole railway network.

6.9.1.4. Influence of the proposed innovation on the IM/RU problem

In the IN2TRACK3 project, adhesion estimation methodologies were conducted through simulation and lab tests (TRL3-4). In the FP3-IAM4RAIL project, we aim to further develop the techniques for trials through simulation, lab tests and the use of real-life data. The inclusion of actual characteristics of rolling stocks is a major challenge, and we need to realise how the developed techniques can be applied for test experiments in the field.

Progress so far in this use case includes collection of parameters and development of modelling approaches. CAF and Alstom have collected drive train parameters such as inertia, gear ratio and motor equivalent circuit parameters, along with other information. Alstom conducted a field test and provided data for different slip conditions during braking and acceleration. The data includes motor variables such as current, voltage, slip, etc. TUDelft/ProRail is developing physics-based friction models to provide a driver advisory indicator. A state-of-the-art electromechanically coupled model of locomotives was developed, to test faster simulation time and accuracy of the

models. A methodology based on the phase difference between torque and wheel speed was developed to estimate the maximum coefficient of friction in real-time. Using this model, the methodology was evaluated under different simulation conditions, such as constant speed, constant acceleration, varying slip conditions, varying normal weight and varying modulation frequency. This model will act as a demonstrator to provide a driver advisory indicator to estimate the coefficient of friction (COF) between wheel and rail.

6.9.2. UC6.4: Demonstrator's KPI

6.9.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct

Table 23: UC6.4 KPIs on a FP level from the Grant Agreement

In demonstrator #2, Asset Management and Rolling Stock, we aim to increase service availability by reducing in-service failures/faults. The core of the research in this use case is to develop models for adhesion estimation. Thus, the KPIs proposed for this use case include the accuracy of estimation and computational time required by the models to produce the estimation of COF during the time period of the modulation.

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
6.4-1	Accuracy of COF estimation	NA

Table 24: UC6.4 PIs

6.9.2.2. PI6.4-1 – Accuracy of COF estimation

Short description

When the technology is implemented, with the accurate estimation of COF, the driver's decision-making will be able to consider sufficient adhesion force for acceleration and braking. Thus, the in-service failures due to low adhesion conditions could be managed with better driver decision-making and future actionable instrumentation to control COF, such as sanding. With real-time estimates of the coefficient of friction, the braking and acceleration curve of the train driving can be predicted. Thus, the braking and acceleration distances can be optimised/minimised. This will lead to better optimisation of the railway capacity by using an online approach instead of the conservative solution currently applied (considering the worst-case scenario for the unknown COF condition). New technologies, such as ATO, will also benefit from this innovation. As for the innovation targets for the FP3-IAM4Rail project, the core work is on estimating forces, creepage and COF. The use case focuses on modelling approaches, and we test the estimation provided by the algorithms versus the values of COF included in the simulations.

How to compute PI6.4-1

Here are the measurable elements that will be used to measure PI's:

- DAI: estimation of the COF by the methodology
- COF: actual coefficient of friction provided by simulator or estimated by controlled conditions (low adhesion conditions versus normal conditions)
- PI6.4-1: accuracy of the methodology

Then, PI6.4-1 is to estimate the accuracy of the driver advisory indicator that estimates the COF under simulation and controlled experimental conditions by:

$$PI_{6.4\text{-}1} = abs\ (DAI - COF) / (COF)$$

6.10. UC6.5: Wayside signalling equipment monitoring system

This use case spans Task 6.4 "Development of hardware improving Rolling Stock's future lifecycle and maintenance" and subtask 6.4.2 "Cyber security device development".

6.10.1. Overall aim of the use case

6.10.1.1. Problem to be solved

Technology is now a key element in rail transport, and its use has become increasingly common to improve efficiency, safety and passenger experience.

However, this increase in IT systems and their interconnection also introduces new cybersecurity risks that have not been considered and managed to date. For example, modern trains are often equipped with entertainment systems, security systems, speed control systems and other electronic components that are connected to a communications network. If one of these

components is hacked, it can have a significant impact on the entire railway system, which can cause impacts such as service disruptions, panic among passengers or event accidents.
It is also important to consider that railway systems can be attractive targets for targeted cyber-attacks, due to their direct relationship with countries' strategic services and infrastructures, as well as the large amount of sensitive data they can handle.
Having railway cybersecurity monitoring systems in place will make it possible to detect possible cyber-attack attempts and reduce the consequences they may have, as well as to adapt to compliance with cybersecurity guidelines, regulations and standards, the development of which is gaining importance worldwide.

6.10.1.2. Industry current position / baseline

Historically, railway cybersecurity issues have not been a priority, allowing for a scenario with limited or non-existent controls and supervision measures. Current situation is a railway industry that needs to initiate a process of change and adaptation in response to new emerging threats, as well as regulations.

6.10.1.3. Subproblem addressed by the use case and measurable objectives

The current problem is centred on a railway industry with limited or absent technical cybersecurity controls and monitoring measures.
The use case focuses on defining and creating initial mechanisms to introduce the first elements of monitoring, with the objectives of defining and implementing technical controls and alert mechanisms against cyber-attacks on the train itself, both through internal systems and from train to ground communications.
The problem addressing will focus on the management of the top threats according to ENISA Threat Landscape (ETL) report in 2022, applying them to on-board railway systems and communications:

- Ransomware.
- Malware: detecting and warning of cyber-attacks using zero-day vulnerabilities.
- Social engineering: techniques to fool the passenger through digital interaction with train systems.
- Threats against data: stealing data from the train, especially related to personal data such as images, CCTV records etc.
- Threats against availability cyberattacks for Denial of Service (DDoS) against train operation or high-risk effects on operational systems (speed, braking, external CCTV…).
- Disinformation – misinformation: techniques to induce the passenger into believing a false risk scenario (fire, smoke, bomb...).
- Supply chain targeting: attacks against software or hardware in the supply chain or managed by third parties.

6.10.1.4. Influence of the proposed innovation on the IM/RU problem

The use case will introduce and improve cyber security capabilities in railway systems focusing on reducing risks derived from the threats that affect them, through the following key points:

- Detection of cyber-attacks and anomalies through the internal network.
- Detection of anomalous activity and behaviour in on-board systems.
- Active monitoring and control of authorised (maintainers) and unauthorised connections.
- Monitoring of vulnerabilities and technical threats.
- Telemetry collection and preventive and reactive monitoring.

6.10.2. UC6.5: Demonstrator's KPI

6.10.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect

Table 25: UC6.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
6.5-1	Compliance with cybersecurity standards	15%
6.3-2	Reduce the impact of top threats	5 of the top 7

Table 26: UC6.5 PIs

6.10.2.2. PI6.5-1 – Compliance with cybersecurity standards

Short description

Increasing train cybersecurity compliance in line with current relevant industry cyber security standards such as ISA62443 or TS50701. The use case must be able to meet 15% of the cybersecurity requirements set out in ISA62443-3.2.

How to compute PI6.5-1

Support at least a 15% of the cybersecurity requirements (SR) indicated in ISA62443-3.2 in the security level 2 (SL-2). There are 60 security requirements in Security Level 2.

6.10.2.3. PI6.5-2 – Reduce the impact of top threats

Short description

Reduce the likelihood and consequences of at least 5 of the top 7 threats identified by ENISA in its Threat Landscape (ETL) report 2022. The effects of a threat are reduced if it is possible to prevent its materialisation before it happens or to contain the effects once it has happened.

How to compute PI6.5-2

Demonstrate that it is possible to detect or contain threat materialisation by simulating real cases of threat materialisation in laboratory environments. Each type of threat detected or contained will be computed with respect to the total according to ENISA.

6.11. UC6.6: On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany

This use case spans Task 6.2 “Demonstration and validation of Rolling Stock (on-board) inspection and monitoring systems”.

6.11.1. Overall aim of the use case

6.11.1.1. Problem to be solved

Currently, maintenance is based on fixed intervals. These fixed regimes may not represent the best maintenance strategy regarding train availability, plannability of maintenance actions and economic issues.

An on-board bogie diagnostic solution may be an enabler for a condition-based maintenance process.

Hence, the SMO bogie diagnostic solution shall be applied to one train operating in Germany. Intelligent algorithms shall be implemented to the bogie diagnostic solution enabling the detection of faulty bogie components.
In contrast to use case UC5.1 “Bogie monitoring system (on-board)” focusing on identifying most promising monitoring methods based on simulation and roller rig tests in a first step, this use case UC6.6 aims at installing the ready-to-use SMO bogie diagnostic solution on at least one train operating in Germany to elaborate the benefits for the maintenance. Hence, together with the train operator and the maintainer the benefits of this bogie diagnostic solution shall be elaborated and shall be maximised.

6.11.1.2. Industry current position / baseline

Maintenance is currently done based on fixed intervals possibly not representing the most cost-efficient maintenance strategy as component failure may occur right after a planned inspection. Additionally, component lifetime may not be fully exploited.

6.11.1.3. Subproblem addressed by the use case and measurable objectives

Results of the SMO bogie diagnostic solution shall support the maintenance staff in planning, optimising and adapting the maintenance actions and processes.

6.11.1.4. Influence of the proposed innovation on the IM/RU problem

The Bogie Diagnostic (BD) solution supports the maintenance process by providing full insight (24/7) in each component's health state and hence enables:

1. 100% availability of rolling stock.
2. Better plannability of maintenance actions.
3. Lower maintenance costs over the product lifecycle.

6.11.2. UC6.6: Demonstrator's KPI

6.11.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct
V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy (as defined by ISO) improvement of 10%)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect

Table 27: UC6.6 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
6.6-1	Application of SMO bogie diagnostic solution	NA
6.6-2	Integration of results to maintenance process	NA

Table 28: UC6.6 PIs

6.11.2.2. PI6.6-1 – Application of SMO bogie diagnostic solution

Short description

PI6.6-1 shall assess if the SMO bogie diagnostic solution is successfully applied (in the sense of hardware and software) to at least one train operating in Germany.

How to compute PI6.6-1

PI6.6-1 is measured by evaluating the availability of results provided by the SMO bogie diagnostic solution. All results (for every considered bogie component) are provided once a day. PI6.6-1 represents exactly this availability of results.

6.11.2.3. PI6.6-2 – Integration of results to maintenance process

Short description

The results of the SMO bogie diagnostic solution support the maintenance process and – ideally – are integrated into the maintenance management system.

How to compute PI6.6-2

PI6.6-2 assesses if the results of the SMO bogie diagnostic solution are used within the maintenance process and really support the maintenance staff. Achieving this target would really support the path to CBM (condition-based maintenance), cf. baseline in section 6.10.1.2.

6.12. UC6.7: Digital twin for energy

A digital twin is going to be developed to analyse the energy consumption, normal behaviours in the train fleets.

This use case spans Task 6.3 “Data analytics. Development of predictive and prescriptive workflows for maintenance actions based on component health status and capability of decision making” and subtask 6.3.3 “Monitoring and predictive analytics using data available on The Netherlands railway type sections. Onboard systems”.

6.12.1. Overall aim of the use case

6.12.1.1. Problem to be solved

A big part of the operational cost of rolling stock assets is due to the energy consumption. Moreover, there is a big concern regarding Europe energy dependence with other countries and the carbon footprint due to climate change.

6.12.1.2. Industry current position / baseline

Currently one of the main costs for operators goes to electrical energy. The main objective of the Energy Digital Twin is to get better knowledge about these costs and optimise them.

6.12.1.3. Subproblem addressed by the use case and measurable objectives

Developing this digital twin to find the best way to operate trains from an energy consumption perspective requires the development of a theoretical model.
First, it is necessary to define a model architecture, prepare data and validate the model's consumption calculation.
On the other hand, it is necessary to define the parameters that affect consumption and that do not depend on driving, and also to define the parameters that allow the impact of driving on consumption to be evaluated.
Once this is done, the final driving consumption analysis tool will be developed.

6.12.1.4. Influence of the proposed innovation on the IM/RU problem

In this use case a digital twin to model the energy consumption of a particular train will be developed. This digital twin will make use of theoretical models, design data and real data gathered from the operation of the train.

In addition to this, the digital twin will be used to find the optimal way to operate the train regarding energy consumption subject to particular operational constraints (time constraints, circulation requirements, …). Then, the results will be validated against real data gathered.
By analysing the energy consumption and building model, related anomalies can also be detected.

6.12.2. UC6.7: Demonstrator's KPI

6.12.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	High/direct

Table 29: UC6.7 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
6.7-1	Accuracy of the energy consumption model	5%
6.7-2	Expected improvement in energy reduction	5%

Table 30: UC6.7 PIs

The first PI will measure how good the model is, which is something required to trust in estimations regarding energy consumption reduction, while the second PI is linked to business.

6.12.2.2. PI6.7-1 – Accuracy of the energy consumption model

Short description
The PI will measure, in terms of percentage, how similar the energy consumption provided by the model is compared to the actual energy consumption. We will be able to get the error of the model in relation to the data obtained from the train.

How to compute PI6.7-1
The PI will measure, in terms of percentage, how similar the energy consumption provided by the model is compared to the actual energy consumption. The actual energy consumption of the NSR (Atlantic climate type) fleets is directly measured using LeadMind, the proprietary online data platform from CAF, which allows us to obtain precise real-time data on the energy usage of the

train. This enables a direct comparison between the real consumption recorded by LeadMind and the predicted consumption generated by the model. By leveraging this data, we can accurately assess the model's performance in predicting energy consumption, ensuring that the PI reflects a true and reliable measure of the model's accuracy.

6.12.2.3. PI6.7-2 – Expected improvement in energy reduction

Short description

The PI will measure the theorical maximum energy savings that can be achieved and provide information on how to achieve that theorical optimum energy consumption (changing the acceleration curve, reducing speed…).

How to compute PI6.7-2

The PI will play a crucial role in identifying the maximum potential reduction in theoretical energy consumption. By comparing the actual energy usage of the train, measured in real-time through LeadMind, with the predicted consumption generated by our model, the PI will highlight the discrepancies between the two. This comparison will allow us to pinpoint areas where energy efficiency can be optimised. The insights gained from this PI will enable us to adjust operational strategies and refine the predictive model, ultimately guiding us toward the maximum possible reduction in theoretical energy consumption. By continuously monitoring and improving these metrics, we can drive more sustainable and cost-effective train operations.

6.13. UC6.8: Smart maintenance scheduling tool

Development of a decision optimisation support strategy for PDM scheduling using, e.g., ML for improving the scheduling of asset maintenance activities.

This use case spans Task 6.3 "Data analytics. Development of predictive and prescriptive workflows for maintenance actions based on component health status and capability of decision making" and subtask 6.3.4 "Maintenance scheduling strategies".

6.13.1. Overall aim of the use case

6.13.1.1. Problem to be solved

Under a PVM strategy, it was relatively easy to forecast and schedule in a sensible way the different maintenance tasks required while complying with operational requirements. Information was quasi-static, and the number of inputs was relatively small and manageable manually or with existing processes and tools by the maintainers and operators.

However, information coming from the different algorithms and data gathered from the fleet is dynamic in nature and its amount is vast, which makes it difficult to schedule and organise required maintenance tasks along with operational requirements in such a dynamic environment. In this sense, an intelligent system is required to act as a decision support system able to handle this information to help operators make sense of all this data and decide which actions shall be taken

to optimise availability and eventually reduce the overall life cycle cost. This will lead to a scenario in which the operators can exploit all the advantages and improvements of a condition-based maintenance program.

The proposed maintenance planning tool will serve as an integrated platform designed to manage and optimize maintenance activities for equipment and systems. Initially, the tool will integrate the traditional PVM approach, scheduling regular interventions based on time intervals or equipment usage, with the primary objective of preventing failures before they occur.

The tool will evolve towards a mixed approach, and it will incorporate advanced condition-based maintenance capabilities. This will involve the integration of real-time sensors, data management systems and predictive analytics that collect and process critical information on the equipment's condition. Based on these insights, the system will automatically adjust maintenance plans, prioritizing interventions according to the actual condition of the assets rather than relying solely on predefined schedules.

Additionally, the tool will leverage artificial intelligence techniques to optimize workshop operations. AI will consider various constraints, such as the availability of workshops, technicians and stored materials, to create efficient maintenance schedules. By integrating this information, the tool will ensure that maintenance activities are planned and executed with minimal disruption, making the best use of available resources and reducing downtime.

In summary, this mixed-approach maintenance planning tool will not only enhance operational efficiency and optimize resource usage but also extend equipment lifespan by integrating component health information, PVM plans and the constraints of maintenance activities. By combining the reliability of PVM with the precision of condition-based maintenance, and with the added intelligence of AI-driven scheduling, the tool will drive more effective and streamlined maintenance processes.

6.13.1.2. Industry current position / baseline

Currently, a potential for improvement is identified in the asset management, the maintenance scheduling in the depots as well as the warehouse management and its integration in the overall (maintenance) management.

6.13.1.3. Subproblem addressed by the use case and measurable objectives

In this use case a dynamic scheduler will be implemented. This dynamic scheduler will provide a general overview of the current fleet state, will manage all different PDM alerts and outputs (such as health index, severities, etc.), dynamic availability requirements, legal requirements such as PVM plan, depot constraints such as manpower, depot capacity and will propose a sequence of required maintenance tasks optimising multi-criteria objectives regarding cost and train availability.

This scheduling will be dynamic as part of their inputs are dynamic in nature. This means it will enable maintenance managers to take quick and timely decisions thanks to this decision support tool, that will adapt its proposal based on current and updated situation by collecting real-time information from the assets.

6.13.1.4. Influence of the proposed innovation on the IM/RU problem

The system will help maintenance managers to take correct and informed decisions in a manageable way making the most of the PDM alerts and outputs as it will enable maintenance managers to take timely action in a dynamic environment. This will lead to lower life cycle cost of the fleet and optimisation of the maintenance workshops as it will be easier to take the correct decisions.

6.13.2. UC6.8: Demonstrator's KPI

6.13.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct
V	Tools which provide at least 3 possible strategies of long term management (with an accuracy (as defined by ISO) improvement of 10%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 31: UC6.8 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
6.8-1	Savings in maintenance cost	10%
6.8-2	Increase in fleet availability	5%

Table 32: UC6.8 PIs

6.13.2.2. PI6.8-1 – % Savings in maintenance cost

Short description

Costs associated to the rolling stock maintenance shall be reduced thanks to the application of the models and tools to be developed in this use case. This PI will measure the savings in maintenance cost associated to the application of the Smart Maintenance Scheduling System in terms of percentage.

How to compute PI6.8-1

This PI will be measured by computing the maintenance cost in a simulated scenario in which all these tools are in place. This will be based on the evidence gathered during the project about precision/recall of the ML algorithms, the type of failures detected and the implementation of the new maintenance plan in a simulated scenario.

6.13.2.3. PI6.8-2 – Increase in fleet availability (%)

Short description

This PI will measure the gains in availability thanks to the application of a smart maintenance scheduler system. This PI will measure, in a simulated scenario, the time the fleet has to be in maintenance, and it will compare it with the time required so far.

How to compute PI6.8-2

This PI will be measured by scheduling different maintenance tasks via the use of the Smart Maintenance Scheduler system during a fixed period of time and computing the expected time required to maintain the fleet.

On the other hand, a similar exercise will be done applying techniques currently in place. The ratio between these two will be computed.

6.14. UC7.1: Bogie Monitoring System (wayside – acoustic, 2D- images, video, laser and RFID)

Wayside acoustic, visual, laser and RFID data may carry information on the health status of different bogie components. This use case has the potential to enhance the monitoring capability of the WP demonstrators (ES and NL), especially for bogie health monitoring.

In this use case, data will be collected from different technology sources, like video technology, train identification, accelerometers, noise technology and 2D scanning. Part of the work will be data captured from wayside technologies.

This use case spans Tasks 7.2 “Wayside Inspection Technology including Railway Checkpoints” and 7.3 “Design & Deployment strategy for Railway Checkpoint and other Demonstrators”.

6.14.1. Overall aim of the use case

The first main goal of the use case is “collecting assets status data based on new data sources from multiple sensors and supported by common EU shared specifications”.

Inspecting:

- Wheel parameters.
- Wheel defects.
- Bearing condition.
- Brake system condition.
- Physical anomalies of the general condition of the bogie through 2D images.

6.14.1.1. Problem to be solved

One way- to improve the safety of rolling stock, as well as its availability and reliability, is through automated inspection based on automatic monitoring equipment. These teams work 24 hours a day without failure and, more importantly, if connected to machine learning, it continuously learns to anticipate the detection of failures and breakdowns.
With this approach, we can initially generate an extensive database, enabling us to develop algorithms that not only detect failures but can also be upgraded to predict when maintenance will be required for the rolling stock. For instance, in the case of wheel flange measurement, its measurement will be automatic and with the historical data and circulation forecasts it can accurately determine the next appropriate time for maintenance or wheel replacement with a considerable level of precision.

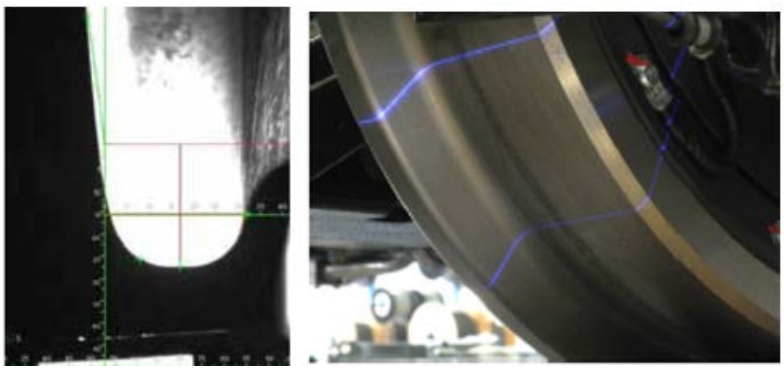

Figure 4: Wheel profile

At the same time, a significant reduction in PVM costs is expected, since the maintenance intervals will be adjusted when necessary and will not be carried out by kilometres travelled, as has been done so far in terms of PVM.

The current use case development level corresponds, in both of the cases, CAF and TALGO, to a prototype development stage.

Train maintenance inspections on bogies are critical to avoid service disruptions due to failing trains. Currently, train maintenance inspections are done manually and periodically.

Figure 5: Bogie, Isometric view

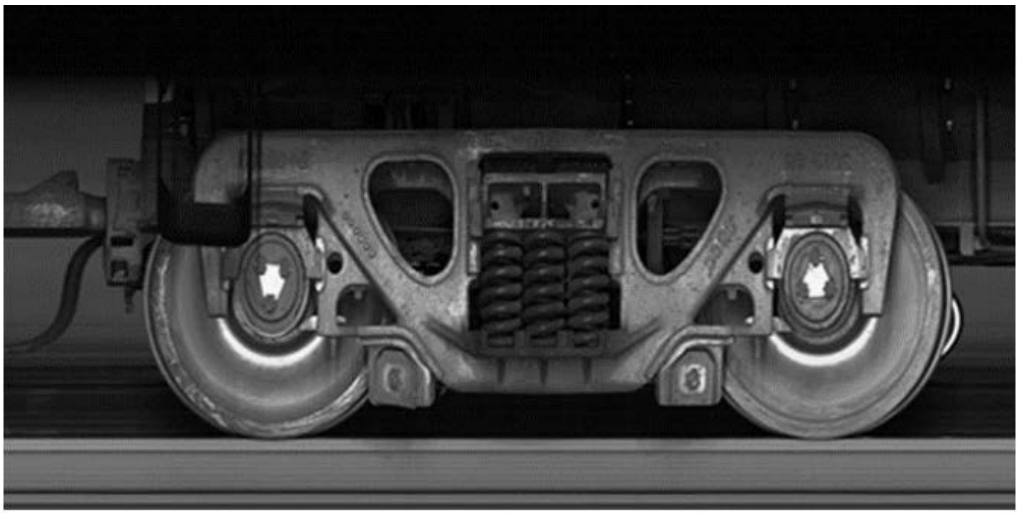

Figure 6: Lateral bogie picture, taken by the WTMS

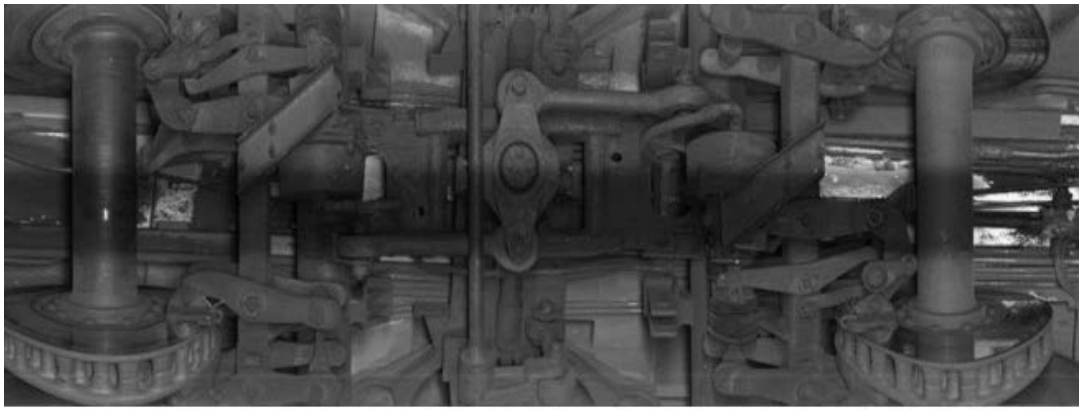

Figure 7: Underfloor bogie picture, taken by the WTMS

Rolling stock owners/maintenance managers are very interested in solutions that can help to increase fleet availability and reliability. Condition-Based Maintenance (CBM) is believed to be an attractive lever for gaining maintenance efficiency. Bogie components, e.g. axle bearings, motors, gearboxes, are often classified as business-case-positive in the implementation of CBM. To implement CBM, a condition monitoring solution is often needed. One possible solution is wayside monitoring.

Figure 8: Representation of Cloud information transfer from the wayside system

There are two safety-critical systems for rolling stock that the deliverable will focus on. The first is the rolling stock's braking system. A failure of the brakes on an axle can lead to an accident, due to an increase in the braking distance. The second would be the condition of the axle bearings, which as we know, throughout the history of railway have caused many accidents due to the

breakage of these bearings. A recent accident in East New Palestine, Ohio, USA, where a freight train suffered a catastrophic bearing failure, can be cited as a prominent example.
By collecting visual and acoustic datasets of bogies, which can then be analysed to define patterns, bogie monitoring can be done automatically and more frequently. This will be done using the different technologies: acoustic, 2D images, video and laser.
This information can support the increasing of the security and the reliability of the whole system, as well the reduction of maintenance costs.

6.14.1.2. Industry current position / baseline

Control points on the track are devices that have been implemented in the railway infrastructure for many years, from equipment that detects hot boxes or hot brakes, pantograph height or falling objects, among others.

However latest advances in sensorisation and the standardization of these devices have made it possible to increase the number of devices installed on tracks, as well as to increase the parameters that they are capable of recording. An example of this is automatic measurement equipment for wheel parameters, and although in the past there have been some manufacturers that have developed and offered automatic measurement equipment, the acquisition price was too high for a viable purchase. The combination of advances regarding data sharing, cloud storage together with AI allows us to optimise data management and, most importantly, decision-making about maintenance actions.

Currently all inspection works carried out in rolling stock maintenance tasks are done manually by one person, and with tools that have not changed for decades. If this individual is mistaken or performs the job incorrectly, there is no means of verification available. Therefore, one way to improve the safety of rolling stock for the IM and digitise these processes is through automated inspection solutions.
By storing this information in the cloud and using an algorithm, a decision about what to do with the train can be made; for example, it will be possible to determine whether to take the train out of service and sent to re-profiling or to change bearings or wheels.

Hot Axle Box Detector (HABD) is a widely applied wayside solution for monitoring axle bearing temperature. However, when a temperature alarm is triggered, the bearing is already close to functional failure. In this case, the train speed often needs to be reduced, which in turn may cause interruptions to the train service. This limits the potential of HABD for CBM.

Figure 9: La Sagra wayside system

Figure 10: Dutch working prototype, Gouda, wayside system

Figure 11: Dutch definitive wayside system, Harderwijk, in progress

Compared to temperature, acoustic datasets can provide an earlier indication of potential bearing failure. Thus, wayside acoustic monitoring is believed to be more attractive for CBM, in the sense that it gains more time to plan maintenance activities and resources. Currently, there are very limited suppliers of wayside acoustic solutions for axle bearing monitoring.

6.14.1.3. Subproblem addressed by the use case and measurable objectives

The wayside acoustic data may carry information on the health status of different bogie components, not only limited to axle bearings (outer or inner), it also can provide information on the gearbox bearings and motor bearings. To study the potentials of wayside acoustic monitoring for other bogie components, the following sub-problems are expected to be addressed by the demonstrator:

- Perform tests with known degraded bogie bearings.
- Conduct tests under varying weather conditions such as in the Netherlands and Spain.
- Conduct tests with different train speed of the train.
- Perform data analysis offline (in office) to check if the known component degradation can be detected.

The measurable objectives will be:

- Measurement of wheel parameters sh, sd and qr for safety purpose
- Check the wheel tread status
- Measurement of the wheel diameter
- Check the bogie status
- Check the brake system status
- Check the bearings status

PI verification (true or false)

One of the most complicated tasks in this UC and, in general, in all monitoring tasks using a measurement gantry, is to ensure that the measurable characteristic of the bogie, a defect, becomes a true value, that is, that it really is a fault, and it is not a false value, resulting in a false alarm.

These false alarms force the rolling stock to be removed from commercial circulation and therefore will entail an associated economic cost and a great impact on circulation, since we will have to verify the defect in the workshop, with the economic cost that this entails.

On the other hand, it is necessary to consider that this PI will be associated with each of the variables to be measured in the bogie, so for example there will be a PI associated with the wheel, another with the condition of the bearing and so on. A very low value in this PI will force the measuring equipment to be discarded, since very low reliability entails a very high economic cost, making it necessary to replace this equipment with another one that allows greater precision.

Therefore, in conclusion we see that precision will be the PI of utmost importance in this UC.

Alarm trigger threshold

A hard job in this Work Package will be to determine under what threshold this measurable characteristic allows an alarm to be triggered and for it to become a defect to be reviewed in the workshop. This value will not be a determined value in many cases but surely a statistical correlation that allows us to predict.

6.14.1.4. Influence of the proposed innovation on the IM/RU problem

If we want to increase the traffic of rolling stock on the tracks and, at the same time, maintain high safety standards, it is necessary to automate certain inspection tasks to continue having competitive rail transport as well as safety. Both the IM and the RU are interested in this project, although with different visions. The RU´s main motivation is to reduce maintenance costs; however, the IM seeks to maintain or improve the safety of the rolling stock that circulates on its rail network. In addition, the infrastructure manager wants to prevent damage caused by defective rolling stock as much as possible.

By collecting visual data of bogies, which can be analysed, bogie monitoring can be done automatically and more frequently. This will require enough 2D images of the bogies of the trains to be effective. Therefore, this data should at least contain information regarding elements from Bogies, such as:

- Axle bearings Missing/loose bolts
- Cables (loose/damaged/broken)
- Meta data (train type, location, timestamp etc.)
- Dampers missing components.
- Brake pads wear.
- Wheel wear and damages.

Regarding the visibility of the defects, the following categories should be considered:

- The resolution of the data should be high enough to be able to zoom in on smaller defects.
- The lighting of the data should be set up to also allow for monitoring during the night.
- The sensor angle(s) should cover all relevant parts of the bogie where defects may occur.
- Climatic influences such as fog, rain or snow, as well as heat.
- The influence of speed on the capturing of the data: record wayside acoustic data and the related operational data (train number, train speed, axle no., etc.).

The proposed innovation has the following potential positive influences:

- For rolling stock owners /maintenance managers maintainers:
  - Savings from extension of routine component overhaul and inspection intervals.
  - Savings from reduction of unnecessary component replacement.
  - Savings from reduction/avoidance of in-service component failures.

- For Infrastructure Managers (IM)
  - Savings from reduction of network disruptions due to in-service component failures.

6.14.2. UC7.1: Demonstrator's KPI

6.14.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10%)	High/direct
VII	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect

Table 33: UC7.1 KPIs on a FP level from the Grant Agreement

These significant PIs, related to PRIME KPI Catalogue, have been identified to assess critical aspects of train performance and maintenance:

PI	Description	Target
7.1-1	Wheel defects	NA
7.1-2	Wheel profile defects	NA
7.1-3	Degree of network utilization – all trains	NA
7.1-4	Accuracy	NA

Table 34: UC7.1 PIs

These PIs serve as valuable tools for railway operators to optimise maintenance efforts as well as minimise safety risks.

6.14.2.2. PI7.1-1 – Wheel defects

Short description

Number of derailments per million of kilometres. The root cause for derailments will be some failure in the wheel; this failure could be related to profile or tread.

How to compute PI7.1-1

This PI7.1-1 is calculated in safety dimensions, as accidents to measure occurs due to wheel profile issues:

$$PI_{7.1-1} = \frac{Number\ of\ derraiments\ due\ to\ the\ wheel}{kilometers - train} \times 100$$

6.14.2.3. PI7.1-2 – Wheel profile defects

Short description.
We can increase the rolling stock maintenance interval by regularly measuring the wheel profile because we can determine when the wheel will need to be replaced or re-profiled. This way maintenance cost and the frequency of workshop uses can be reduced. There is an impact in the degree of network usage because if we have less wheelsets in the workshop for re-profiling, we have more trains running on track with passengers.

How to compute KPI2
This PI7.1-2 is related to KPI ID 62 (in PRIME Platform of Rail Infrastructure Managers in Euro) Maintenance expenditures in relation network size,

$$PI_{7.1-2} = \frac{Number\ of\ reprofiles\ kilometers}{kilometers\ -\ train}$$

6.14.2.4. PI7.1-3 – Degree of network utilisation – all trains

Short description
Usage is an essential measure of the performance of the Infrastructure Manager (IM). One of the most important objectives for IM is to use its infrastructure as effectively as possible. A high-level industry KPI is the degree of network utilisation – all trains (KPI ID92 in PRIME Platform of Rail Infrastructure Managers in Europe).

Wayside bogie monitoring helps to reduce network disruptions due to in-service component failures, which may in turn contribute to an effective utilisation of the infrastructure.

How to compute PI7.1-3
This PI is defined as the average daily train-km on main track related to main track-km. Better availability per year due to unplanned work:

$$\text{PI}_{7.1\text{-}3}\ \text{Degree of network utilization} = \left(\frac{Total\ monthly\ train-km}{Main\ track-km \cdot 30}\right) \cdot \left(1 - \frac{Delta}{100}\right)$$

Where:

- Total monthly train-km = The total number of kilometres travelled by train in a month
- Main track-km = The total length of main track available.
- Delta [%] = time current unplanned work out of inspection, vs time planned work out of detection = unplanned work reducing the availability of the infrastructure

6.14.2.1. PI7.1-4 – Accuracy

Short description

Bogie component fault detection is, in principle, a binary classification problem. Accuracy is a metric for evaluating classification models.

How to compute PI7.1-4

For binary classification, accuracy can be calculated using the following formula.

$$PI_{7.1-4}Accuracy = \frac{(TP + TN)}{(TP + TN + FP + FN)}$$

Where:

- TP = True Positive
- TN = True Negative
- FP = False Positive
- FN = False Negative

6.15. UC7.2: Pantograph Monitoring System (wayside – video and 2D-3D images)

In this use case we will collect data from different technology sources, like video technology, train identification and 2D and 3D scanning. Part of the works will be data captured from wayside technologies.

This use case spans Tasks 7.2 “Wayside Inspection Technology including Railway Checkpoints” and 7.3 “Design & Deployment strategy for Railway Checkpoint and other Demonstrators”.

6.15.1. Overall aim of the use case

Asset condition data collection based on new data sources from multiple sensors and supported by a common specification shared by the EU.

6.15.1.1. Problem to be solved

One of the ways to improve the safety of rolling stock, as well as its availability and reliability, is through automated inspection based on automatic monitoring equipment. These systems work 24 hours a day without failure and, more importantly, when connected to machine learning, it continuously learns to anticipate the detection of failures and breakdowns.

With this approach, we can initially generate an extensive database, enabling us to develop algorithms that not only detect failures but also predict when maintenance will be required for the rolling stock. For instance, in the case of a pantograph defect, its measurement will be automatic, and, with historical data and circulation forecasts, it can be accurately determined the next appropriate time for lathe maintenance or band strip replacement with a considerable level

of precision.
At the same time, a significant reduction in PVM costs is expected, since the maintenance bands will be adjusted when necessary and will not be on a per-kilometre basis, as has been the case until now.
One of the ways to improve the safety of rolling stock, as well as its availability and reliability, is through automated inspection based on automatic monitoring equipment. The systems operate 24 hours a day without failure and, more importantly, when connected to machine learning, they constantly learn to anticipate the detection of malfunctions and defects.

With this approach, we can initially generate a comprehensive database, allowing us to develop algorithms that not only detect failures, but also predict when maintenance is needed for rolling stock. In the case of carbon strip measurement, for example, the measurement will be automatic, and with the historical data and circulation predictions, the next appropriate time for maintenance can be accurately determined with a considerable degree of precision.

At the same time, a significant reduction in the cost of PVM is expected, as maintenance bandwidths will be adjusted as needed and not performed based on miles travelled, as has been the case to date.
The current use case development level corresponds in the cases of the CAF and TALGO solutions to both prototypes' development stage.

Train maintenance inspections are critical jobs to prevent service interruptions due to train failures and to improve the safety of rolling stock operation. We consider that maintenance is a critical job to ensure the safety of passengers and the infrastructure, but it is a job carried out manually, by operators, some of whom have little training or are exhausted, and may make mistakes, and also regarding its inspection procedure where high safety risk appears (high voltage area and works at heights).

It must be taken into account that failures in the infrastructure due to failures in the pantographs cause very high economic losses, as it could cause a snag with the catenary, making it necessary to change the catenary wire, rescue the material that is retained in that area, in addition to all the disruption to passengers, loss of reputation and future passengers.

6.15.1.2. Industry current position / baseline

Control points on the track are devices that have been implemented in the railway infrastructure for many years, from equipment that detects hot boxes or hot brakes, pantograph height or falling objects, among others. However, the latest advances in sensorisation and the standardization of these devices have made it possible, on the one hand, to increase the number of devices installed on tracks and, on the other, to increase the parameters they are capable of recording. An example of this is automatic measurement equipment for pantographs parameters, and although in the past there have been some manufacturers that have had automatic measurement equipment, their price was so high that their acquisition was not viable. The combination of advances regarding data sharing, cloud storage together with AI, allows us to optimise data management

and, more importantly, decision making on maintenance actions.

Currently all inspection works in rolling stock maintenance tasks are done manually by one person, and with tools that have not changed for decades. If this individual is mistaken or performs the job incorrectly, there is no means of verification available. Therefore, one way to improve the safety of rolling stock for the IM and digitise these processes is through automated inspection solutions. By storing this information in the cloud and using an algorithm, decision about what to do with this train can be made; for example, it will be possible to determine whether to take the train out of the service and send it to change carbon band.

For the IM it is crucial to reduce the number of pantograph hooks with the catenary, due to the high cost that each incident produces from the economic point of view. If we want to increase the circulation of trains in our network with sufficient reliability (requirement that is demanded and appreciated by the client), it is necessary to be sure that there are no failures in the pantographs. In the current context of the increase of private railway operators in the different railway network lines, it is essential for the IM to be sure that the pantographs leave the workshop in perfect conditions. A continuous pantograph analysis, while train passes through the Wayside, permits to provide a continuous information of the carbon strip status (wear, damages, degradation, etc.) analysing in real time the maintenance action to be considered.

6.15.1.3. Subproblem addressed by the use case and measurable objectives

There are two groups of sub-problems addressed by this use case:

- Pantographs defects that can affect to the catenary.
- Meta data that can give information of the composition of the train.
- Conduct tests under varying weather conditions such as in the Netherlands and Spain.
- Conduct tests with different train speeds

The measurable objectives will be:

- Check the pantograph status: carbon band width and thickness.
- Check the pantograph structure.

6.15.1.4. Influence of the proposed innovation on the IM/RU problem

If we want to increase the traffic of rolling stock on the tracks and, at the same time, maintain high safety standards, it is necessary to automate certain inspection tasks to continue having competitive rail transport as well as safety. Both the IM and the RU are interested in this project, although with different visions. The RU´s main motivation is to reduce maintenance costs; however, the IM seeks to maintain or improve the safety of the rolling stock that circulates on its rail network.

If we want to expand the movement of rolling stock on the railroad while maintaining high safety standards, it is necessary to automate certain inspection tasks to continue providing competitive rail transportation and safety. Both the infrastructure manager and the rail operator are interested

in this project, albeit with different visions. The rail operator's main driver is to reduce maintenance costs; however, the infrastructure manager's goal is to maintain or improve the safety of rolling stock on its rail network. In addition, the infrastructure manager wants to prevent damage caused by defective rolling stock as much as possible.

By collecting visual data of pantograph, which can be analysed, pantograph monitoring can be done automatically and more frequently. This will require enough 2D and 3D images of the pantographs of the trains to be effective. Therefore, this data should at least contain information regarding:

- Pantographs:
    - Low thickness of carbon bars
    - Chipping/crumbling of carbon bars
    - Broken/deformed arms/horns
    - Defect cables
- Meta data (train type, location, timestamp, etc.)

Regarding the visibility of the defects, the following categories should be considered:

- The resolution of the images should be high enough to be able to zoom in on smaller defects;
- The lighting of the images should be set up to also allow for monitoring during the night; The camera angle(s) should cover all relevant parts of the pantograph where defects may occur (e.g., a front/side view angle of the pantograph is required for monitoring the thickness of the carbon bar);
- Climatic influences such as fog, rain or snow, as well as heat.

We expect to drastically reduce the number of hooks on the catenary, which would allow us to improve punctuality and the cost of corrective maintenance of the infrastructure.

6.15.2. UC7.2: Demonstrator's KPI

6.15.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect

Table 35: UC7.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
7.2-1	Pantograph defects	NA
7.2-2	Accuracy	NA

Table 36: UC7.2 PIs

6.15.2.2. PI7.2-1 – Pantograph defects

Short description.
Catenary pantograph hook-ups have a very high cost to any IM and it is not only a tangible economic issue, but also an intangible one, such as the loss of confidence of travellers due to a delay in the means of transport. That is why it is necessary to work in teams that allow anomalies to be detected in the pantographs at the entrance to the workshop. Anticipating these failures will significantly contribute to a more economical (as infrastructure maintenance costs will fall) and more reliable transport, as there will be no annoying and unpredictable hitches.

How to compute PI7.2-1
This PI7.2-1 is related to KPI ID 62 Maintenance expenditures in relation to the network size.

$$PI_{7.2-1} = \frac{N° \ of \ pantograph \ defects}{N° \ of \ total \ pictures \ per \ month}$$

6.15.2.3. PI7.2-2 – Accuracy

Short description

Pantograph components fault detection is, in principle, a binary classification problem. Accuracy is a metric for evaluating classification models.

How to compute PI7.2-2

For a binary classification, accuracy can be calculated using the following formula.

$$PI_{7.2-2}Accuracy = \frac{(TP + TN)}{(TP + TN + FP + FN)}$$

Where:

- TP = True Positive
- TN = True Negative
- FP = False Positive
- FN = False Negative

6.16. UC7.3: General physical anomaly detection Monitoring System (wayside – Video and 2D-3D images)

The use case encompasses development, monitoring, data collection and analysis. It involves the development of different technologies installed on wayside infrastructure to monitor physical anomalies. It also includes determining and recording relevant data required for general physical anomalies monitoring. Furthermore, it involves analysing this data to determine whether rolling stock has exceeded gauges or whether there has been an absence of train components.
Thanks to technologies such as 2D-3D imaging, scanning or video recording, continuous diagnostics on train elements such as bogie components, fairings elements, stoppers clearance or antenna condition, for example, can automatically determine a status diagnosis in real time, and provide the maintenance team a CBM action to consider.

Defined diagnosis will be able to detect any anomalies in underframe elements such as:

- Brake system: measurement of pad wear or detection of any loosened brake discs bolt.
- Bogie components: detection of any out-of-gauge or loosen bogie damper; out-of-parallel antennas or measurement of stoppers.
- Lateral/underframe fairings: detection of any loose or out-of-gauge fairings.

This use case spans Tasks 7.2 “Wayside Inspection Technology including Railway Checkpoints” and 7.3 “Design & Deployment strategy for Railway Checkpoint and other Demonstrators”.

6.16.1. Overall aim of the Use case

6.16.1.1. Problem to be solved

One of the ways to improve the safety of rolling stock, as well as its availability and reliability, is through automated inspection based on automatic monitoring equipment. This equipment works 24 hours a day without failure and, more importantly, if connected to machine learning, it continuously learns to anticipate the detection of faults and failures.
With this approach, we can initially generate an extensive database, enabling us to develop algorithms that not only detect failures but also predict when maintenance will be required for the rolling stock. For instance, in the case of fairings measurement, its measurement will be automatic, and with the historical data and circulation forecasts, it can be accurately determined the next appropriate time for lathe maintenance or wheel replacement with a considerable level of precision.

At the same time, a significant reduction in PVM costs is expected, since the maintenance bands will be adjusted when necessary and will not be on a per-kilometre basis, as has been the case until now

One of the ways to improve the safety of rolling stock, as well as its availability and reliability, is through automated inspection based on automatic monitoring equipment. The systems operate 24 hours a day without failure and, more importantly, when connected to machine learning, they constantly learn to anticipate the detection of malfunctions and defects.

With this approach, we can initially generate a comprehensive database, allowing us to develop algorithms that not only detect failures, but also predict when maintenance is needed for rolling stock. In the case of carbon strip measurement, for example, the measurement will be automatic, and with the historical data and circulation predictions, the next appropriate time for maintenance can be accurately determined with a considerable degree of precision.

At the same time, a significant reduction in the cost of PVM is expected, as maintenance bandwidths will be adjusted as needed and not performed based on miles travelled, as has been the case to date.

The current use case development level corresponds in the case of the TALGO or CAF solutions to each prototype development stage.

Train maintenance inspections for the detection of general physical anomalies, for example rolling stock exceeded gauges, are critical to avoid service disruptions or infrastructure damages.
Currently, train maintenance inspections are performed manually and periodically. Within FP3-IAM4Rail it will be possible to monitor the health of the assets without stopping the train (so more availability and over maintenance reduction).

6.16.1.2. Industry current position / baseline

Control points on the track are devices that have been implemented in the railway infrastructure for many years, from equipment that detects hot boxes or hot brakes to pantograph height or falling objects, among others. However, the latest advances in sensorisation and the standardization of these devices have made it possible, on the one hand, to increase the number of devices installed on tracks, and on the other hand to increase the parameters that they are capable of recording. An example of this is automatic measurement equipment for wheel parameters, and although in the past there have been some manufacturers that have had automatic measurement equipment, their price was so high that their acquisition was not viable. The combination of advances regarding data sharing, cloud storage together with AI allow us to optimise data management and, more importantly, decision making about maintenance actions.

Currently all inspection works in rolling stock maintenance tasks are done manually by one person, and with tools that have not changed for decades. If this individual is mistaken or performs the job incorrectly, there are no means of verification available. Therefore, one way to improve the safety of rolling stock for the IM and digitise these processes is through automated inspection solutions. By storing this information in the cloud and using an algorithm, decisions about what to do with this train can be made; for example, it will be possible to determine whether to take the train out of the service and send it to re-profiling or change the carbon band.

Currently there are many tasks to maintain a good health in these systems. However, sometimes, with current methodologies, it is easy perform excessive (and therefore more costly) and is hard to always ensure good condition for operation.

6.16.1.3. Subproblem addressed by the use case and measurable objectives

The measurable objectives will be obtained by:

- Video, 3D and 2D *images.*
- Data analysis.

The measurable objectives will be taking information from:

- Pantograph status
- Fairings anomalies
- Wheels status
- Brake monitoring

6.16.1.4. Influence of the proposed innovation on the IM/RU problem

If we want to increase the traffic of rolling stock on the tracks and, at the same time, maintain high safety standards, it is necessary to automate certain inspection tasks in order to continue having competitive rail transport as well as safety. Both the IM and the RU are interested in this project, although with different visions. The RU´s main motivation is to reduce maintenance costs; however, the IM seeks to maintain or improve the safety of the rolling stock that circulates on its

rail network.

Because the criticality of these assets and the ongoing development of the systems, we will be able to monitor their health without requiring train stops. As a result, we can expect increased availability and reduced maintenance requirements.

IM will be safer because this system monitors train performance and avoids any failure as they can be anticipated.

6.16.2. UC7.3: Demonstrator's KPI

6.16.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect

Table 37: UC7.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
7.3-1	Effort spent in visual inspections	NA
7.3-2	Anomalies detected with new technologies	NA

Table 38: UC7.3 PIs

The use case consists of developing monitoring systems, the monitoring itself, data collection and data analysis. Also, it is important to develop various technologies to be installed along the track to monitor physical anomalies. Another objective of this use case is to determine and capture

relevant data needed for general physical anomaly monitoring and analyse this data to determine, for example, violations of standards within bogies and pantographs of rolling stock.

6.16.2.2. PI7.3-1 – Effort spent in visual inspections

Short description

Not entirely convertible to clean time but when the total system is in place:

- Time per inspection = 20 minutes, once per 48 hours is 15 x per month.
- Walking time to train is approximately 5 minutes.
- For 512 units, that's 512 x 15/month x (20+5 min) = 3200 hours.
- Estimated time inspection by operator on a screen 10 minutes.
- For 512 units, that's 512 x 15/month x 10 min = 1280 hours.

How to compute PI7.3-1

$$PI_{7.3-1} = \Sigma \text{ hours for visual inspection in a month (or \% shorter inspect time)}$$

6.16.2.3. PI7.3-2 – Anomalies detected with new technologies

Short description.

The number of anomalies to be detected will be higher than in the case of physical controls, also because initially a learning system will be critically adjusted to reduce the number of false negatives. We ultimately expect 0.5% of the number of controls to show an anomaly.

How to compute PI7.3-2

$$PI_{7.3-2} = \Sigma \text{ detected defects via new inspection techniques}$$

6.17. UC7.4: Data path diagram use case

Development of a generic, applicable safety certification for CBM data path.

This use case spans Tasks 7.4 “Use of data analytics with data from mounted sensing for rolling stock and wayside equipment” and 7.4.1 “Data path diagram”.

6.17.1. Overall aim of the use case

6.17.1.1. Problem to be solved

Due to the new type of maintenance strategy CBM, ECM2 functions face challenges in adapting their maintenance regimes. The standards regarding safety (DIN EN 50126) and the adaptation of the maintenance rules (DIN EN 17023) do not reflect the CBM topic in detail. Due to the level of innovation and the lack of available experience there is no generic standard for the creation of a

safety certification within the CBM maintenance process, therefore a quick implementation of CBM use cases is not possible.

6.17.1.2. Industry current position / baseline

Basis: Development of a CBM End to End System (S2R).

6.17.1.3. Subproblem addressed by the use case and measurable objectives

Not applicable.

6.17.1.4. Influence of the proposed innovation on the IM/RU problem

By using the generic safety case methodology via CBM data paths (guideline), it is easier for users to transfer the requirements from the standards to the specific CBM conditions. This will allow IM/RU to save time in preparing the safety case and adapting the rules and regulations maintenance for further use cases. In addition, possible risks due to standards and guidelines (e.g., a specific security requirement) are transparently highlighted at an early stage, thus preventing a showstopper in the use case development. Furthermore, a faster implementation of safety-relevant topics within the use case development can lead to more acceptance for CBM within the organisation (no time-consuming processes).

6.17.2. UC7.4: Demonstrator's KPI

6.17.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect

Table 39: UC7.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
7.4-1	Reduction of the timespan	NA

Table 40: UC7.4 PIs

6.17.2.2. PI7.4-1 – Reduction of the timespan

Short description

Reduction of the timespan for the implementation of safety relevant CBM use cases into the productive maintenance environment.

How to compute PI7.4-1

$$PI_{7.4-1}\ \Delta\text{ts} = ts_0 - ts_1$$

Where:

- ts_0 is the timespan from the beginning of handling the safety requirements for the software components of the CBM DataPath until the finalisation of the safety certification report ("Sicherheitsnachweis") – without making use of the generic safety case methodology.
- ts_1 is the timespan from the beginning of handling the safety requirements for the software components of the CBM DataPath until the finalisation of the safety certification report ("Sicherheitsnachweis") – whilst making use of the generic safety case methodology.
- $[\text{Delta}]\text{ts} = ts_0 - ts_1$ is the time saved from the beginning of handling the safety requirements for the software components of the CBM DataPath until the finalisation of the safety certification report.

The formula for measuring the savings in the CBM data path is only a theoretical approach. In reality, only one of the two variants will be used, with or without the procedure.

6.18. UC7.5: CBM algorithms for freight

The results of this use case will be demonstrated potentially in the second call for projects, even though the activities take place in WP7 of FP3-IAM4Rail. CEIT and FT are the partners who participate in this use case.

In this use case the CBM algorithms for anomalies detection in freight, which will be developed in ST7.4.2, will be assessed. The ST7.4.2 takes place between M6 and M42. The CBM algorithms will be focused on wheel flats. Wheel flat is increasing maintenance costs from infrastructure to rolling stocks. It can damage wear and tear on rails, sleepers and other tracks components, as well as damage the wheel itself, bearings, axles and suspension systems. In term of energy flat wheel will increase traction energy and also cost of operation. That's why the focus will be on flat wheels and

axle generators.

In case of CEIT, synthetic signals will be used in order to work under a controlled environment (multibody simulation environment). The CBM algorithms for freight are actually under development. It is expected that the input parameters for the CBM algorithms will be the vehicle accelerations. Since the detection of algorithms are actually under development, at this stage it's not possible to set where the acceleration measuring points will be located (if at the axle box, the bogie or the platform). It will depend on the final version of the detection algorithms.

For the development of CBM algorithms for freight, a complete vehicle multibody model of freight wagon with Y25 bogie has been developed by CEIT using the Simpack software.

For evaluating the performance of the CBM algorithms for freight within UC7.9, the idea is to simulate different geometries of wheel flats in the different scenarios, varying running conditions (running speed, vehicle load, track irregularities). It is expected to consider up to 3 running speeds, two load conditions and two levels of track irregularities based on ERRI B176. The vehicle accelerations will be obtained by means of time integrations.

The following figure shows an overview of the freight vehicle model developed by CEIT and an example of the expected axle box vertical acceleration when a wheel flat is simulated.

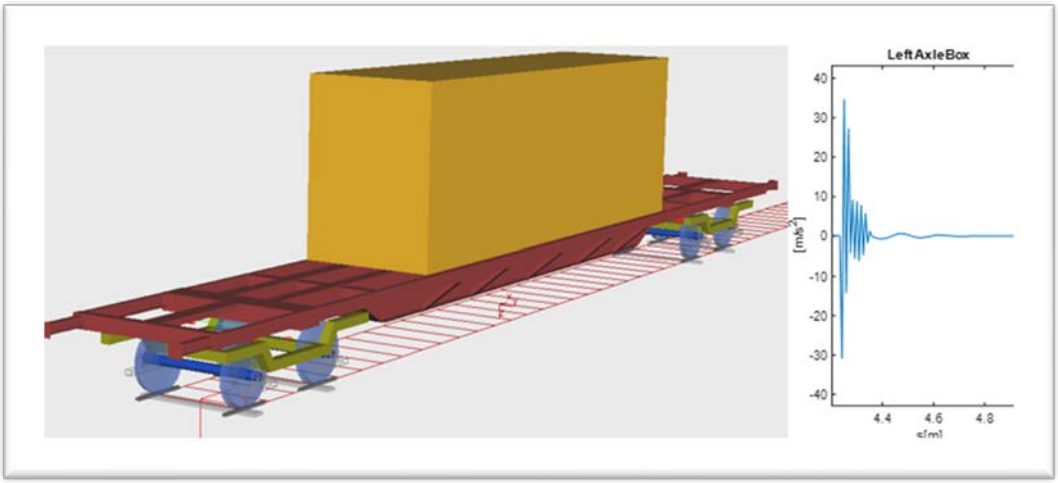

Figure 12: Freight vehicle model developed by CEIT

Then, FT will monitor the axle generator from 1 to 4 on the freight wagon of the existing fleet. The architecture is designed to pre-elaborate data by edge-computing before communicating data to the cloud for the CBM algorithm treatment and optimization. Axle generators will provide energy for the wheels.

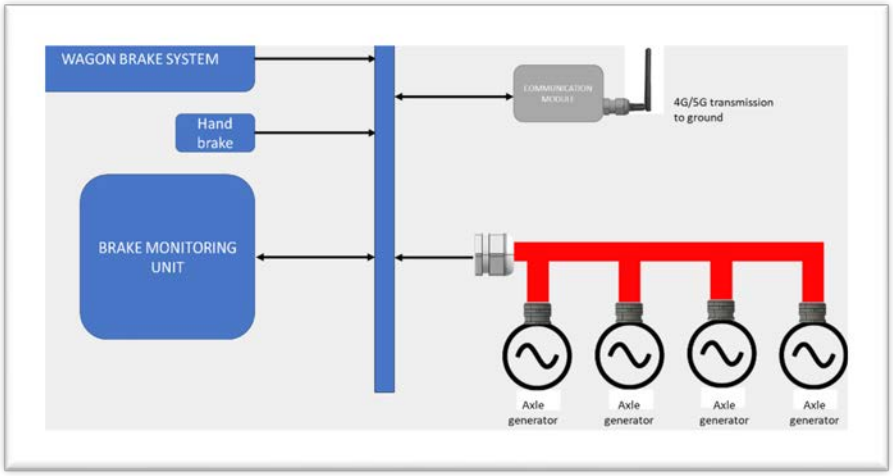

Figure 13: FT onboard system architecture for axles monitoring

This use case spans Tasks 7.4 “Use of data analytics with data from mounted sensing for rolling stock and wayside equipment” and 7.4.2 “CBM algorithms and methodologies for freight”.

6.18.1. Overall aim of the use case

6.18.1.1. Problem to be solved

Railway Undertakings face challenges in preventing failures in the running gear of freight wagons. While condition-based maintenance solutions offer the potential to improve maintenance practices, they can be costly to implement and may not always detect anomalies at an early stage. Therefore, there is a need for continued research and development to enhance the effectiveness, simplicity and cost of these solutions, and ensure the safe and efficient operation of freight rail networks.

6.18.1.2. Industry current position / baseline

Traditional maintenance practices often rely on fixed inspection schedules or mileage-based maintenance, which may not consider the actual condition and usage patterns of the wagons. This approach can result in either excessive maintenance, leading to unnecessary costs, or insufficient maintenance, increasing the risk of failures and associated safety hazards.

Condition-based maintenance solutions aim to address these challenges by using real-time data and advanced analytics to monitor the condition of the running gear. These solutions typically involve installing sensors on critical components of the wagons to collect data on factors such as vibrations, temperatures and wear patterns. By analysing this data, maintenance teams can identify potential anomalies or signs of wear and initiate maintenance actions proactively.

However, there are some limitations and challenges associated with condition-based maintenance solutions. Firstly, implementing these solutions across an entire fleet of freight wagons can be

costly and difficult to deploy. It requires significant investments in sensor technology, data collection systems and data analysis infrastructure. Additionally, there may be challenges in integrating the sensor systems with the existing fleet and ensuring data connectivity and compatibility.

Even though some research and innovation has taken place in the arena of preventing failures in the running gear of freight wagons, and a few products have become commercially available, the adoption of these strategies by the industry is not occurring at a desirable rate. This slow adoption can be attributed to the industry's reluctance to change.
Moreover, condition-based maintenance solutions may still fall short in detecting anomalies at an early stage. By the time the sensors or analytics detect a problem, it may have already evolved to a more critical stage, increasing the risk of failure. This delayed detection can be attributed to various factors, such as the limitations of the sensor technology, the complexity of analysing vast amounts of data in real-time and the dynamic nature of the operating conditions of freight wagons.

6.18.1.3. Subproblem addressed by the use case and measurable objectives

Running gear anomaly detection using simple and low-cost sensors. The algorithms will be developed using synthetic data generated by simulation using state-of-the-art software tools that represent the relevant environment (TRL6) in which the systems will operate (TRL7). This way, a better control for generating faulty scenarios and labelling data will enable better detection and diagnostic capabilities.

The objectives for this use case are:

- To develop a model that assesses the interaction between a railway (freight) vehicle and the track.
- To model faulty conditions and scenarios (in both the vehicle and infrastructure) that represent the defects/anomalies that will be assessed by the algorithms.
- To generate a set of (labelled) synthetic data for the relevant set of faulty conditions and scenarios.
- To develop anomaly/defect detection/diagnosis algorithms for different elements of the running gear of railway (freight) vehicles. An example of potentially target defects/anomalies is wheel flats.
- To assess the validation of the algorithms, benchmarking their results against the characteristics of the (faulty) conditions and scenarios initially generated.
- Pave the way for the future validation of the algorithms in FA5 (TRL7).

6.18.1.4. Influence of the proposed innovation on the IM/RU problem

The innovation proposed by the use case will contribute to improve the operation of (freight) Railway Undertakings, impacting in the following (high-level) PRIME KPIs:

- Improve freight trains punctuality (KPI #29) by reducing down-times due to failures in the running gear.

- Improve the average delay minutes per asset failure (KPI #35) by reducing the number of failures in the running gear.
- Reduce maintenance costs by improving the Life Cycle Cost of the running gear.
- Improve safety of operations with healthier running gear.
- Reduce track access charges due to the reduction of the damage caused on the track.

Additionally, the Infrastructure Managers community will benefit from the innovation, as "healthier" running gear circulating on tracks will have a less negative impact in the degradation of the infrastructure. This way, the innovation will impact also in the following (high-level) PRIME KPIs:

- Reduce track failures (in relation to network size – KPI #55) due to the (lower) damage that healthy running gear causes on the track.
- Reduce track-related costs (KPIs #60 to #125), as a consequence of the above.

6.18.2. UC7.5: Demonstrator's KPI

6.18.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #2: Asset Management & Rolling Stock and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO2 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	High/direct
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect

Table 41: UC7.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
7.5-1	Detection of anomalies	NA
7.5-2	Diagnosis of anomalies	NA

Table 42: UC7.5 PIs

6.18.2.2. PI7.5-1 – Detection of anomalies

Short description

Sensitivity of the anomaly detection algorithms, i.e. the number of anomalies detected by the algorithms with regards to a ground-truth (synthetic) dataset. An example of potentially target defects/anomalies is wheel flat.

How to compute PI7.5-1

$$PI_{7.5-1} = \frac{N° \ of \ anomalies \ detected \ by \ algorithms \ and \ confirmed \ in \ ground \ truth \ data}{N° \ of \ anomalies \ in \ ground \ truth \ data} \times 100$$

6.18.2.3. PI7.5-2 – Diagnosis of anomalies

Short description

Sensitivity of the anomaly diagnosis algorithms, i.e. the number of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to a ground-truth (synthetic) dataset. An example of potentially target defects/anomalies is wheel flats.

How to compute PI7.5-2

$$PI_{7.5-2} = \frac{N° \ of \ anomalies \ diagnosed \ by \ algorithms \ and \ confirmed \ in \ ground \ truth \ data}{N° \ of \ anomalies \ in \ ground \ truth \ data} \times 100$$

7. Cluster D - Infrastructure Asset Management.

The infrastructure asset management cluster addresses (i) long-term maintenance and costs (WP8), (ii) track systems (WP9), (iii) innovative multi-purpose IAMS infrastructure applications (WP10 and WP11), and (iv) civil assets, including structures, earthworks and geotechnics (WP12 and WP13). Relevant use cases are listed in Table 43.

UC ID	Title	Relevant WP/DO
8.1	Long term asset management and LCC	WP8/DO3
8.2	Holistic long term asset management	WP8/DO3
9.1	Sensing railway superstructure system components	WP9/DO4
9.2	Railway infrastructure monitoring using fibre optics	WP9/DO4
9.3	Track geometry and S&C condition monitoring	WP9/DO4
9.4	Prescriptive maintenance for railway infrastructure	WP9/DO4
11.1	Linking (new) monitoring technologies to asset management issues	WP11/DO4
11.2	Fusion of (on-board and wayside) monitoring data for an enhanced fault detection and diagnosis	WP11/DO4
12.1	Multiscale monitoring of civil assets	WP12/DO4
12.2	Bridges and earthworks assets management aided by geotechnics	WP12/DO4
12.3	Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	WP12/DO4
12.4	Data Analysis for condition monitoring	WP12/DO4

Table 43: Cluster D use cases

7.1. UC8.1: Long term asset management and LCC

This use case will contribute to strengthening existing tools for the long-term management of railway bridges by increasing prediction accuracy stemming from modelling uncertainty. Moreover, other data sources will be evaluated to identify available sources of information that can enhance the performance of today's methods for estimating remaining service life.
The remaining service life of bridges plays an important role in making safety-critical decisions regarding operations and maintenance. Today, these decisions are based on conservative estimates of safety factors and scheduled maintenance guidelines. These result in an estimate of life and maintenance intervals that are insensitive to the actual condition of the bridge, thereby increasing safety risk and maintenance costs. By instrumenting the bridge with appropriate sensors, the sensory information can be utilised to correct the model-based estimates recursively and improve accuracy. Besides using new data-driven techniques, the sensory information, in combination with several other data sources, can be investigated to develop computationally efficient techniques to rapidly assess the remaining service life.
These developments, the high-accuracy models with reduced uncertainty as well as data-driven

techniques, will provide the operation & maintenance personnel with an accurate assessment of the infrastructure health and assist in reliable data-driven decision-making.
The developed tools will provide decision support towards the choice of minor maintenance, major maintenance, or reinvestment in the infrastructure to ensure that the primary functions are fulfilled. The use case is developed in WP8 task 8.2 “Remaining useful-life analysis”.

7.1.1. Overall aim of the use case

7.1.1.1. Problem to be solved

Many Norwegian railway bridges are near or over the end of their useful life. The remaining service life of existing railway bridges must be determined to ensure the future safe and reliable operation of the bridges and allow efficient distribution of limited funds for maintenance and renewal of the railway infrastructure.

7.1.1.2. Industry current position / baseline

Railway bridge maintenance and renewal decisions are based on the one hand, on regular inspections to understand the current state and, on the other hand, on the use of historical data and statistical models to forecast degradation and, thus, useful life.
Numerical models are essential in railway asset management due to the vast number of components in each individual bridge and the number of bridges in the railway network that need service life assessment. The models are used to represent the loading and damage mechanism and to predict the response in the structure.
A lot of work has been performed on the modelling uncertainty of the two first aspects, but modelling uncertainty related to structural modelling has largely been neglected in the literature despite its large influence on lifetime estimate. Uncertainty quantification theory and methodology are widely available and applicable to the present problem in useful life estimation of railway bridges.

7.1.1.3. Subproblem addressed by the use case and measurable objectives

The objective is to improve the remaining service life estimation of civil structures, with a view to safely extending the asset life, thereby reducing renewal costs. This is achieved by the development of new techniques, methods and algorithms based on new cross-border data sources from existing multiple sensors (i.e., multi-sourced), which will fill the gaps where data capture does not currently exist and supplement existing data (i.e., big data). These combined and richer data will be used to analyse remaining service life estimations on a deterministic basis and to enhance the historical analysis. To acquire this new data, rather than relying on one organisation increasing sensor usage, the policy is to leverage multi-source and multi-organisation data capture. Core developments in this task include:

- Development and validation of decision support for long-term planning of renewal or investments and disposal of civil structures.

- Provision of measurements, parameters and data for structural health monitoring and input to the creation of models for predicting the remaining service life of civil structures.
- Model concept definition, validation of results and measurements by the asset managers. Techniques, methods, algorithms and creation of models provided by universities and research centres with a focus on turning raw data, first into meaningful measurements and then by analysis into results (e.g., estimations using probability-based methods).

7.1.1.4. Influence of the proposed innovation on the IM/RU problem

Lundamo Bridge is representative of Norwegian steel bridges, -where about 90% of these were built before the 1960s- and is under the responsibility of Bane NOR, the Norwegian national railway infrastructure owner. Furthermore, it will establish numerical procedures for determining and quantifying uncertainty in model-based evaluation of bridge service life and demonstrate the efficiency of data-driven methods in detecting damages and evaluating remaining service life. These outcomes contribute to the development and validation of decision support for long-term asset management of civil structures.
The model-based analysis will establish a procedure for building a numerical model of railway bridges, e.g. how to select connection stiffness, material constants and level of detail in modelling.
The goal is to obtain measurement data of different bridge components in traffic and data from model simulations of these bridges and verify data-driven models for health assessment using the measurements from the test facility at NTNU.
A comparison of data from measurements and simulations will be conducted to quantify uncertainty in models of railway bridges for service life estimation.
Furthermore, data-driven approaches for early degradation detection in structures will be developed using cross-border data measurements and from the test facility at NTNU with accelerometers and other advanced sensors, e.g., acoustic emission, to determine the efficacy of data-driven techniques for estimating remaining service life. The long-term goal is to develop an LCC-efficient methodology for bridge asset management with sufficient accuracy based on IoT and data-driven technologies.

These tasks will contribute towards:

1. Determining a data model suitable for cross-border evaluations that are necessary to perform asset management of steel bridges.
2. Minimal sensors and additional sensors (if any) that are required to provide accurate remaining service life predictions.
3. Quantify uncertainty in the model-based evaluations of the bridge life, thereby assisting maintenance personnel in making safe operation and maintenance decisions.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
Railway bridge maintenance LCC	NRD	Norway	Lundamo bridge

Table 44: Infrastructure asset management prototypes

7.1.2. UC8.1: Demonstrator's KPI

7.1.2.1. List of KPIs and related justification for the choice

The demonstrator, where the use case is placed, aims to provide strategies for long-term asset management with an accuracy improvement of 10%. The means of verification: statistical approach for the accuracy of tools in estimating remaining service life.
The final goal is to improve the accuracy of the estimated state of the infrastructure from measurements and assessment through some proposed methods. This is achieved by comparing the measured and estimated response to determine a suitable description of modelling uncertainty that can be utilised to correct the service life assessment. Further, in the use case, we aim to reduce the cost of ownership. The rationale is that the split between OPEX and CAPEX may not be so clear since accurate estimations might increase short-term maintenance costs but reduce long-term costs, increase maintenance costs but prolong service life before renewal and replacement, and so on. As for verification, we aim to estimate maintenance costs by comparing the case in which no technology is implemented (baseline) versus the scenario when the complete information provided by the implemented technologies is provided. The latter will be performed by measuring direct cost in combination with project savings.
The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #3: "Long Term Asset Management" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO3 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
V	Tools which provide at least three possible strategies of long-term management (with an accuracy -as defined by ISO- improvement of 10%)	High/direct
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect

Table 45: UC8.1 KPIs on an FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
8.1-1	Accuracy of estimated response to traffic loads based on the bridge modelling	NA
8.1-2	Overall cost of operation (OPEX and CAPEX)	NA

Table 46: UC8.1 PIs

Relation to FP3-IAM4RAIL's project KPIs

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP8	WHY
KPI V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy -as defined by ISO- improvement of 10%)	The KPI that mainly relates to the research in this use case relates to the adapted long-term management solution, and we aim for a fair comparison with the baseline.

Table 47: UC8.1 direct KPI impact

7.1.2.2. PI8.1-1 – Accuracy of estimated response to traffic loads based on the bridge modelling

Short description

The closeness between actual response in structure and response is estimated by a numerical model.

How to compute PI8.1-1

The PI will be computed by comparing measured and estimated responses to determine a suitable description of modelling uncertainty that can be used in service life assessment. The difference and/or ratio between the measured and estimated response is a direct measure of the accuracy of numerical models.

7.1.2.3. PI8.1-2 – Overall cost of operation (OPEX AND CAPEX)

Short description

Modelling uncertainty can be avoided completely in service life assessment by using measured response instead of estimated response by the model, i.e., by using data-based service life assessment.

Compared to the historical costs based on conventional service life assessments, a deviation in the total costs (CAPEX and OPEX) in maintenance, repairs, refurbishment and reinvestment is expected because of improved accuracy in estimating the remaining service life. The reduction in the overall costs will have a cascading effect on improving availability without compromising the bridge's core functions.

How to compute PI8.1-2

The PI will be computed by calculating the measured and projected CAPEX and OPEX costs related to maintenance, repair and renewal. For ease of comparison, the PI will be evaluated annually.

7.2. UC8.2: Holistic long-term asset management

The objective of this use case is to provide decision support for a more holistic long-term asset management.
The contribution to AM comes from three types of decision support (D1-D3), developed for the purpose of increasing asset dependability and reducing resource consumption:

- D1: Management of dynamic maintenance programs and resource-effective execution
- D2: Maintenance optimisation in a dynamic maintenance program
- D3: Dynamic maintenance programs in train plan

This use case contributes to supporting decision-making within AM of railway assets. This use case is an expected result from demonstrator #3.

The use case is developed in WP8 task 8.1 “Holistic Asset Management”, task 8.3 “Simulated train services for maintenance optimization” and task 8.4 “Digital Maintenance Planning System”.

7.2.1. Overall aim of the use case

7.2.1.1. Problem to be solved

Railway asset management can be conducted from different planning perspectives, e.g., operational (up to 2 years), tactical (2 - 5 years), and strategic (5 - 20 years). Infrastructure managers are, in many cases, lacking adequate decision support for tactical and strategic asset management planning. Maintenance programs and maintenance concepts are available for operational asset management. They are, however, often static (almost unchangeable) and difficult to coordinate with other planning perspectives. Another challenge facing IM managers is planning and executing operations simultaneously with multiple AM plans. The main objective of railway AM is to provide the required dependability from the assets while consuming a minimum of resources. Increased integration between AM planning perspectives and traffic operations is required in order to facilitate required dependability with optimised utilisation of resources.

7.2.1.2. Industry current position/baseline

An objective of railway AM is to maintain the required level of dependability from infrastructure assets with a minimum use of resources. The value of proposed decision supports is determined by the improvement of dependability and resource utilisation. The baseline for the study stems from available data and information at respective IM.

7.2.1.3. Subproblem addressed by the use case and measurable objectives

Demonstrator provides three types of decision support:

D1 Management of dynamic maintenance programs and resource-effective execution

Optimising the utilisation of resources requires decision support tools that today lack holistic analysis of information (correlation of multiple CBM sources and correlation of maintenance activities with asset conditions) together with the integration of holistic CBM and analytics with the three AM planning (operational, tactical and strategic) to support the decision process.
The development of decision support for the management of dynamic maintenance programs and resource-effective execution within the maintenance concept will provide:

- IAMS Holistic condition monitoring and decision support for management of dynamic maintenance programs and resource effective execution based on a holistic view with different assets involved (i.e., geographical correlation, time correlation), assets providing diagnostic (or context) about other assets, exo-data (weather) and predictions.

- Analytics rendering and visualisation of spatial-temporal data. Algorithms for translating various localisation coding to and from a pivot representation, with uncertainty of measurement. Algorithms for matching positions to an infrastructure and reconstructing a trajectory on the network (or the network itself). Matching algorithms between routes, routes and areas and tool for visualisation/HMI.

D2 Maintenance optimisation in a dynamic maintenance program

On the Iron Ore line, there is a need for improvement in the maintenance concept in terms of better coordination between traffic operation, reinvestment activities and maintenance planning. Maintenance programmes must become more flexible to facilitate a more rational maintenance concept.
Track and S&Cs are linear assets. They age differently, are installed on different occasions and experience varying loads, which causes them to degrade differently throughout the network. The fixed maintenance plans and schedules often do not consider this variation of degradation across the network. Hence, there is a need for a more dynamic maintenance program.
An objective is to develop a system that describes RAMS parameters for the track as functions of assets' status, components and traffic, hence serving as decision support for maintenance optimisation in a dynamic maintenance program.
Because of the uncertainties involved in the degradation of distributed assets, discrepancies between data gathered from CMMS (Computerised Maintenance Management Systems), and modelling & simulation, this use case aims to demonstrate TRL6 (technology demonstrated in relevant environment) as compared to TRL8 (system complete and qualified).

D3 Dynamic maintenance programs in the train plan

Most asset maintenance measures significantly reduce the capacity of a railway line, which is why these measures in railway operations must be planned for the long term and across borders. To achieve this goal, there is a great need to improve communication between all actors involved. Maintenance activities must be considered in the timetable as part of the network capacity

planning process. Therefore, the definitions of maintenance activities are to be captured in a digital format with high accuracy. This concerns all planning phases, from strategic/long-term and tactical planning and capacity management to real-time support of the TMS.
The objective is to set up and demonstrate a system (DMPS) for maintenance planning on a cross-border line, allowing the registration and planning of maintenance activities based on a microscopic infrastructure data model for all process phases. The planned maintenance activities are to be transferred to the network capacity planning system for consideration as Temporary Capacity Restrictions (TCR) with respect to the required train regulations to address the impact of these activities.

7.2.1.4. Influence of the proposed innovation on the IM/RU problem

Successful decision support applications contribute to value creation, allowing for the possibility of achieving the same level of dependability with fewer resources utilised (if desired) or even greater dependability. Such development contributes to the fulfilment of infrastructure managers' main objective, as well as sustainability objectives; it also strengthens the railway's market position versus other modes of transportation.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
Train services for maintenance optimisation	TRV	Sweden	Virtual

Table 48: Holistic long term asset management prototypes

7.2.2. UC8.2: Demonstrator's KPI

7.2.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #3: "Long Term Asset Management" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO3 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy -as defined by ISO- improvement of 10%)	High/direct
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect

Table 49: UC8.2 KPIs on an FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
8.2-1	Availability	NA
8.2-2	Total maintenance cost (resources used)	NA

Table 50: UC8.2 PIs

Relation to FP3-IAM4RAIL's project KPIs

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP8	WHY
KPI V	Tools which provide at least 3 possible strategies of long-term management (with an accuracy -as defined by ISO- improvement of 10%)	The KPI that mainly relates to the research in this use case relates to the adapted long-term management solution, and we aim for a fair comparison with the baseline

Table 51: UC8.2 direct KPI impact

7.2.2.2. PI8.2-1 – Availability

Short description

Availability is the ability to provide train slots according to timetable. As this PI does not exist yet, the baseline is not available. For this reason, this PI provides a new approach for calculating availability.

How to compute PI8.2-1

The availability is calculated by:

$$PI_{8.2-1}(Availability) = \frac{MUT}{MUT + MDT}$$

Where:

- MUT is the mean uptime
- MDT is the mean downtime

7.2.2.3. PI8.2-2 – Total maintenance cost (resources used)

Short description

Change in total maintenance cost before and after implementing the optimised schedule suggested by the application.

How to compute PI8.2-2

PI8.2-2 is calculated as a percentage change in the total maintenance cost before and after the implementation of an optimised schedule. The initial maintenance cost is derived from the infrastructure manager's available data. Calculation of costs after implementation is based on simulation of the effect of the optimised schedule on cost.

7.3. UC9.1: Sensing railway superstructure system components

This UC provides sensing solutions for track superstructure at the component level. We have three components being analysed: sleeper, ballast and catenary system. The following activities are described as subprojects from the use case on components.

Intelligent sleeper: a new concept of intelligent sleeper, using reinforced graphene as an additive in concrete, is assessed. The sleeper includes harvesting energy capabilities with multi-sensor data recording and processing (temperature, flood detections, loading conditions or vibrations), including communication modules and effective tools for automatically assessing its conditions and decision-making. The main contribution of this innovation is the resolution of key technical challenges. Across the board, cost reduction is also achieved, as the product is stronger and more durable, minimising the need for maintenance. In addition, implementing full instrumentation with sensors allows real-time monitoring of the railway asset, facilitating more accurate and efficient maintenance. Maintenance prediction can be improved by using smart sleepers to predict failure and/or the need for replacement before performance and replacement thresholds are reached or exceeded. Smart sleeper information will benefit maintenance practices by focusing more on predictive maintenance and contingency actions. This provides a reduction in maintenance costs. It is part of the task evaluation of the actual cost reduction, which highly depends on the percentage of graphene, among other factors.

On-board LIDARs for Ballast: LIDAR sensing is studied to estimate ballast profiles and volume to allow decision support using visual conformity evaluation. Cloud point data from LIDAR is to be integrated into existing track maintenance tools. There is currently no database of ballast assets in track, both in terms of profile and quantity. The challenges consist of quantifying the volume of ballast volume and qualifying the type of profile on the track at 80km/h, as well as comparing with ballast profile standards for each track section of the network. Both data acquisition and asset identification and matching with large-scale databases are challenges.

Interface BIM and Design model for the contact line: research on the interface between BIM models and design applications for contact lines is conducted. Different modelling approaches are examined, and the resulting implications for the design of objects and attributes and their relationships form the basis for a flexible interface for translating between different models.

The partners involved in this use case, which comprises the activities about component analysis in Task 9.1 "Sensing solutions for superstructure smart assets", have not reported synergies/risk of duplication of work.

The use case is developed in WP9 subtask 9.1.1 “Intelligent sleeper”, subtask 9.1.2 “Onboard monitoring LIDARs for Ballast” and subtasks 9.1.3 “Interface between BIM and Design models for Contact line system”.

7.3.1. Overall aim of the use case

7.3.1.1. Problem to be solved

This use case aims to pave the way toward smart/intelligent assets at the component level by focusing on sensing requirements. Part of the research involves capturing the essential characteristics of each component analysed (sleeper, ballast and contact line); however, incorporating innovation at component levels into asset management solutions encounters some common challenges. For instance, the data fusion with information about the asset from different measurement devices and sources. Various types of interfaces exist, such as those between different components and those connecting different systems, ranging from the data acquisition system to the higher level of feature analysis for extracting key information used in the maintenance plans. In the future, this will enable additional information from these assets to trigger a better-tailored maintenance scheme and facilitate data updates between the physical system and virtual twins of each component.

Intelligent sleeper: railway sleepers are a construction element whose primary function is maintaining the track gauge and uniformly transmitting the loads from the rail to the ballast. They also provide transverse stability to the track through their friction with the ballast. To build one kilometre of the railway line, it is necessary to install 1,666 sleepers (approximately one sleeper every 60 cm). This estimation shows the enormous number of sleepers used to construct lines.
Concrete sleepers are the most used option in ADIF, especially in high-speed lines, due to their good durability, a useful life of more than 30 years and a good resistance. Concrete is a material capable of withstanding large loads. It provides stability and greater adaptability in fixings, among other advantages. However, cement is considered one of the most polluting elements within construction materials, given that its production consumes high energy levels and emits greenhouse gases. Also, these concrete sleepers do not incorporate any monitoring to be able to carry out better planning of maintenance works, help in decision-making or improve traffic safety.
Therefore, developing new sleepers with better and more sustainable material properties seems important. Additionally, the goal is to develop an intelligent sleeper that can measure and monitor critical parameters from any location and detect critical changes in time. The measurement technology can be used for monitoring purposes. Multi-sensors for data recording and processing (temperature, flood detection, track settlements, landslides, loading conditions or vibrations) and effective automatic condition assessment and decision-making tools will be developed.

On-board LIDARs for Ballast: ballasted tracks are common in various railway networks, and new methods to effectively plan the replacement of ballast are needed in the industry. The latest technology for onboard LIDAR measurements makes the estimation of key parameters of the ballast layer, such as profiles and volumes, possible. Still, the technology must be validated and embedded into existing maintenance management tools. To evaluate how the estimation of

volumes is possibly track-dependent, validation campaigns with different structures are to be considered.

Interface BIM and Design model for the contact line: an appropriate model of a complex real-world situation is a crucial first step for research, development and engineering. The considered models will vary accordingly as requirements vary vastly depending on the exact purpose of the model. Models usually consist of several objects resembling real-world entities, with attributes to describe them further. Furthermore, objects have relationships with other objects. Models will vary in their object granularity, object properties and, consequently, in the relationship definitions. An example of it is a catenary connected to a cantilever attached to a pole. All these objects are connected, but depending on the models, this scenario can yield different outcomes. One model might describe the catenary as a single object, whereas a different model might break it down into contact and messenger wires. The same goes for the cantilever: it might be described as a single object or arbitrarily being broken down into (groups of) tubes, arms, etc. Attributes, such as positions (in different coordinate systems), material and sizes, follow accordingly. Specific values, such as (relative) positions, coordinates and distances, may exist in one model but not in the other. Thus, translating data described in one model to another, for whatever purpose, is a complex task.

7.3.1.2. Industry current position / baseline

Intelligent sleeper: synthetic or plastic sleepers are now emerging as an alternative for these cases. These sleepers are made of recyclable and non-polluting materials. In addition to their greater environmental sustainability compared to those made of concrete or wood, their advantages include their longer service life (more than fifty years), versatility and elasticity, and greater insulation and atmospheric resistance.
The objective in this use case is to improve the current concrete sleepers by incorporating graphene and replacing part of the cement used in manufacturing the concrete of the sleepers. According to the bibliography consulted, the mechanical and electrical properties of the shaped concrete will be substantially improved. Also, the carbon footprint of graphene is lower than the footprint of cement. Therefore, a more sustainable and environmentally friendly material will be developed. Furthermore, this incorporation of graphene as an additive allows an improvement in the LCC, reducing cracks and degradation due to environmental conditions.
At the same time, the development of a full sensorisation, including temperature and humidity sensors, microphones and accelerometers, will help increase traffic safety, as it will allow the IM to identify possible defects and anticipate failures on the track. It would also increase efficiency in maintenance activities since identifying and predicting these defects in advance allows us to reduce maintenance times and plan maintenance activities optimally.
ADIF frames these tests within its innovation and sustainability strategy and joins similar initiatives carried out by railway administrators in other European countries, such as France, Switzerland or Germany.
As a baseline for comparison, the results obtained from the standard samples in the laboratory will be used, which will be compared with the results of the modified samples.

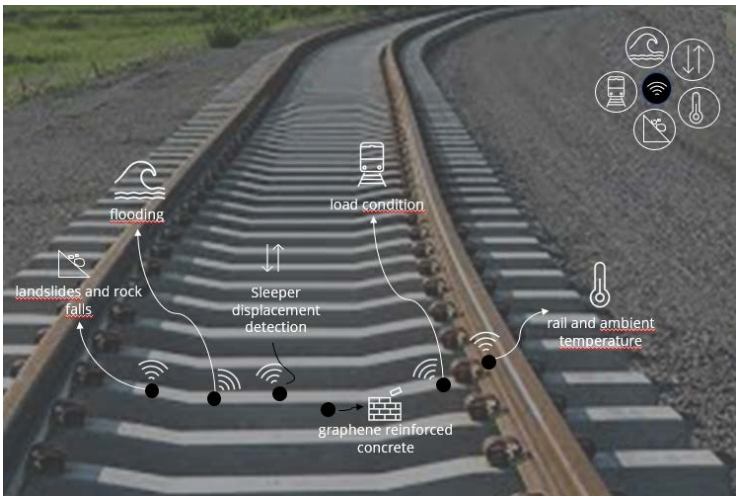

Figure 14: The concept of a smart sleeper is reinforced with graphene as an additive

On-board LIDARs for Ballast: track geometry recordings, GPR and other measurements are typically aimed at estimating the parameters of the ballast layer. Defining the complementarity of LIDARs concerning these traditional approaches is part of the task in this UC. Based on visual conformity evaluation, the on-board LIDAR sensing will estimate profiles and volumes. The estimation of such parameters is more challenging than that of traditional methods. Visual inspection and track recordings could be considered as part of the baseline.

Interface BIM and Design model for the contact line: for BIM purposes, many rail administrations and other organisations, such as design applications software vendors, have defined their own BIM model. Some of these models are based on more general standards, such as the IFC definitions, which allow extension via custom objects. Others incorporate the IFC 4.3 Rail, w.r.t. overhead lines, a very conservative approach. Consequently, the BIM model exchange for overhead contact lines is mainly reduced to exchanging 3D objects with very limited attributes. Importing such a model into a design application is impossible, as all the crucial semantic data is missing.
The exchange of a semantic model is only possible with high (manual) efforts. A project-specific solution is often implemented to quickly remedy this dilemma without further regard to core software development quality criteria, like modularity and reusability. As outlined before, it is unfeasible to create a one-size-fits-all model. With software vendors and other actors further refining their models or creating new task-specific models, there is a constant need to translate data to interoperate.

7.3.1.3. Subproblem addressed by the use case and measurable objectives

Intelligent sleeper: one of the main objectives of the project is to study the incorporation of graphene into the concrete that makes up railway sleepers to obtain a material with better strength, durability and conductivity properties while at the same time, being more sustainable from an environmental point of view. Nowadays, one of the main challenges in society is to achieve more sustainable infrastructures, and to this end, graphene is being introduced into concrete.

Replacing part of the cement in concrete with graphene makes the material more sustainable, as less cement, which is highly polluting, is used. Moreover, by incorporating sensor technologies in the sleepers, we are able, on the one hand, to obtain precise information on the current state of the infrastructure, which is of great value for railway traffic management. On the other hand, this sensorisation also contributes to more efficient maintenance. In short, incorporating graphene and sensors in railway sleepers allows us to obtain railway assets with improved, more sustainable properties and thanks to sensorisation, we can carry out higher-quality maintenance, which translates into a reduction in costs and service failures. The initial TRL is 5, and the expected final TRL is 8, which includes the expected implementation of the smart sleeper in the track, with the sensors installed and running. Developments regarding material testing will require additional research and analysis.

On-board LIDARs for Ballast: in this use case, one of the targets is to design estimation methods that convert cloud points from LIDAR into useful information about the ballast layer. We aim to develop estimation methods for ballast profiles and volumes. Then, based on visual conformity evaluation, the key parameters estimated are to be embedded into the decision support tools at SNCF. A major challenge is the further development of the technology and the analysis of its estimation in a wider variety of railway track structures, which might require a combination of track information and data.

Interface BIM and Design model for the contact line: one of the main objectives in this use case is to study the BIM models for overhead contact lines of two large European rail administrations, namely ADIF and Deutsche Bahn (DB), and to extract similarities and differences between these definitions. By combining these findings with the knowledge of other models, we can define a proper so-called “intermediate representation”, which will serve as the basis for translating data described in one model into another.

7.3.1.4. Influence of the proposed innovation on the IM/RU problem

Intelligent sleeper: the improvements achieved with the incorporation of graphene and sleeper sensing capabilities are as follows. Obtaining a material with better resistance, durability and conductivity properties will result in the development of railway assets that will result in significant economic savings in maintenance work. Also, as it is a material with greater resistance, it will reduce service failures. Creating a more environmentally sustainable material reduces the carbon footprint and generates a more environmentally friendly material. The updated knowledge about the rail traffic situation in real-time will help to make the operation of the railway infrastructure more efficient. Being informed of the condition of the railway sleepers will enable more efficient maintenance to be carried out, thereby reducing the number of failures in service.

To the best knowledge of the partners in Task 9.1.1, no reported results on the use of graphene in sleepers are available. However, various works and research have indicated better concrete behaviour when adding graphene. In this use case, the goal is to evaluate possible improvements in the strength and durability of concrete in the sleeper in a railway environment. As explained in the article "Graphene Reinforced Cement Composites: A Review", it has been reported in recent

years that graphene-reinforced cement composites exhibit exceptional mechanical properties, durability and multi-functionality due to the unique intrinsic properties of graphene (Lin, Y., & Du, H. 2020, Graphene Reinforced Cement Composites: A review. Construction and Building Materials, 265, 120312. https://doi.org/10.1016/j.conbuildmat.2020.120312).

In addition to an extensive experimental scientific bibliography, there are also graphene-based additives, which, as their website indicates, have developed 4th generation graphene-based additives for concretes and mortars, capable of improving mechanical performance, durability and thermal conductivity, allowing the design of more efficient and sustainable concretes and mortars (Smart Additives - Graphenano Smart Materials. (s. f.). Graphenano Smart Materials. https://www.graphenanosmartmaterials.com/en/smart-additives/). Based on the bibliography consulted and the first results obtained experimentally in the laboratory in this project, we consider that it is technically feasible to obtain products with better resistance and durability. Thus, in this use case, we aim to evaluate the performance of this innovation for railway sleepers.

On-board LIDARs for Ballast: the expected improvement is in integrating the estimated parameters of the ballast layer in the decision-making process for ballast replacements. Then, we expect to have better-informed decisions based on a more updated and accurate estimation of key parameters of the ballast for different track locations. We aim to generalise the measurement technique to make it available for a broader range of railway structure conditions.

Interface BIM and Design model for the contact line: we expect an improved understanding of different approaches to define BIM models for overhead contact lines. We aim to define a common method to translate from one BIM model to another and to design applications. Finally, higher reusability of implementations to translate BIM models from one to another and to design applications.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Industry current position / Baseline	Country use case	Use case location
Intelligent sleeper (Sleeper)	ADIF	Concrete sleepers are one of the most used and, therefore, most resource-consuming elements; currently, no parameters are measured or monitored. Laboratory tests will be carried out with normal and additive concrete to calculate the KPIs.	Spain	Test at Institute of Applied Magnetism (IMA), CEDEX.
Onbaord LiDARs for ballast	SNCF	Visual inspection is typically used to estimate the parameters of the ballast layer. This UC aims to estimate profiles and volumes.	France	Tests in France.
BIM and design model for the contact line	Siemens	The BIM model exchange for overhead contact lines is currently mostly reduced to the exchange of 3D objects. Importing those models into design applications is difficult since all crucial semantic data is missing.	Germany and Spain	The conversion between 2 BIM schemes (DB, Germany and ADIF, Spain) will be considered as the case study.

Table 52: Sensing railway superstructure system prototypes

7.3.2. UC9.1: Demonstrator's KPI

7.3.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
X	Time reduction (from design to manufacturing) (20%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 53: UC9.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
9.1-1	Reduction of the maintenance cost	10 %
9.1-2	Reduction of in-service failures	25 %

Table 54: UC9.1 PIs

Relation to FP3-IAM4RAIL's project KPIs

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	By incorporating graphene in the concrete of the sleeper and the complete sensing, we are obtaining a material of greater strength and durability, which means less maintenance work and, therefore, a reduction in maintenance costs. In the case of the estimation of ballast volume and the development of BIM for Catenary, the tools will enable systematic asset management. However, for the estimation of the wider impacts, particularly for Ballast Volume estimation, a prolonged duration is required and thus is not in the scope of FP3-IAM4RAIL.
XIV	Cost reductions of the interventions (by at least 10%)	

Table 55: UC9.1 direct KPI impact

7.3.2.2. PI9.1-1 – Reduction of the maintenance cost

Short description

The main objective of this PI is to check whether maintenance costs can be reduced:

- The incorporation of graphene in the composition of the sleepers, as we are achieving a more resistant and durable material, will lower maintenance costs.
- Incorporating a complete system of sensors in the sleepers allows us to know the state of the railway assets precisely and in real time. Therefore, more effective maintenance can be carried out, with the corresponding economic savings in maintenance work.
- Better models for the overhead contact line and better ballast sensing technologies will allow better-informed maintenance decisions. For instance, continuous monitoring might make early defect detection possible and provide sufficient time for planning and optimising maintenance operations.

How to compute PI9.1-1

In order to evaluate the maintenance cost savings of the Intelligent Sleeper, durability tests will be conducted in the laboratory.

These tests will compare the performance of the traditional sleeper with that of the graphene-enhanced sleeper, analysing its durability. It will evaluate how the material resists wear over time, which directly influences the frequency of maintenance required. If the material is more durable, the need for repairs will be reduced, resulting in long-term cost savings.

7.3.2.3. PI9.1-2 – Reduction of in-service failures

Short description

The main objective of this PI is to check if breakdowns can be reduced:

- The incorporation of graphene in the composition of the sleepers, as we are achieving a more resistant and durable material so that having a material with better properties will produce a better mechanical behaviour and, therefore, will have fewer breakdowns in its useful life.
- Incorporating a complete system of sensors in the sleepers allows us to know precisely and in real-time the state of the railway assets. Therefore, predictive maintenance can be carried out to solve faults before they occur.
- Continuous monitoring of ballast and state-of-the-art modelling approaches for the contact line can potentially reduce and monitor the severe defects in both components. Then, imminent breakdowns can be prevented by the adequate integration of interfaces.

How to compute PI9.1-2

In order to evaluate the reduction of in-service failures of the intelligent sleeper, mechanical tests will be conducted. These tests will compare the performance of the traditional sleeper with that of the graphene-enhanced sleeper, focusing on its mechanical strength. By using mechanical strength testing, the ability of the material to withstand loads and stresses during use is measured, which is directly related to the probability of operational failure.

7.4. UC9.2: Railway infrastructure monitoring using fibre optics

The technology for using distributed acoustic sensing (DAS) has shown interesting results in various application domains. In FP3-IAM4RAIL, the core of this use case is to demonstrate the application of distributed sensing based on fibre optics for monitoring railway superstructure components and events. New methodologies will be developed by tailoring state-of-the-art technologies and solutions for distributed sensing to the specific applications and their railway environments, such as train identification and intrusion detection.

Two main prototypes have been selected: rockfall detection and flat wheel detection. First, test sites adapted to the use cases must be identified and prepared. Then, interrogators DAS must be developed and/or provided and installed. Then, data has to be generated, and scientific algorithms must be developed and tested over that available data. Those algorithms are the way to detect vibration events. Finally, the algorithms must be validated through independent data. Their performance must be evaluated through long-term measurements.

The partners in Task 9.2 are not reporting synergies/risk of duplication of work. While in both FA3 and FA4 fibre optics are used, the applications are different: FA3 focuses on infrastructure/vehicles, and FA4 in areas beyond the infrastructure.

The use case is developed in WP9 subtask 9.2.1 “Optical fibre data analysis”, subtask 9.2.2 “Train identification and intrusion detection” and subtasks 9.2.3 “Dark fibre”.

7.4.1. Overall aim of the use case

7.4.1.1. Problem to be solved

Inspection and monitoring of asset status and operational performance information are crucial for controlling the operation and maintenance activities in the railway industry. Regarding train operation, the detection and monitoring of train positions are essential for a train management system. For maintenance purposes, accurate measurement of the asset state is vital to enable optimal maintenance planning and avoid safety-related failures that could reduce capacity.

Fibre optics allow multiple applications, as reported in the literature. It is a well-known fact that fibre optics detect vibrations from trains or even humans walking near the tracks. A possible application is then real-time monitoring to detect vibrations in the railway environment, such as continuous train detection or localised events detection. Currently implemented techniques are not standardised, yet the potential of fibre optics for redundant and better-informed monitoring of train information while travelling is open for research. For instance, while the train detection feature might be redundant, detecting its vibrations provides additional insights into the train-track system, such as flat wheels.

In this use case, the aspects of interest for monitoring and detection include the infrastructure and degradation of the vehicle fleet and fault states and the measurement of track properties such as rock fallouts or other energetic localised vibration events, Regarding vehicles, it is important to

measure maintenance aspects related to the interaction between the vehicle and the track to prevent damage to the track system, such as wheel flats and unstable bogies. Currently, sensors and detectors are predominantly located at specific geographical points. However, larger areas can be covered more efficiently by utilising a distributed technology like DAS.

The development of new technologies for distributed sensing, based on fibre optics, for train monitoring, detection and identification of trains and events detection, will enhance the management of assets and their maintenance. The information obtained by the distributed sensing system can be relevant for determining asset status and enhancing the results obtained in maintenance tasks. By including the measurements of this technology in prescriptive maintenance and optimised maintenance strategies, we can increase the quality and efficiency of maintenance in terms of costs, possession time and sustainability.

7.4.1.2. Industry current position / baseline

Fiber optics are already installed along railway tracks for telecommunication purposes. They can be used as sensors to monitor parameters using distributed fibre optics sensing technology. New fibre optics can also be installed for the same purposes. The distributed sensing system is commonly used to monitor parameters such as acoustic vibrations in the track (DAS) and temperature (Distributed Temperature Sensing, or DTS). Vibration monitoring can determine important parameters such as train movements and the position, speed and direction of the rolling stock. Furthermore, the vibration detected by fibre optics contains information from the infrastructure. A deep analysis of some parameters can indicate the current condition of the railway track.

Various DAS applications have been developed over the past decade in different industries. The technology utilises backscattered light from the interaction between light and matter in the core of the fibre to measure changing properties at different positions along the fibre. The technology employs different approaches, leading to different performances for each part of the use case. Many use cases have also been identified for railways, and many proofs of concept have been carried out.

7.4.1.3. Subproblem addressed by the use case and measurable objectives

The specific use case aims to develop a fibre optic-based system to determine the location of the trains, the condition of wheels and the detection of rock falling methods based on the DAS technology using existing fibre optics installations. The fibre optic cable, running parallel to the railway, comprises multiple fibre optics. Through the use of DAS, each fibre optic may work as a distributed sensor. The signals from these cables can be processed to determine the location of the train and detect events such as intrusion in the railways.
Although still in a stage of scientific evolution, the technology for distributed acoustic sensing is sufficiently mature. However, its implementation in railway systems on a large scale has been limited. Utilising existing railway fibre optic cables allows for cost-effective installations, although it also brings many challenges, such as those related to the fact that their installation primarily focuses on data transmission rather than DAS applications (the coupling with the environment can

be poor). Many challenges must be overcome to achieve sufficient performance. This use case aims to investigate this aspect of DAS technology. The study targets TR6/7, where tests will be performed on a track section. Some analyses of the measurement signal may fall within the range of TRL2/3.
Currently, measurements of fibres along the Iron Ore line have been conducted. An algorithm for detecting wheel defects has been developed, and its results were validated in a train with four-wheel defects. This validation was performed by comparing the algorithm's output with wheel impact measurements obtained from wayside measurement systems. Regarding the rock-falling case, the process of designing experiments and installing sensors and equipment has started.

7.4.1.4. Influence of the proposed innovation on the IM/RU problem

Aligned with the objectives of WP9, within the scope of FP3-IAM4RAIL, the main problems that need to be addressed by this specific use case refer to the agility in taking maintenance actions on assets and optimising those actions. The distributed sensing system with fibre optics technologies allows real-time information about the railway state and events that may occur in it. Monitoring the status of assets and retrieving data on events can be useful for further analytic techniques, presumably contributing to a better and more agile maintenance plan.
Finally, larger rail sections can be monitored using existing or additional dark fibre installations. Compared to a traditional strain gauge or vibration measurement systems, fibre optic measurement systems consist of a distributed measurement, equivalent to many sensors along the tracks, enabling the detection of wheel defects in locations without wheel impact detectors and many other events.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Industry current position / Baseline	Country use case	Use case location
Fibre Optics – DAS technology	SNCF	Fibre optics are already installed for telecommunication. They can be used as distributed sensors to monitor acoustic, vibrations and temperature. These measured parameters can be applied to various applications, such as train movement detection and condition assessment of the track. Traditional sensors are strain gauges or vibration measurement systems, which are point sensors. Fibre optics offers distributed measurements, with a capacity of geolocating events within some meters.	France	Rockfall detection. The test site is in Eastern France.
Dark fiber	TRV/LTU		Sweden	Iron Ore line and test facility TRV

Table 56: Fiber optics prototypes

7.4.2. UC9.2: Demonstrator's KPI

7.4.2.1. List of KPIs and related justification for the choice

Calculating a specific KPI for this use case is challenging since the benefits of the system need to be quantified for different applications. The primary advantage will be increased information about the assets. Cost considerations can also serve as a possible KPI. Implementing new systems may introduce additional costs, and evaluating the benefits of these systems is necessary to compare them against the potential increase in cost.

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (increased by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 57: UC9.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
9.2-1	Detection of infrastructure anomalies and assets monitoring	10%
9.2-2	Detection of vehicle anomalies	100%

Table 58: UC9.2 PIs

<u>Relation to FP3-IAM4RAIL's project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	The locations tested will be analyzed considering the inclusion of the new technology, which is currently not available with a competitive approach. Regarding vehicle anomalies, the tests will explore the solutions and consider differences/synergies with traditional local trackside measurements.

Table 59: UC9.2 direct KPI impact

7.4.2.2. PI9.2-1 – Detection of infrastructure anomalies and assets monitoring

Short description

Monitoring systems will be improved and used to detect anomalies such as rock falls and other located intense vibrations along the track that could lead to a later incident.

How to compute PI9.2-1

The baseline is defined based on the current practice for detecting the incidents. For example, when rock fall detectors are available, we will use such data for comparison. The intense vibrations are usually not understood or detected, so we will rely on the inspections triggered by fibre optics that lead to maintenance actions.

The PI will then be calculated based on the total anomalies detected by current means, compared to those detected by fibre optics.

$$PI_{9.2-1}\%\ Anomalies\ detected = \frac{Number\ of\ Detections}{Total\ number\ of\ anomalies}\ x\ 100$$

Where:

- Detections: they are the number of anomalies detected
- Total of anomalies: they are the total amount of anomalies

7.4.2.3. PI9.2-2 – Detection of vehicle anomalies

Short description

It covers the characterisation and estimation of vehicle anomalies, particularly flat wheels.

How to compute PI9.2-2

The vehicle anomalies are calculated by:

$$PI_{9.2-2}\%\ Anomalies\ Detected = \frac{Number\ of\ Detections}{Total\ number\ of\ anomalies}\ x\ 100$$

Where:

- Detections: they are the number of anomalies detected
- Total of anomalies: they are the total amount of anomalies

7.5. UC9.3: Track Geometry and S&C condition monitoring

This use case aims to improve the condition monitoring for both plain track geometry and switches and crossings (S&Cs). More specifically, its target includes the following:

- To improve the accuracy of the prediction of the track geometry condition, looking both into the propagation of the single-track geometry exceptions (short-term) as well as the deterioration of the track geometry indexes considering longer sections of the track.
- To approach the turnout monitoring and maintenance from a holistic point of view by specifying and creating Turnout Health Indexes (THI) and Turnout Maintenance Indexes (TMI) that allow Infrastructure Managers (IMs) to prioritise entire turnout replacements and the maintenance and replacement of individual components.
- To improve the detection of rail head surface defects, track defects and S&Cs quality using smartphones and on-board sensing solutions (such as video images and acceleration) to support the validation process.

The outcomes of this use case will support increasing the track and turnout availability by reducing the number of speed restrictions, improving condition monitoring and supporting root-cause analysis of the failures and alerts, contributing to extending the lifecycle of the track and S&Cs overall and its components. The partners in Task 9.3 are not reporting synergies/risk of duplication of work.

The use case is developed in WP9 subtask 9.3.1 “Track, S&C and Rail monitoring using acceleration signals and video-images”, subtask 9.3.2 “Plain Track Geometry Impact analysis and resurfacing work cycle detection” and subtasks 9.3.3 “Health and maintenance indicators for S&Cs”.

7.5.1. Overall aim of the use case

7.5.1.1. Problem to be solved

The first problem to address is evaluating low-cost solutions for monitoring track and S&Cs. A key challenge is to reduce the person-hours on track for manual work to detect and assess defects (such as squats, wheel burns, etc.). Further, visual inspections strongly depend on the lighting conditions, which can be overcome by using infrared technology. State-of-the-art methods and tools can solve anomaly detection problems and prediction. In the project, their performance using measurement data from commercial trains (for smartphone technologies), SNCF track monitoring trains, and the Trainlab of DB in Germany will be evaluated.
Another problem addressed in this use case includes how to improve the interpretability and usability of existing measurement outputs. Despite the accuracy and reliability of the mobile/mechanized track geometry measuring systems, there are still cases in which interpretation and data translation are required to elevate the data to the right quality level for

running predictive analytics. Equivalently, mobile and wayside inspection systems for Turnout conditions introduce more than ever the necessity to combine different information and translate it to actionable insights and support IMs in making the right decisions for Turnout maintenance and planning.
Therefore, one of the scopes of this use case is to provide the base for the standardization of THI and TMI that weigh and combine the different Turnout component characteristics, components' failure modes, and Turnout's operational characteristics, which nowadays remain unlinked or with limited interdependencies.
Concurrently for the plain track, using modern and advanced analytics, the use case aims to improve the data quality and understand how the current plain track condition can evolve in the future considering two levels of analysis.

- The first level focuses on identifying and predicting the single-track geometry defect using the concept of the defect fingerprint to identify defect repeatability and bridge potential localization misalignments introduced by the measuring systems.
- The second level focuses on increasing the accuracy of the track geometry indexes prediction at longer sections of tracks, targeting the generation of medium and long-term maintenance plans using advanced analytics.

For both levels, the use case foresees an automatic detection of resurfacing works based on the actual measurement signals that will improve the prediction of track geometry.

7.5.1.2. Industry current position / baseline

The use of diverse track measuring systems for the plain track introduces, by default, a degree of misalignment of the parameters recorded by the different localisation units on board. Moreover, the current diagnostic systems are expensive and require extensive knowledge of how to operate them. At this point, the detection is entirely done during visual inspections (followed by a manual ultrasonic measurement for classification for railhead detection). For low-cost solutions, we are referring to smart portable solutions for which the Installation, Operational and Maintenance Costs are significantly smaller than the introduction of dedicated systems in Diagnostic Vehicles or fixed non-flexible installations.
Regarding S&Cs, Infrastructure Managers currently use different mobile and wayside diagnostic systems for monitoring the condition of each turnout component; dedicated Turnout Geometry systems monitoring key track geometry parameters; fixed wayside diagnostics monitoring the vibrations across the turnout during train passes; track and rail vision systems reporting surface irregularities and component clearances. Though this plethora of diagnostic systems allows IMs to detect failures, neither the timing nor the maintenance works planned consider an integrated approach that advances the prioritisation of the track and turnout maintenance, and renewal works and how each condition input impacts the overall Turnout and the Track performance.
Furthermore, the infrastructure's asset layout must be considered during the identification of the track geometry condition defects to avoid the generation of false alarms and increase the reliability and quality of the information.
Moreover, historical works that impact Track Geometry are not accurately reported, and as a result, this affects the analysis of the historical behaviour of track geometry and, hence, the prediction of future interventions.

7.5.1.3. Subproblem addressed by the use case and measurable objectives

The specific use case addresses the following challenges:

- Identification of the minimum data requirements for running the analytics.
- Collection and reliability of the condition and maintenance information.
- Integration between conditions measured and identified by different diagnostic systems.
- Reliable processing of the collected data.
- Automatic data validation of the Plain track geometry defects using Machine Learning algorithms.
- Development of methods to identify the number of rail defects per distance and limit the number of false positives.
- Creation of an application for different smartphone operating systems to measure the accelerations on board and comply with national and international standards and validation procedures. The measurable objective is to validate the measurements on a certain type and smartphone model.
- Definition of the Plain track geometry defect fingerprint using Machine Learning algorithms.
- Definition of interpretable turnout health and maintenance indexes (THI and TMI).

The security of the S&C inspectors is of concern, as they may have to put themselves in a dangerous position depending on where the track is located. Another aspect to consider is that the evolution of a defect can only be followed up via minutes made by the inspectors, not by comparing the actual situation (like two pictures can be compared). Furthermore, the inspections must be performed during the daytime, since they require enough daylight. Finally, a few inspection trains already bring the images/video of switches and crossings to the office. However, they have to pass on each possible communication of the switch or crossing. This means two passages on normal switches and diamond crossings but three (for a single) or four (for a double) passages on slip switches.

Plain Track geometry monitoring will be improved by the automatic recognition of the track resurfacing works and maintenance cycles that impact the track geometry quality. Similarly, the use of machine learning techniques will be considered. In this manner, plain track geometry prediction becomes independent from the availability of the actual resurfacing works logs that are reported inaccurately or missing in most cases. The use case proceeds with the prediction of the plain track geometry evolution in two parallel processes. The first relates to the evolution and propagation of the single-track geometry defect, and the second focuses on the prediction of medium to long-term interventions for longer sections of tracks by monitoring track quality indexes.

Regarding the track geometry defects, given that the task also includes detecting the resurfacing works, this work package will concentrate primarily on the following isolated defects as per EN 13848-5: Alignment D1, Twist, Longitudinal Level D1. Regarding the track quality indexes, which will be calculated at the segment/section level, we will refer to the standard deviations of the Alignment D1 and Longitudinal Level D1 as per EN 13848-6. In addition, the turnout health and maintenance indexes (THI and TMI) will support the prioritization of turnout replacements and the

replacement of turnout components.

With the plethora of different measuring systems and technologies in place, besides Track Geometry insights, IMs also obtain insights for the entire infrastructure, e.g., rail surface condition, fastening and ballast condition, and substructure condition. However, there is still the need to monitor how assets behave under certain conditions and how much they are bound and related to neighbouring asset and network conditions. Therefore, this use case aims to provide an insight into the impact that certain features/inputs have on the deteriorating behaviour of track geometry and S&Cs condition and allow IMs to prove with objective analysis already-known high-risk dependencies and explore new amongst the different recorded conditions.

7.5.1.4. Influence of the proposed innovation on the IM/RU problem

Instead of needing special equipment and experts for measurements, every engineer with the application, the right type of smartphone, and a set of instructions can perform the necessary measurements. Solving the main research challenges by means of automated system on an inspection train implies that the inspection of switches and crossings can be performed at any time of the day (that is to say, the registration of the images/video), which can be analysed by track inspectors in the secure environment of the office, without having to travel to the inspected track section. After the inspection train has passed, the entire switch or crossing can be inspected, and images of consecutive inspections can be compared directly. With automated detection of the running surface rail defects, the workload during visual inspections will be reduced (but still remains necessary for other types of defects). The IM will have access to more reliable data and more frequently (6 times per year instead of 1 time per year on the part of the network covered by the measurement train ESV).

At the same time, IMs can increase the accuracy of the prediction compared to traditional modules as well as the time required to run these analytics by automating the process from data cleansing to work cycle detection and forecasting next interventions. Another benefit is that the prediction of the track geometry parameters and/or indexes becomes independent of the actual reporting of the work logs. With the automatic detection of the work cycles directly from the track geometry signals, IMs do not have to report the historical resurfacing works that impact the quality of the track. Instead, the impact is automatically detected using Machine Learning algorithms. With the introduction of machine learning algorithms, IMs can assess a list of predominant inputs/features that impact the deteriorating condition of the track geometry and objectively support their decision-making process, advance root-cause analysis, and prescribe the appropriate maintenance and renewal actions. IMs can use objective data to improve the balance between planning maintenance and renewal activities. IMs will be able to re-assess the prioritization of the resurfacing works in the medium and long term by considering how single-track geometry defects are propagating within the same section and how these affect the overall behaviour of a section.

Moreover, this use case will allow IMs to assess the interdependencies between the components within the Turnout itself and across different Turnouts. Using a standard Turnout and Maintenance Index, IMs will optimise the inspection and maintenance plans, reduce speed restrictions and

failures due to late reactions and promote the application of prescriptive maintenance. The key benefit of this indexing approach is the provision of a consistent and objective method of prioritising turnout maintenance on a major line segment, region, territory or even system wide. This is particularly important on a busy rail line where there is a high number of high-speed passenger and freight trains, where track possession time is extremely limited, and the ability to take a turnout out of service for maintenance or repair is likewise limited. The significant number of turnouts found on a railway line, coupled with other factors, makes it necessary to identify urgently turnouts that require immediate or future maintenance.

Moreover, a single Turnout Health Index (THI) is utilised as part of an IMs' broader maintenance management tool. For instance, this approach could be implemented in a maintenance (operating) budget allocation system, where budgets are assigned to Maintenance Engineers based on the current condition and needs of their respective regions. Quantifying the relative importance of turnouts has been a traditional difficulty in any such allocation system, so using the turnout condition index could be of great value. Prioritisation of turnout maintenance, repair, and replacement is a key issue, given the substantial number of turnouts in any rail system and the high rate of degradation associated with these turnouts, particularly on the high-traffic density routes. This is of even greater value when the sub-indices (TMIs) prioritise specific maintenance activities as a function of specialised equipment or components (e.g., grinding, tamping, etc.). In this way, specific types of equipment (Tampers, S&C grinders, etc.) and maintenance resources (welding crew, bolt tightening team, etc.) can be prioritised based on a numeric ranking of those conditions addressed by the specific maintenance activity.
In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Industry current position / Baseline	Country use case	Use case location
Upgraded CTM 2.0 monitoring system (acceleration signals, transfer via Bluetooth)	DB	1) Detecting and accessing plain track defects relies on visual inspection and requires proper lighting conditions. 2) After visual inspection, a manual ultrasonic measurement is conducted, requiring person-hours. 3) For SC, mobile devices are used to measure turnout geometry, fixed wayside monitoring systems are used to measure vibrations at turnouts due to train passages, and track and rail vision systems are used for reporting surface irregularities and component clearances.	Germany	Prototype test in the lab validation on the VT 612 measurement train Test in the advanced train lab ATL
Smartphones (for onboard acceleration measurements)	SNCF		France	Various locations.
Infrared cameras (for S&C monitoring)	SNCF		France	Various locations.
A methodology for facilitating the automatic identification of maintenance works and outliers	MERMEC		Germany, France, and Spain.	1) Track relevant data of 300 km from DB. 2) Track relevant data of 100 km from the SNCF high-speed line. 3) track relevant data of 100 km from the ADIF high-speed line.
A methodology (to develop turnout health index)	MERMEC		Spain	Relevant information of 8 turnouts on the ADIF "Madrid Levante" high speed line is considered.

Table 60: Track geometry and S&C monitoring prototypes

7.5.2. UC9.3: Demonstrator's KPI

7.5.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 61: UC9.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
9.3-1	Optimisation of track work prioritisation	10 %
9.3-2	Optimisation of turnout work prioritisation	10 %
9.3-3	Performance of inspection solutions	5 %

Table 62: UC9.3 PIs

<u>Relation to FP3-IAM4RAIL's project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
XIII	Increased accuracy of inspections with respect to conventional interventions (25%)	In this Use Case, we extend the current capabilities of measurement methods. The increase in performance is expected because: 1) Detecting and accessing plain track defects relies on visual inspection and requires proper lighting conditions. 2) After visual inspection, a manual ultrasonic measurement is conducted, requiring person hours. 3) For SC, mobile devices are used to measure turnout geometry, fixed wayside monitoring systems are used to measure vibrations at turnouts due to train passages, and track and rail vision systems are used for reporting surface irregularities and component clearances.
XIV	Cost reductions of the interventions (by at least 10%)	

Table 63: UC9.3 direct KPI impact

7.5.2.2. PI9.3-1 – Optimisation of track work prioritisation

Short description

The specific PI is based on the number of planned KMs shifted backwards, forward, or newly introduced in the plan due to the automatic recognition of the work cycles compared to the current condition in which the reliability and accuracy of the work history affect the forecasting of the next resurfacing interventions. Aligning the historical cycles and increasing the prediction accuracy by shifting the planned works backward or forward translates into work optimisation.

How to compute PI9.3-1

The following formula is used to calculate the PI9.3-1 related to subtask 9.3.2.

$$PI_{9.3-1} = \left| \frac{CBPW_{UC}^{BW} + CBPW_{UC}^{FW} + CBPW_{UC}^{NEW}}{CBPW_B} - 1 \right|$$

where:

- UC, means use case scenario;
- B, means baseline scenario where the planned activities are based on the current traditional deterioration models without the ability to automatically detect and to adjust the plans dynamically;
- CBPW, means the number of condition-based planned works;
- BW, means condition-based planned works moved backwards;
- FW, means condition-based planned works moved forward;
- NEW, means newly introduced condition-based planned works.

7.5.2.3. PI9.3-2 – Optimisation of turnout work prioritisation

Short description

The specific PI is based on the number of maintenance works and/or inspections that will be prioritised based on the new Turnout Health and Maintenance indexes compared to the current maintenance and inspection regime. A positive delta illustrates an increase in safety and prevention of possible failures, while a negative delta results in the reduction of unnecessary maintenance work. In both scenarios, the reduction of costs (direct and indirect) is driven by the condition-based identification of the work priorities.

How to compute PI9.3-2

The following formula is used to calculate the PI9.3-2 related to subtask 9.3.3.

$$PI_{9.3-2} = \left| \frac{CBWP_{UC}}{CBWP_B} - 1 \right|$$

where:

- UC, means use case scenario;
- B, means baseline scenario where the prioritised activities are based on the current turnout conditions and standards;
- CBWP, means the number of condition-based work priorities.

7.5.2.4. PI9.3-3 – Performance of inspection solutions

Short description

For subtask 9.3.1, we evaluate the performance of technologies and methods by considering the following:

1) The rate of running surface defects found by automated detection in relation to the defects found by visual inspection (which percentage of the defects identified during visual inspection has also been detected automatically).
2) The number of automatically detected running surface defects that turn out not to be running surface defects is divided by the length of the rail analysed.
3) The quantification of statistical and frequential differences between a smartphone and the reference system
4) The mean time, which is needed to analyse the images and videos of the Infrared technology per type and category of switches and crossings.
5) Since this KP describes the rate of reported defects between both monitoring methods, the analysis of the images and videos shouldn't miss many defects reported after a visual inspection.
6) The rate of reported defects from the traditional CTM system compared to the BT CTM prototype.

How to compute PI9.3-3

The following methods are used to calculate the PIs related to subtask 9.3.1.

1) The number of running surface defects identified both during the visual inspection and by automated detection is divided by the total number of running surface defects reported during the visual inspection.
2) The number of false positives is divided by the rail length analysed.
3) 95th percentile of the acceleration difference in each direction and PSD ratio between the signals on a certain domain.
4) Mean of the time needed to analyse a number of switches/crossings of the category of interest.
5) The PI is calculated by dividing the number of defects found in a set of switches and crossings by both methods by the number of defects found by an individual method (let us say that during the visual inspection, 100 defects are reported, and through the analysis of the images and videos 105, of which 90 are common between the two defects lists – the KPI for the correlation between the two methods should be 90/100 = 90% - which should be sufficiently high- whereas the ration between the number of commonly found defects and the number of defects found with the analysis of the images and videos, 90/105 = 86% says something about the additionally found defects - the lower, the better).

For the baseline scenarios, we consider the following:

- The baseline for railhead defect detection and infrared. Is currently the visual track inspection performed by people on the track is.
- For smartphones, the baseline is the very expensive and complex on-board sensing technology.

7.6. UC9.4: Prescriptive Maintenance for Railway Infrastructure

This use case (UC) focuses on approaches for prescriptive maintenance using data from various sources, such as monitoring solutions or inspections. It paves the way for more efficient maintenance that follows the steps determined before a defect occurs. The work in this UC includes the development of technologies, algorithms, and models required to apply advanced solutions for structural health monitoring, anomaly detection, prediction of degradation, and validation campaigns in railway environments. The monitoring solutions in this UC are being tested under various conditions and scenarios to evaluate their current and extended capabilities and limitations. The maintenance strategies, developed for different scenarios and boundaries, will be evaluated in terms of complexity, possession time, and cost reduction, among others.

The partners in Task 9.4 indicate that the key innovations and integration methods developed, consisting of Lindometer, laser Doppler vibrometer, lipping analysis, anomaly detection via traction signals, anomaly detection via ABA and methods for prescriptive maintenance, etc., are not being considered in other tasks, so no synergies/risk of duplication is reported.

The UC is developed in WP9 subtask 9.4.1 “Data acquisition, signal processing, and data-based modelling”, subtask 9.4.2 “Sensing technology development”, subtask 9.4.3 “Data analytics for performance indicators and anomalies”, subtask 9.4.4 “Prediction of track condition based on

multi-sensing", subtask 9.4.5 "Data-driven decision making" and subtask 9.4.6 "Planning and scheduling of maintenance".

7.6.1. Overall aim of the use case

7.6.1.1. Problem to be solved

The modal shift to rail, necessary to achieve the EU target of a 30 % share of total transport by 2030, poses major challenges for the rail infrastructure. Above all, the already scarce time spent on track maintenance will be considerably reduced in the future. In addition to improvements and construction of new lines, innovative and efficient maintenance procedures and strategies are key factors in ensuring the required track availability and capacity. A shift from short-term to mid- or long-term planning is necessary to maximise the possession time for the maintenance measures and minimise the impact on the operation. However, this requires data-driven solutions, which enable, among other things, degradation prediction and interpretable information in combination with physical explanations about root causes for defects and anomalies. This provides a much broader view during maintenance planning as it is based on thresholds and allows the creation of strategies to remove anomalies at their source. Therefore, in this UC, the focus is on prescriptive maintenance, which incorporates state-of-the-art techniques (for example, advanced analytics, AI, big data, etc.) to anticipate failures but, most importantly, to provide holistic/explainable solutions for delaying or eliminating failures. In this way, the efficiency and sustainability of the railway system can be increased via maintenance design and deterioration predictions, and precious knowledge about the root causes of track deterioration can be generated.

Railway infrastructure must be maintained in a defined condition, considering the latest findings on the different types of failures and degradation mechanisms in the various components. Common problems affecting railway assets can include failures originating from the use of infrastructure components, failures in the rolling stocks, events due to exogenous factors such as third parties and weather conditions, etc. Standardised inspection and diagnostic methods are to be supplemented by new or improved sensing technologies to obtain a better data basis for more efficient maintenance. State-of-the-art monitoring solutions from other fields are not yet broadly applied in the railway maintenance business. They are needed to keep infrastructure managers (IM) and railway operators (RO) well informed about, among others, the safety and reliability of the railway infrastructure. As one of the objectives of the rail sector in Europe is to replace other modes of transport (such as the private car) by rail, offering safer and reliable services is crucial to retain existing users and to gain the trust of possibly new users. Regarding maintenance, the most common practice of IMs is reacting to inspection results, which leads to short-term planning and, thus, inefficient and expensive maintenance measures. Medium-term planning is often based on the experience of the infrastructure operator due to the lack of forecasting tools and the traditional planning approach.

Root cause analysis in conjunction with LCC-based analysis is not a common practice. As a result, maintenance is not designed to address all the current challenges in railway systems, which are not only to ensure a level of availability but also to be sustainable, as individual faults tend to recur

after a short time. Thus, health condition monitoring, detection of anomalies, and data-driven maintenance play a vital role in ensuring safety, availability, and service reliability and in prolonging the life span of the infrastructure. The early detection of defects and anomalies throughout sensing technologies allows preventive and root-cause-oriented maintenance activities to be conducted before failures occur, thus showing great potential for cost savings. The continuous monitoring of critical components has not only increased the level of safety but drastically increased the availability of the infrastructure, as early warning systems include the repairs or replacement of these components during the routine maintenance slots.

In 2024, the review paper about AI for railway infrastructure (which is a key component to achieve Prescriptive Maintenance), jointly developed by ProRail, DB, and TUDelft, received the award of best paper of the journal Intelligent Transportation Infrastructure from Oxford University Press (https://doi.org/10.1093/iti/liad016).

7.6.1.2. Industry current position / baseline

The most common practice of IMs is reacting to inspection results, which leads to short-term maintenance planning as the defects need to be removed until the next inspection. This reactive approach implies failure-oriented remedies, which are less sustainable in many cases. The defects are likely to reoccur, and the IMs get trapped in a vicious circle. There is often a lack of knowledge about the root causes of a defect, and an LCC-based maintenance decision is not standard. Existing and well-known monitoring solutions, such as the measurement of axle box accelerations (ABA), are usually limited to one or two parameters, such as longitudinal level, and therefore cannot detect all relevant faults. The installation of monitoring systems on in-service trains is very complex and cost-intensive. In addition, the trains do not cover the entire route, generating large amounts of data on the frequently travelled sections. Thus, new or improved solutions are necessary for the monitoring systems and related data analytics.

Previous projects (such as IN2SMART, IN2SMART2, IN2TRACK, IN2TRACK2, IN2TRACK3) have developed techniques for monitoring railway tracks to detect anomalies in track geometry and rail surface, predict track geometry, and evaluate transition geometry in S&Cs, among others. The results achieved in these projects were rather proof of concept, meaning that the automatic and commercial use of the developed models and data analytics in rail operations was not possible at the end of the projects.

The Technical Readiness Level (TRL) of the techniques considered in this UC is between TRL 4 and TRL 6. Further field tests and various improvements are still necessary for the technologies to avoid manual interventions and examinations and to increase the validity, effectiveness, and interpretability of the measurement results. Higher detection rates and fewer false detections are essential for confidence in measurement sources.

For example, further work is necessary to avoid "false positive" cases where a non-existing defect is detected. In the case of anomalies, they need to be detected, characterised, and recorded to take the appropriate maintenance actions. Track geometry monitoring must be extended to

include lateral alignment, twist, and gauge monitoring to provide a complete overview of the track condition. Maintenance is often scheduled with a low priority to avoid disrupting railway service operations. This results in insufficient blocking time and makes effective maintenance difficult or impossible. The UC tackles this issue by means of a new planning tool that plans and optimizes maintenance shifts based on track geometry prediction.

7.6.1.3. Subproblem addressed by the use case and measurable objectives

This UC focuses on:

- defining data models and interfaces;
- the regular collection and pre-processing of data from various sources, such as monitoring, inspections, and traffic management systems (TMS), and
- development, improvement, and validation of sensing technologies relevant to prescriptive maintenance of track and S&C.

In this UC, the measurement data to be obtained (either from existing sources or through additional measurement campaigns) and their evaluation include:

- Track geometry aspects such as periodical long-wavelength and ride comfort, video images, and axle box acceleration (ABA) data are available from IMs that conduct these with measurement vehicles to estimate the general properties/conditions of the track.
- Eddy current-based sensor (Lindometer) - to detect anomalies in fastening systems and insulated joints, with a demonstration on the rail track in Sweden and Germany. Exploratory work to measure lateral alignments will be done.
- Laser Doppler Vibrometer (LDV) and ABA will be obtained to estimate the transfer function of the railway track, which accounts for inputs (loading) and outputs (frequency responses) to represent track dynamic properties. From moving vehicles, accelerometers are employed to estimate the dynamic train load on railway tracks, and a laser Doppler vibrometer (LDV) is used to scan railway tracks and measure their vibration response as the vehicle moves. Decision support of track maintenance by estimating track stiffness and transfer functions of railway tracks will be proposed. Progress in this activity can be read in https://doi.org/10.1155/2023/6420772, and https://doi.org/10.1109/TII.2024.3485764). The PhD work of the key findings regarding LDV received the Best PhD Thesis Award 2024 by ERRAC (The European Railway Research Advisory Council).
- A feasibility study of LiDAR technology to continuously scan structures by measuring their vibration. This will allow the potential application of LiDAR technology to measure the geometry and dynamic properties of railway tracks from a moving train. The scope of this feasibility study includes activities considered low TRL, with lab tests and including the following: 1) Experiment design that enables continuous scanning of a LiDAR system on a vibrating structure. 2) Static and continuous-scanning vibration measurements using the LiDAR system. 3) Signal validity and quality analysis at different stand-off distances and scanning speeds at laboratory conditions.
- Wheel rotation speed and wheel slip – detection of vertical track defects based on the mechanical response of the train to these defects (using already installed train speed sensors). Feasibility study and evaluation of track geometry analysis with existing sensors on the train

(speed sensors, traction motor phase current, etc.) to provide a possible solution for track monitoring.

- Analysis of a country-wide evaluation of lipping (plastic deformation) in the Netherlands on the transition zone of common crossings. An algorithm assessed all (4559) crossings in remotely operated turnouts that were measured (in Q1 and Q2 of 2023) by a geometry measurement train, and its results were manually validated (to test the performance of the algorithm). A multi-sensing approach does this with the help of existing measuring trains for S&C. After the characterization of anomalies (position of lipping), the root cause analysis will be performed. A better understanding of root causes will move maintenance from fixing the symptoms to addressing the causes of the degradation.
- The planning and execution of maintenance will use, in addition to track condition monitoring, additional data like the train timetable to minimize disturbance of the train operation, maximise the efficiency of the maintenance, and thus minimise the costs.

7.6.1.4. Influence of the proposed innovation on the IM/RU problem

Monitoring of relevant track geometry parameters provides an almost continuous overview of the condition of the track. This results in the ability to respond to a rapidly growing defect before speed reduction or track closure becomes necessary. Additionally, monitoring supports better forecasting and, thus, medium-term maintenance planning. The use of monitoring systems like ABA, which provides information about the dynamics of the track in contrast to conventional inspection systems, leads to new knowledge and a better understanding of the degradation process, allows the detection of anomalies, and provides input for root cause analyses. Checking the quality of a maintenance measure immediately after it has been carried out also provides important data for evaluating the measure and improving degradation models.

This UC provides the fundamentals and important building blocks for prescriptive maintenance. Characterisation of anomalies and root cause analysis provide the information necessary to address the root cause of a defect before correcting it. This supports the shift from addressing symptoms to dealing with root causes.

The prediction of track deterioration, one of the most important building blocks for prescriptive maintenance, is improved and validated through measurements. The maintenance planning tool used in this project uses all relevant information collected in this UC to build efficient shifts for maintenance execution. This data is used for planning maintenance activities that consider the train schedule, additional network data, and diversion tracks. The aim is to minimise the impact on train operations and maximise the efficiency of maintenance execution.
In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Industry current position / Baseline	Country use case	Use case location
A methodology for prescriptive maintenance	DB InfraGO	1) The standard practice is reacting to inspection results, leading to short-term maintenance planning to remove the defects before the next inspection. Mid-term planning is based on IM experience without forecasting tools and a traditional training approach. 2) Lack of root cause analysis and LLC-based analysis cannot guarantee a level of availability and sustainability of railway systems. 3) Outcomes from previous projects were likely proof of concept and haven't reached the needs at commercial levels.	Germany, the Netherlands	Rhine-Alpine-Corridor. Relevant information, such as geometry-related data from DB and ProRail, maintenance history, etc., are the inputs.
Lindometre (eddy current-based sensor) for defect detection	TRV and Alstom		Sweden, Germany	Iron ore line in Sweden. Germany (Rhine-Alpine-Corridor)
A methodology (using traction system data for defect detection)	Alstom		The Netherlands	Linked with WP6. Sensors on ICNG trains of NS. Different lines in The Netherlands can be covered.
A methodology (for evaluating deformation at common crossings)	ProRail		The Netherlands	No specific location is reported. Assuming (most of) S&C in the Netherlands will be considered.
Train-borne LDV (for track condition monitoring)	ProRail/TU Delft		The Netherlands	A segment of ballasted track in Rotterdam, the Netherlands
LiDAR technology for structure (i.e. track) vibration measurement	ProRail		The Netherlands	Laboratory tests, the Netherlands

Table 64: Prescriptive maintenance for railway infrastructure prototypes

As described above, detecting forms an important basis for root cause analysis. Eliminating the detected anomalies once the root causes are known leads to increased track availability and

performance. The PIs of this UC measure the increased information of the prototypes, which is very useful in planning maintenance.
The assessment will be conducted on a specific rail freight corridor section. Particular technologies and methodological solutions will be tested in different countries and lines to compare with the baseline provided by current practices in the railway lines they are tested on.

7.6.2. UC9.4: Demonstrator's KPI

7.6.2.1. List of KPIs and related justification for the choice

The objectives this UC aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10 % in specific use case)	Little/indirect
VII	Infrastructure Operation: reduction of service failures (25 % reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	High/direct
IX	For repair: extension of remaining life (25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25 %)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25 %)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10 %)	High/direct

Table 65: UC9.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this UC:

PI	Description	Target value
9.4-1	Completed campaigns	100 %
9.4-2	Detection of anomalies	50 %
9.4-3	Correlation between anomalies and track geometry deterioration	20 %
9.4-4	Validation of track geometry prediction	90 %

Table 66: UC9.4 PIs

Relation to FP3-IAM4RAIL's project KPIs
Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Prototypes in this UC provide more comparable and reliable parameters than currently available methods which serve well as monitoring data acquisition in Digital Twin. For instance, we will able to monitor new physical and condition-based parameters for insulated rail joint, fastenings, and sleepers. This requires the extension of currently available datasets per asset.
XII	Increased accuracy of inspections with respect to conventional interventions (25 %)	Automated data acquisition and analysis of the prototypes in this use case are expected to be better than conventional interventions, since the latter is unable to estimate some of the parameters we are measuring.
XIV	Cost reductions of the interventions (by at least 10 %)	Once anomalies detection, root cause analysis and LCC analysis are being considered, the maintenance will be more sustainable, and the costs of interventions will be reduced.

Table 67: UC9.4 direct KPI impact

7.6.2.2. PI9.4-1 – Completed campaigns

Short description

In this UC, testing and validation campaigns in the laboratory and in the real field will be conducted. Depending on the prototype, the aim PIs are as follows:

- Lindometer – Measurement campaign on railway trolley x 1 and measurement campaign on train x 1. The aim is to carry out both campaigns.
- LDV – Laboratory test campaign on V-track rig x 1 and measurement campaign on train x 1. The aim is to carry out both campaigns.

How to compute PI9.4-1

As PI9.4-1 focuses on gathering data from measurement campaigns, it is described as successfully completed campaigns:

$$PI_{9.4-1} = \frac{N_a}{N_b}$$

Where:

- N_a the number of successfully completed campaigns
- N_b the total number of campaigns planned.

7.6.2.3. PI9.4-2 – Detection of anomalies

Short description

The monitoring systems and associated data analyses will be improved, deployed, and validated to detect defects or anomalies. Assets defects detections will be conducted based on measurement principles specific to each prototype. For instance, there are examples of detection of rail surface defects, track geometry irregularities, defective insulated joints, defective fastening, poor sleeper supports, etc. As with anomaly detection problems (defects, in this case, are the anomalies), the aim is to have a measurement system that indeed detects anomalies (with a high number of true positives) and clearly discriminates from healthy conditions (with a high number of false negatives). The challenge is then to reduce the number of false positives (healthy components detected as anomalies) and false negative detections (anomalies detected as healthy).

How to compute PI9.4-2

Each prototype will determine the type of anomaly, the detection method and its performance. As PI9.4-2 is intended to obtain a report of the performance of the anomaly detection measurement and algorithms involved, a simplified PI is defined, and it shows the validation of detected anomalies compared to those detected by different means. It is calculated as follows:

$$PI_{9.4-2} = \frac{N_t}{N_r}$$

Where:

- N_t the number of defects detected with the newly tested technology
- N_r the number of anomalies detected with an alternative means as a reference, i.e. visual inspection or assessing currently available measurement systems

7.6.2.4. PI9.4-3 – Correlation between anomalies and track geometry deterioration

Short description

Track geometry measurements are standard in the industry and serve as test parameters in this PI. Track geometry deterioration is often triggered by rail anomalies. The correlation between the track geometry deterioration and the anomalies obtained with the developed prototypes will be analysed. For example, a correlation between detected anomalies in the rail surface and the deviation in the track geometry will provide a natural way to relate the prototype with existing geometry measurement techniques. Those sections in which high degradation is detected, are of major interest in this calculation. Another example is LDV and ABA, where correlations with the geometry measurement of the longitudinal level will be obtained.

How to compute PI9.4-3

To represent the correlation coefficients in PI9.4-3, we consider two methods:

$$PI_{9.4-3} = \frac{N_a}{N_b}$$

Where:

- N_a number of sections with anomalies detected and track geometry deviation
- N_b number of sections with anomalies detected with the prototype.

The determination may be challenging because a certain period of time is necessary to observe the track deterioration, and in the meantime, the rail anomalies may be maintained by the IM. The number of sections out of all the measurements with high degradation in geometry will be calculated (with, for example, high TQI or a high standard deviation), and the number of sections will be obtained where a high number of defects is detected with the prototype. The values, in this case, are detections at an aggregated spatial level (for example, at sections of different lengths, such as 25 m). This determination is related to the sections with detected anomalies, not those sections in good quality.

Alternatively, the direct values of the signals could be analysed by a correlation coefficient as follows:

Covariance (track geometry, measured signal prototype) / (std (track geometry) std (measured signal prototype))

In the latest case, the digital signals are directly analysed to provide the correlation between the two measurement techniques, baseline track geometry, and the signals from the prototype. This is an aggregated version compared with geometry. The PI is based on the same principle. It just includes the case of correlation analysis directly from the signals.

7.6.2.5. PI9.4-4 – Validation of track geometry prediction

Short description

Valid prediction of track geometry degradation is essential for successful implementation and use in maintenance planning. The prediction model will be improved, and additional data will be included to increase its validity. The deviation between predictions and measurements will be analysed for each 25 m section. After about a year, the deviation between the predicted and measured track geometry will be less than or equal to 10 % in 90 % of the sections.

How to compute PI9.4-4

PI9.4-4 is to be calculated as follows.

$$PI_{9.4-4} = \frac{N_{\alpha < 10\,\%}}{N_t}$$

Where:

- α = |Prediction-measurement| / measurement
- $N_{\alpha \leq 10\,\%}$ number of sections with α < 10 %

- N_t total number of sections.

In this calculation, the sections that have been maintained and the sections with unexpected deterioration due to external events are excluded.

7.7. UC11.1: Linking (new) monitoring technologies to asset management issues

This use case contributes to demonstrator #4 (Asset Management & Infrastructure) of the project serving as the first step in implementing new sensor technologies in an operational rail environment. It aims to assess the feasibility and effectiveness of integrating these technologies into the existing asset management framework.

The use case focuses on linking (new) monitoring technologies to asset management issues in an operational environment. It involves deploying the sensors on the rail infrastructure subsystems, including wayside and onboard sensors, to gather diagnostic and prognostic information. By utilising these sensors, the project aims to provide traceable data for continuous asset condition monitoring, enabling maintenance experts and asset managers to make informed decisions. By conducting experiments and data analysis, the use case helps to identify potential challenges that may arise from the deployment of new (embedded) monitoring systems. It serves as a crucial groundwork to identify specific asset issues that can be identified, possibly at an early stage and being able to predict its evolvement and plan timely interventions.

By exploring and analysing the data collected from the new sensor technologies, the use case aims to identify relevant patterns and insights that can address specific asset management issues. This helps to bridge the gap between the potential of the new technologies and their practical implementation in the rail industry. The use case also demonstrates the interoperability and cross-border applicability of the solutions by conducting early demonstrations in different operational scenarios across EU member states.

Overall, this use case plays a crucial role in the demonstrator of the project by laying the foundation for the integration of new sensor technologies in the rail infrastructure. It helps to assess the compatibility, effectiveness, and potential challenges of these technologies in an operational environment. The insights gained from this use case will inform subsequent steps and developments in the project, leading to further advancements in asset management practices and ultimately improving the performance and reliability of the rail infrastructure subsystem.
The use case is developed in WP10 task 10.2 “Initial developments and quick wins for MSMP demonstration” and WP11 task 11.3 “Analytics and decision support for short term MSMP based management and work preparation” and task 11.4 “Integrated Demonstration – considering the Use Case and next exploitation strategies”.

7.7.1. Overall Aim of the use case

7.7.1.1. Problem to be solved

The problem to be solved is the assessment of how new monitoring technologies can contribute to existing and critical asset management issues in the rail industry. While these technologies offer potential capabilities in detecting specific issues, their integration and usage may introduce unforeseen challenges and complexities.

To fully understand the insights provided by the data collected through these monitoring technologies, experimentation and data analysis are necessary. For example, axle box accelerometers may reveal both rail wear and rail geometry issues, while ground penetrating radar could identify ballast problems as well as unexpected issues like badger burrows. It is crucial to leverage data experiments and the expertise of data scientists to uncover the comprehensive range of asset management issues that can be addressed by these technologies. The problem to be addressed is to identify patterns that can be observed and link them to specific issues.

7.7.1.2. Industry current position / baseline

The baseline for monitoring solutions in the rail industry varies for each technology, while some technologies may have no prior experience or relevant tests in the rail sector, others may have limited experience in addressing specific issues while remaining unexplored for other issues. This means that the latent potential of some technologies is often unexplored. While some sensors may initially appear expensive in relation to their perceived benefits, the industry recognises that their true value lies in serving multiple asset management issues.

Currently, asset management processes heavily rely on traditional inspection methods and limited data sources, leading to suboptimal decision-making, inefficient resource allocation, and increased maintenance costs. However, by effectively integrating new monitoring technologies, the industry aims to overcome uncertainties and risks, unlock their full potential, and enhance asset management practices. This proactive approach allows for the comprehensive utilisation of the data gathered, enabling the detection of relevant patterns and insights that can highlight underlying asset management issues. By harnessing the capabilities of these technologies, the rail industry can optimise maintenance planning, minimize disruptions, and achieve cost benefits that surpass their initial perceived expenses. Ultimately, this integration will lead to improved asset performance, enhanced safety, and increased operational efficiency.

7.7.1.3. Subproblem addressed by the use case and measurable objectives

The use case addresses the sub-problem of identifying and addressing asset management issues that will be enabled by the integration and combined usage of new monitoring technologies. The measurable objectives include:

a. Experimenting with the data collected from the new monitoring technologies to identify relevant patterns and insights related to asset management.

b. Leveraging the expertise of data scientists to analyse the data and detect potential issues or challenges that may impact asset management processes.
c. Developing a deeper understanding of the relationship between the data generated by the monitoring technologies and the asset management objectives.
d. Identifying specific asset management issues that can be addressed through the integration of new monitoring technologies and proposing suitable solutions.
e. Assessing the feasibility and effectiveness of integrating the new monitoring technologies into the asset management framework through pilot projects or demonstrations.

The use case can be seen as consisting of two distinct steps:

- In the first step, we focus on the direct utilisation of technology and its data, linking it to specific rail infrastructure issues. This phase aims to quickly address and tackle targeted problems, potentially leading to immediate benefits and quick wins. (it represents this use case 11.1).
- In the second step, we adopt a more scientific and comprehensive approach. We explore the integration of data from different technologies to achieve more accurate and insightful results. This stage involves a deeper analysis of the data to uncover additional information about the infrastructure's behaviour, condition and potential issues. While this step requires more effort and resources, it promises to provide a more thorough understanding of the railway system and its performance (it represents the following use case 11.2).

We will follow a layered approach by developing a set of specific applications relevant for end-users. These applications will leverage the high-level architecture of the prototype platform (see D11.1) in the two different use cases, contributing to the high-level demonstrator (#4) with several mixed-traffic and highspeed pilot demonstration sites in Spain and the Netherlands (see section 7).

7.7.1.4. Influence of the proposed innovation on the IM/RU problem

The proposed innovation of linking new monitoring technologies to asset management issues addresses not only the rail infrastructure manager's problem but also meets the needs of various users, such as engineering companies and maintenance service providers. By proactively identifying and mitigating potential challenges and risks, this innovation benefits multiple stakeholders involved in asset management. Through data experimentation and collaboration with data scientists, the innovation enables the detection of relevant patterns and insights that unveil underlying asset management issues.

This proactive approach empowers the industry to anticipate and tackle these issues before wider deployment, resulting in minimised disruptions, optimised maintenance planning, and reduced costs. Ultimately, this innovation empowers rail infrastructure managers, engineering companies, and maintenance service providers to make informed decisions based on a comprehensive understanding of asset conditions. This comprehensive approach leads to improved asset performance, enhanced safety, and increased operational efficiency, benefiting all stakeholders involved in the rail ecosystem.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Application	Use case	Explanation	Pilot location
Reality Model	11.11 & 11.2	Uses different technologies, however not really data fusion technology.	Netherlands
Holistic Switch Monitoring and Diagnostic Model	11.1 & 11.22	Utilizing information from established monitoring (e. g. wayside switch monitoring) and inspection (e.g. track geometry measurements) technologies with new embedded technologies, machine learning and traceable diagnostic models.	Netherlands
Multi-Sensor Track Monitoring	11.1 & 11.2	Fusion of axle-box accelerations with image data and information from ground penetrating radar.	Netherlands
Detection of Fasteners with ABA	11.1 & 11.2	Development of a reliable signal filtering and processing algorithm for the detection of fastener defects, using tagged image data to select track segments with the desired defects where the ABA signal is to be analysed.	Netherlands
Sound Recordings from ABA for Diagnostics	11.1 & 11.2	Development of an accurate digital twin of LEONARDO to enhance the vehicle-borne Multi-Sensor Track Monitoring by introducing system knowledge based on enhanced models.	Netherlands
Track Geometry Measurement from Passenger Vehicle	11.1	ABA signals are used.	Spain
Inspection Turnouts: Analysing 3-Dimensional Reconstruction	11.1 & 11.2	Establish the health status of turnouts by analysing their three-dimensional reconstruction.	Spain
Switch Monitoring	11.1 & 11.2	Uses various technologies and functionalities.	Spain

Table 68: Linking (new) monitoring technologies to asset management issues prototypes

7.7.2. UC11.1: Demonstrator's KPI

7.7.2.1. List of KPIs and related justification for the choice

The objectives of this use case are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	High/direct
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 69: UC11.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
11.1-1	Detection of anomalies	NA
11.1-2	Diagnosis of anomalies	NA

Table 70: UC11.1 PIs

<u>Relation to FP3-IAM4RAIL's project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	We consider different applications and apply a holistic approach. For each application, a dataset is being set up and will be analyzed to define the ground truth, serving as the basis for testing the developments. Baselines and targets are established for each application and will be addressed in WP11 during the course of the project.
VII	Infrastructure Operation: reduction of service failures (25% reduction)	
IX	For repair: extension of remaining life (25%)	
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	
XIV	Cost reductions of the interventions (by at least 10%)	

Table 71: UC11.1 direct KPI impact

7.7.2.2. PI11.1-1 – Detection of anomalies

Short description

Sensitivity of the anomaly detection algorithms, i.e. the number of anomalies detected by the algorithms with regards to ground-truth datasets.

How to compute PI11.1-1

$$PI_{11.1-1} = \frac{Number\ of\ anomalies\ detected\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

Where:

- Number of anomalies detected implies the use of new algorithms to detect anomalies
- Number of anomalies in ground truth data is the total amount of anomalies

7.7.2.3. PI11.1-2 – Diagnosis of anomalies

Short description

Sensitivity of the anomaly diagnosis algorithms, i.e. the number of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to ground-truth datasets.

How to compute PI11.1-2

$$PI_{11.1-2} = \frac{Number\ of\ anomalies\ diagnosed\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

Where:

- Number of anomalies diagnosed implies the use of new algorithms to diagnose anomalies.

- Number of anomalies in ground truth data is the total number of anomalies.

7.8. UC11.2: Fusion of (on-board and wayside) monitoring data for enhanced fault detection and diagnosis

This use case contributes to demonstrator #4 (Asset Management & Infrastructure) of the project by focusing on the fusion of on-board and wayside monitoring data – and potentially other sources – to improve fault detection and diagnosis in the rail infrastructure subsystem. The objective is to develop a holistic monitoring environment that exploits multi-sensor and multi-vehicle modular architectures, combined with advanced algorithms and models, to enable enhanced fault detection and diagnosis capabilities. The use case aims to demonstrate the effectiveness of fusing data from different sources for more accurate and timely detection of faults, leading to improved maintenance decision-making.
The use case is developed in WP10 task 10.2 “Initial developments and quick wins for MSMP demonstration” and WP11 task 11.3 “Analytics and decision support for short term MSMP-based management and work preparation” and task 11.4 “Integrated Demonstration – considering the Use Case and next exploitation strategies”.

7.8.1. Overall aim of the use case

7.8.1.1. Problem to be solved

The problem is the limited effectiveness of current fault detection and diagnosis methods in the rail industry, as existing monitoring systems rely on either on-board or wayside sensors, providing only a partial view of asset condition. This limitation hinders accurate and timely fault detection, leading to increased maintenance costs, operational disruptions, and potential safety risks.

This use case addresses the above problem by focusing on the fusion of individually tested data sets from on-board and wayside monitoring solutions. The main objective is to combine these data sets to confirm and enhance the accuracy of findings for specific asset issues while also identifying new ones through the utilisation of combined data. The approach involves integrating and analysing data from various monitoring sources to improve fault detection and diagnosis in the rail infrastructure subsystem.

By combining data findings and utilising advanced algorithms and models, the use case aims to develop comprehensive and effective solutions for maintenance decision-making. This requires the application of new data analytics techniques to handle multiple data sets of different kinds and natures. Through this use case, valuable insights will be gained on how to approach the integration and analysis of diverse data sets, leading to improved maintenance strategies and the overall readiness of the technology for real-world implementation in the rail industry.

7.8.1.2. Industry current position / baseline

Currently, fault detection and diagnosis in the rail industry heavily rely on manual inspections, periodic maintenance activities, and limited sensor data. These approaches are time-consuming, labour-intensive, and may not detect subtle or intermittent faults. Additionally, there is a lack of integration between on-board and wayside monitoring data, limiting the overall effectiveness of fault detection and diagnosis.

Furthermore, the industry has not fully leveraged the potential of combining data sets from different sources, and the application of modern data analytics techniques is still relatively new. This means that the industry has yet to explore the benefits of utilizing advanced algorithms and models to analyse and interpret the combined data. By overcoming these challenges and embracing the integration of data sets and modern data analytics, the rail industry can significantly enhance fault detection and diagnosis capabilities, leading to improved maintenance practices, more efficient resource allocation, and ultimately, safer and more reliable rail operations.

7.8.1.3. Subproblem addressed by the use case and measurable objectives

The use case addresses the sub-problem of fusing on-board and wayside monitoring data to enhance fault detection and diagnosis in the rail infrastructure subsystem. The measurable objectives include:

a) Developing monitoring systems that utilise multi-sensor and multi-vehicle modular architectures for data acquisition; this includes collecting the data from different sources and matching the different data sets based on the asset, the location, and the time.
b) Implementing advanced algorithms and models for fault detection and diagnosis, leveraging the fused data from on-board and wayside sensors as well as additional relevant information.
c) Demonstrating the capability to assess the health condition of turnouts through anomaly detection and early prediction of failures.
d) Developing decision support tools based on unsupervised, supervised, and reinforcement learning approaches to aid maintenance decision-making.
e) Achieving higher TRL (Technology Readiness Level) for the developed fault detection and diagnosis solutions, indicating their readiness for real-world implementation.

The use case can be seen as consisting of two distinct steps:

- In the first step, we focus on the direct utilization of technology and its data, linking it to specific rail infrastructure issues. This phase aims to quickly address and tackle targeted problems, potentially leading to immediate benefits and quick wins (it represents the previous use case 11.1.).
- In the second step, we adopt a more scientific and comprehensive approach. We explore the integration of data from different technologies to achieve more accurate and insightful results. This stage involves a deeper analysis of the data to uncover additional information about the infrastructure's behaviour, condition and potential issues. While this step

requires more effort and resources, it promises to provide a more thorough understanding of the railway system and its performance (it represents this use case 11.2).

We will follow a layered approach by developing a set of specific applications relevant to end-users. These applications will leverage the high-level architecture of the prototype platform (see D11.1) in the two different use cases, contributing to the high-level demonstrator (#4) with several mixed-traffic and high-speed pilot demonstration sites in Spain and the Netherlands (see section 7). This use case is demonstrated based on specific applications.

7.8.1.4. Influence of the proposed innovation on the IM/RU problem

The proposed innovation of fusing on-board and wayside monitoring data for enhanced fault detection and diagnosis greatly improves the rail infrastructure manager's ability to identify and address faults in a timely and accurate manner. By integrating data from multiple sources, the innovation provides a more comprehensive view of the asset condition, enabling the detection of subtle or intermittent faults that may otherwise go unnoticed.

This allows for proactive maintenance interventions, reducing the risk of asset failures, minimizing operational disruptions, and improving safety. The application of advanced algorithms and models further enhances the accuracy and reliability of fault detection and diagnosis, enabling maintenance experts to make informed decisions and optimise maintenance planning. Ultimately, the innovation improves the overall asset reliability, reduces maintenance costs, and enhances the operational performance of the rail infrastructure subsystem.
In addition, the following prototypes will be developed and deployed to achieve the expected results:

Application	Use case	Explanation	Pilot location
Reality Model	11.1 & 11.2	Uses different technologies, however not really data fusion technology.	Netherlands
Holistic Switch Monitoring and Diagnostic Model	11.1 & 11.2	Utilising information from established monitoring (e. g. wayside switch monitoring) and inspection (e.g. track geometry measurements) technologies with new embedded technologies, machine learning and traceable diagnostic models.	Netherlands
Multi-Sensor Track Monitoring	11.1 & 11.2	Fusion of axle-box accelerations with image data and information from ground penetrating radar.	Netherlands
Detection of Fasteners with ABA	11.1 & 11.2	Development of a reliable signal filtering and processing algorithm for the detection of fastener defects, using tagged image data to select track segments with the desired defects where the ABA signal is to be analysed.	Netherlands

Application	Use case	Explanation	Pilot location
Sound Recordings from ABA for Diagnostics	11.2	Sound is an extra parameter to be used only in conjunction with other signals such as ABA.	Netherlands
Sound Recordings from ABA for Diagnostics	11.1 & 11.2	Development of an accurate digital twin of LEONARDO to enhance the vehicle-borne Multi-Sensor Track Monitoring by introducing system knowledge based on enhanced models.	Netherlands
Occlusion Monitoring due to Vegetation	11.2	Development of a vision-based monitoring system to detect interferences between trees and critical railway infrastructure elements that could feed a smart maintenance system.	Netherlands
Monitoring Turnouts Acceleration Signals	11.2	Development of a non-intrusive monitoring system to estimate crossing degradation using databases generated by computational models.	Spain
Rail Crack Detection using Microwaves	11.2	Radiofrequency technology to detect the presence of cracks.	NA
Inspection Turnouts: Analysing 3-Dimensional Reconstruction	11.1 & 11.2	Establish the health status of turnouts by analysing their three-dimensional reconstruction.	Spain
Switch Monitoring	11.1&11.2	Uses various technologies and functionalities.	Spain

Table 72: Linking (new) monitoring technologies to asset management issues prototypes

7.8.2. UC11.2: Demonstrator's KPI

7.8.2.1. List of KPIs and related justification for the choice

The objectives of this use case are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	High/direct
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 73: UC11.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
11.2-1	Detection of anomalies	NA
11.2-2	Diagnosis of anomalies	NA

Table 74: UC11.2 PIs

Relation to FP3-IAM4RAIL's project KPIs

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP9	WHY
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	We consider different applications and apply a holistic approach. For each application, a dataset is being set up and will be analyzed to define the ground truth, serving as the basis for testing the developments. Baselines and targets are established for each application and will be addressed in WP11 during the course of the project.
VII	Infrastructure Operation: reduction of service failures (25% reduction)	
IX	For repair: extension of remaining life (25%)	
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	
XIV	Cost reductions of the interventions (by at least 10%)	

Table 75: UC11.2 direct KPI impact

7.8.2.2. PI11.2-1 – Detection of anomalies

Short description

Sensitivity of the anomaly detection algorithms, i.e. the number of anomalies detected by the algorithms with regards to ground-truth datasets.

How to compute PI11.2-1

$$PI_{11.2-1} = \frac{Number\ of\ anomalies\ detected\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

Where:

- Number of anomalies detected implies the use of new algorithms to detect anomalies
- Number of anomalies in ground truth data is the total number of anomalies

7.8.2.3. PI11.2-2 – Diagnosis of anomalies

Short description

Sensitivity of the anomaly diagnosis algorithms, i.e. the number of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to ground-truth datasets.

How to compute PI11.2-2

$$PI_{11.2-2} = \frac{Number\ of\ anomalies\ diagnosed\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

Where:

- Number of anomalies diagnosed implies the use of new algorithms to diagnose anomalies
- Number of anomalies in ground truth data is the total number of anomalies

7.9. UC12.1: Multiscale monitoring of civil assets

This use case aims to design, develop, and implement a system for managing the entire life cycle of civil infrastructure assets, railway infrastructure, and surrounding territories. Maintenance activities are often managed separately and not integrated, requiring a more holistic approach. Information from various data sources must be jointly exploited to support the decision-making of IM operators.

The use case is developed in WP12 subtask 12.3.1 “Multiscale monitoring of civil assets”.

7.9.1. Overall aim of the use case

7.9.1.1. Problem to be solved

The objective is to minimize response times during emergency phases. Use Case tackles civil infrastructure monitoring (railway bridges), hydrogeological risk, vegetation encroachment, and third-party interference.

Civil infrastructure monitoring (railway bridges)
The Italian railway network, due to the complex orographic structure of the national territory, is among those with the highest number of bridges in Europe. Most of the existing infrastructures have been developed starting from the second half of the nineteenth century. Currently, RFI S.p.A. (a company of the FS group) manages, in over 16,700 km of network, about 23,100 civil infrastructures (bridges, viaducts, underpasses, overpasses and overpasses). The basin of Italian civil infrastructures comprises underpasses (37%), bridges (34%), overpasses (22%) and viaducts (7%).

Hydrogeological risk
Hydrogeological instability is caused by weather conditions and affects both Italian territory and population. Railway infrastructure, with over 16,700 km of lines, is also strongly impacted. Timely risk mitigations require awareness of both hydrological risk and asset vulnerability. Mitigations can avoid catastrophic events and repair/maintenance costs. Geomorphological and hydraulic phenomena, triggered by weather conditions like rainfall, raise hydrogeological risk. Knowledge of weather conditions and territory characteristics is essential to mitigate risk.

Vegetation encroachment
Uncontrolled vegetation can lead to damage the infrastructure, hinder routine inspections, and pose safety hazards. In the case of railway lines, vegetation can fall onto trains, obscure railway traffic lights, and block visibility at level crossings. These hazards can result in accidents and service disruptions. Therefore, it is crucial to regularly inspect vegetation located inside and near infrastructure corridors to identify which vegetation requires pruning.

7.9.1.2. Industry current position/baseline

Civil infrastructure monitoring (railway bridges)
RFI monitors the entire railway network and conducts inspection visits for bridges, viaducts, and underpasses. Since 2014, corporate regulatory framework mandates specific procedures and operating methods for the inspection of civil infrastructures. Inspections include surrounding areas like watercourses and slopes that could affect infrastructure stability. Every six years, a more in-depth inspection visit is required, using various means to overcome obstacles.

The purpose of inspections is to identify, quantify, and characterise defects according to the DOMUS standard in the Bridge Management System (BMS). BMS allows for optimal maintenance planning and control of civil infrastructure based on structural and operational factors. The post-processing phase follows the site inspection to create 3D models and sketches. Remote piloted

aircraft systems (UAVs - drones) can aid inspectors in cases where working at contact distance is prohibitive due to complex terrain or structure geometry.

Hydrogeological risk

Best practices for mitigating hydrogeological instability vary based on the type of problem being addressed. Geomorphological and hydraulic phenomena are treated differently, even though rainfall can trigger both. FSI continuously maps real and potential hazards to infrastructure, using Hydrogeological Structure Plans and Flood Risk Management Plans issued by District Authorities. GIS tools are employed to associate hazards with infrastructural assets and prioritize mitigating actions. Mitigating actions are guaranteed through both long-term strategies and real-time monitoring. In situ studies are conducted following critical events, using numerical calculation models. However, District Authorities seldom update Hydrogeological Structure Plans and Flood Risk Management Plans, limiting the confidence in risk mapping and common awareness of the risk.

Vegetation encroachment and third parties' interference

Periodic field visits and dedicated video surveillance are used to control hazards caused by vegetation and other interference along railways. Field visits check general infrastructure health, violation of regulations, and effects of water floods. The maintenance management system is updated with the results of field visit activities. Inspections are performed during and outside service time with frequency and means depending on the online type and maintenance requirements. Best practices include daily clearance checks, weekly to monthly surveys with diagnostic trains, and bi-monthly visual inspections by a walking maintainer. Maintenance actions are prioritised based on survey results evaluated by maintainers.

7.9.1.3. Subproblem addressed by the use case and measurable objectives

Civil infrastructure monitoring (railway bridges)

Flight activities inspect all structural elements of infrastructure. Post-processing phase makes data easy for inspectors to use. Two experimental campaigns started in 2016, showed that aerial technology is feasible and effective for civil monitoring. Advantages include physical accessibility and time savings, as well as an abundance of digital details for potential artificial intelligence use. Artificial intelligence algorithms and photographic analysis identify most types of defects for different structural and material types in accordance with RFI BMS provisions (section 2.2.1).

Hydrogeological risk, vegetation encroachment and third parties' interference

Coexistence of various assets requires dedicated inspection techniques. Managing inspections with the right frequency while balancing performance and cost is a challenging task. Using satellite inspections would improve efficiency by allowing for control of infrastructure and inspection of assets with appropriate frequency.

7.9.1.4. Influence of the proposed innovation on the IM/RU problem

Civil infrastructure monitoring (railway bridges)

FS aims to automate the identification of structural problems and defects in civil infrastructure using machine learning. Machine learning algorithms will classify defects, intensity, and extent according to RFI Defect Catalogue. Residual life estimation and predictive maintenance for civil assets are also planned. A newly developed Asset Management Platform will integrate image acquisition, processing, and classification for automatic defect detection and residual lifetime estimation. Developed methodology/tool will reduce in-situ inspection and asset management costs, indirectly reducing costs related to asset unavailability. Automated aerial data gathering (by drones) and novel processing techniques (machine learning) will reduce cumulative assessment time compared to existing methodology (cranes, platforms, scaffolding, manual data inspection, and manual defect classification).

Hydrogeological risk, vegetation encroachment and third parties' interference

Current methodologies being tested include SANF, Ramses, PSF, unmanned drone monitoring, and satellite monitoring of infrastructure. SANF processes data from rainfall detectors to predict critical rainfall events and provide risk estimation for sites. Ramses employs radar-based monitoring, lightning strike monitoring, and climate models to forecast imminent consequences of heavy rainfalls. PSF uses fixed radar stations for landslide monitoring in critical spots and automatically interrupts train operations when dangerously sized obstacles are detected. Unmanned drone monitoring activity uses AI for the identification of hazardous conditions like dangerous vegetation growth and some track defects. Satellite monitoring initiatives like M.O.M.I.T. and EO4I have shown the feasibility and effectiveness of satellite-based monitoring techniques. These results will be used to further develop high/expected TRL for satellite-based monitoring.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
AI aided Vegetation monitoring via satellite and airborne data fusion	MERMEC	Italy	Milan
Bridges inspection via drones and AI	MERMEC	Italy	-
AI Assets classification & detection of anthropic activities via satellite	MERMEC	Italy	Rome
Hydrological risk estimation via AI	MERMEC	Italy	Turin
Hydrological risk estimation via AI	MERMEC	Italy	Ceringiola
Detection of subsidence and land slide via satellite	Adif	Spain	Villar De Silva

Table 76: Multiscale monitoring civil assets prototypes

7.9.2. UC12.1: Demonstrator's KPI

7.9.2.1. List of KPIs and related justification for the choice

The objectives of this use case are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 77: UC12.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
12.1-1	Bridge inspection -reduction of maintenance costs	10 %
12.1-2	Bridge inspection - reduction of traffic disruption caused by traditional bridge inspection in the railway infrastructure	25 %
12.1-3	Reduction of on-track data collection time	10 %

Table 78: UC12.1 PIs

<u>Relation to FP3-IAM4RAIL's project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP12	WHY
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	Technologies developed in this FA introduce drones and digital/IA solutions to reduce maintenance time and human intervention.
VII	Infrastructure Operation: reduction of service failures (25% reduction)	This KPI relates to the time of traffic disruption/speed reduction, impacting the operability of the line directly referring to the number of trains in service. Studying this KPI, the time the section is in temporary speed limitation will be reduced so that the train service will improve.
XIV	Cost reductions of the interventions (by at least 10%)	This KPI relates to time/cost reduction for track data collection with a new monitoring system using remotely acquired data. Global technological leadership is supported by a combination of innovation and technical standards, defining innovative maintenance decision-making concepts. The harmonisation and simplification of maintenance can be achieved by applying and integrating advanced monitoring approaches, data analytics methodologies, and decision support solutions.

Table 79: UC12.1 direct KPI impact

7.9.2.2. PI12.1-1 – Bridge inspection -reduction of maintenance costs

Short description

This PI aims to check whether the current time and cost of bridge inspection and post-processing can be reduced adopting the use of drones for data collection (without interrupting railway traffic) and AI analytics for post-processing. Faster detection of infrastructure damage or defects allows for correct preventive maintenance and early corrective action by infrastructure managers.

How to compute PI12.1-1

PI12.1-1 computes time and cost savings for inspection and post-processing data using new technological system (supporting drones and AI). To evaluate this PI we will use the following formula.

$$PI_{12.1-1} = \frac{Time/Cost_{traditional_method} - Estimated\ time/cost_{new_method}}{Time/Cost_{traditional_method}} \times 100$$

Where:

- Traditional Method Time/Cost is time/cost required for inspection by traditional method. Estimated new method Time/Cost is time/cost required for inspection by new method.

If PI12.1-1 is positive, it indicates that the estimated time/cost (man/hour for activity on singular bridge span) for the new method is less than the traditional method.

7.9.2.3. PI12.1-2 – Bridge inspection - reduction of time of traffic disruption caused by traditional bridge inspection in the railway infrastructure

Short description

Current bridge inspection procedures require momentary interruption of traffic on infrastructure, affecting railway line availability and circulation. Use of drones for inspection reduces railway traffic interruption and improves safety. The use of AI analytics in post-processing speeds up maintenance and introduces predictive maintenance, improving reliability and availability of rail infrastructure. Predictive maintenance can reduce the need for speed restrictions on railways and improve passenger experience by reducing travel times and avoiding unnecessary delays

How to compute PI12.1-2

Time of traffic disruption caused by traditional inspection on bridges can be compared to the new method approach. The time period will be determined based on the available and measurable data.

$$PI_{12.1-2}(\%\ disruption) = \frac{TSRn}{TSRt} x\ 100\ \%$$

Where:

- TSRt: Time of total traffic disruption caused by **traditional** inspection on bridges.
- TSRn: Time of traffic disruption caused by **new** method approach.

7.9.2.4. PI12.1-3 – Reduction of on track data collection time

Short description

This PI aims to check whether the time and cost of inspection of the track and its surroundings can be reduced. IM operators can jointly use data remotely acquired from satellites, drones, in-situ measurements, and ancillary data as support for track and surrounding monitoring (without interrupting railway traffic). Faster detection of critical areas along the track allows for correct preventive maintenance and appropriate actions if necessary. Actions may include high-resolution data gathering, activation of emergency procedures, and mitigation actions.

How to compute PI12.1-3

PI12.1-3 estimates time and cost savings for data collection before and after application of new monitoring approach based on remotely acquired data. To evaluate this PI we will use the following formula.

$$PI_{12.1-3} = \frac{Time/Cost_{traditional_method} - Estimated\ time/cost_{new_method}}{Time/Cost_{traditional_method}} \times 100$$

Where:

- Traditional Method Time/Cost is time/cost required for conventional data collection
- Estimated new method Time/Cost is time/cost required to gather just data after applying new monitoring approach

If PI12.1-3 is positive, it indicates that the estimated time/cost for the new method is less than the traditional method.

7.10. UC12.2: Bridges and earthworks assets management aided by geotechnics

This use case focuses on the definition and installation of monitoring and inspection devices (including MASW (Multi-channel Analysis of Surface Waves), lidar, LVDT or accelerometers as options, among others) for the collection of information in bridge and earthworks assets with specific pathologies. This information is used in WP13 to build predictive maintenance systems for these assets, enabling the transition from data to information and knowledge on the infrastructure state.

This use case is structured in three tasks:

(1) EO data acquisition and processing.
(2) Ground data processing.
(3) Algorithms and platform for asset management.

The use case has been defined and developed in WP12 subtask 12.3.2 “Bridges and earthworks assets management aided by geotechnics”. Following the installations and developments carried out in WP12, in WP13 subtask 13.2.2 “Ground data processing”, will be carried out the data analysis and in subtask 13.2.3 ”Algorithms and platform for asset management” will be carried out the creation of algorithms for the intelligent management of assets (two earthworks and a bridge), generating and managing alarms to assist maintenance work.

7.10.1. Overall aim of the use case

7.10.1.1. Problem to be solved

Bridge assets management

The scope of this demonstrator is the study of premature deterioration of POT bearings in long bridges (close to 1000 meters), in areas with high thermal gradient, especially if they are designed in a curve from a ground plan with trains passing at speeds higher than 300 kph. These bridges with large relative movements between support and deck and high torsional stresses cause the support elements, such as POT bearings, to suffer damage before the expected service life.

For this reason, a 999 m long bridge has been selected for this demonstrator, called Viaduct over Arroyo de las Huertas de Mateo, located on line 040 (Bif. Torrejón de Velasco – Valencia Joaquim Sorolla pk 285+486), which is supposed to be one of the bridges with the most axial displacements in the entire rail network.

Earthworks assets management

The scope of this demonstrator is the study of specific slope movements. The chosen demonstrator area has a long history of problems associated with instabilities, even before the construction of the railway line in 1880. This area presents a high frequency of rainfall and the presence of a reservoir with continuous rise and fall of the water level, favouring the instability of the slope that consequently can cause problems in the infrastructure, such as loss of track geometry and imbalance in train operations.

For this reason, the slope of tunnel 40, located between PP.KK. 277+100 to 277+457 of the Palencia-La Coruña line has been selected for this demonstrator since it has the characteristics described above as currently active landslides.

We would like to set up a predictive maintenance tool based on a low-cost sensor network. This would allow us to monitor the slope movement to identify if the movement is causing progressive damage on our railway line, act with stabilizing measures, and compare results with those of conventional sensors.

On the other hand, a strategic analysis will be carried out based on satellite images, comparing the variability and the difference that may exist between the images taken at each time interval.

The new sensors (inclinometers to be installed on the slope), the satellite images, and the historical geotechnical data will provide us with relevant information related to the behaviour of the slope and its evolution. Specifically, the detection of the movements will be used for the generation and calibration of a Digital Platform that will allow us to perform a statistical analysis to predict the future behaviour related to the movements on the slope.

7.10.1.2. Industry current position/baseline

Bridge assets management

The current Maintenance System is based on the performance of principal and regular inspections. Visual Inspections by personnel specialised in structural pathology (Principal Inspection) or basic training (Regular Inspection) with a certain frequency each of them, from these visual inspections the failure can only be identified when it has already occurred, which leads to the affection of the exploitation.

Earthworks assets management

Regarding earthworks and more specifically slope movements, the current Maintenance System is based on the reading of measuring instruments such as inclinometers, piezometers, obtaining the data every four months.

7.10.1.3. Subproblem addressed by the use case and measurable objectives

Bridge assets management

One of the main objectives of the project is to gather the necessary knowledge and develop a first tool to change the maintenance strategy of these assets, moving from corrective (replacement for damage) or preventive maintenance (replacement without presenting damage, for having completed its useful life) to predictive maintenance, which warns of the deterioration of these elements before the failure occurs (replacement when the asset has exhausted its functionality).

Earthworks assets management

One of the main objectives of the project is to gather the necessary knowledge and the development of a tool to change the maintenance strategy of these assets, moving from corrective maintenance (stabilisation when the failure has occurred) to predictive maintenance with real time data, which warns that an instability is occurring in the slope and can cause affection to the traffic. In addition, another objective is to verify that no movements occur once the projected stabilising measures have been implemented.

7.10.1.4. Influence of the proposed innovation on the IM/RU problem

Advantages over corrective action:

(1) The impact on railway operation is minimised due to the lack of restrictions, usually speed restrictions, which could serve to quantify the impact: accumulated lost time due to the presence of speed limits or cuts in the line due to the loss of geometry in the track.
(2) The planning of the work and the tendering by an open procedure of free competition is more economically advantageous for the IM than the use of emergency procedures or negotiated by urgency.

Advantages over preventive:

(1) The impact on the railway operation is minimised.
(2) The costs of the work are reduced.

Bridge assets management

IAM4RAIL would like to configure a predictive maintenance tool that allows us to know the progressive damage of the bearing to identify the optimal moment to replace them before the failure or the blockage occurs.

To address this, it seems necessary to design an architecture based on local bearing monitoring as LVDT sensors, but also, the project aims to be able to correlate variations on the dynamic behaviour of the bridge with possible damages in bearings. For this reason, an instrumentation based on accelerometers spread across the interior of the girder has been designed. A continuous monitoring of the dynamic behaviour based on operational modal analysis (OMA) techniques will provide modal parameters.

In addition, some accelerometers are to be installed in the transition areas of the bridge on both edges. They will allow a correlation between the bridge structure and the railway platform.

To avoid the lack of monitoring data during the period between the start of the project and the

installation of the surveillance system, remote monitoring from space, based on interferometry applied to synthetic aperture radar (InSAR) images, is proposed. This technique makes it possible to capture seasonal movements caused by thermal effects and even identify past anomalies through a historical study of available images.

Earthworks assets management

It is intended to deploy a network of low-cost sensors with the objective of gathering real-time on-site data correlated with those provided by existing data (inclinometers, piezometers, crack meter and levelling data) in a digital platform to monitor the movements of the slope with the ability to manage alarms and trigger actions to assist maintenance.

On the other hand, a strategic analysis will be carried out based on satellite images, comparing the variability and the differences that may exist between the images taken at each time interval.

The monitoring systems will provide us with relevant information related to the behaviour of the slope and its evolution. In particular, the detection of the movements will be used for the generation and calibration of a Digital Platform to perform a statistical analysis to predict the future behaviour related to the movements on the slope and to verify that the stabilising measures implemented are working properly.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
Bridges monitoring (POT bearings)	Adif	Spain	Minglanilla
Earthworks monitoring	Adif	Spain	Briones
Earthworks monitoring	Adif	Spain	Villar De Silva

Table 80: Bridge and earthworks assets management aided by geotechnics prototypes

7.10.2. UC12.2: Demonstrator's KPI

7.10.2.1. List of KPIs and related justification for the choice

- The KPIs indicated in the two use cases that build the Spanish demonstrator are aimed at measuring the cost and time that is optimised with the development of a predictive maintenance tool, both for the replacement of POT bearings in bridges and the monitoring of slopes with active movements in earthworks with low-cost sensor networks: Predictive maintenance tool for the POT bearing replacement in bridges.
- Predictive maintenance tool for the monitoring of slope with active movements.

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: “Asset Management & Infrastructure” and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	High/direct
IX	For repair: extension of remaining life (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 81: UC12.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
12.2-1	Failure mode predictability	25 %
12.2-2	Reduction of theoretical time per circulation by failures in the railway infrastructure	25 %
12.2-3	Cost reduction of instrumentation equipment for earthworks	10 %
12.2-4	Reduction of costs in the pot bearings replacement	10 %
12.2-5	Effectiveness of slope stabilisation measures	10 %

Table 82: UC12.2 PIs

<u>Relation to FP3-IAM4RAIL’s project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

PI	IMPACT KPI (GA)	WHY?
12.2-1	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Predictive models will be developed through a digital twin. Currently, there are no predictive models in production for Earthworks and Bridges in ADIF, so we cannot make a comparison with existing data.
12.2-2	25% reduction of in-service failures.	This KPI is directly related to the temporary speed restrictions and time lost per each circulation, parameters that influence the operability of the line by delaying and reducing the number of trains in service. Studying this KPI, the time that the section is in temporary speed limitation will be reduced.
12.2-3	Reduction of maintenance costs up to 10%.	Exact knowledge of the costs of the instrumentation equipment and its effectiveness would reduce some maintenance costs, decreasing the unnecessary ones.
12.2-4	Reduction of maintenance costs up to 10%.	The works processed by emergency represent approximately an extra cost for the administrator of between 45% and 65% compared to a work processed by ordinary procedure. So, with proper planning, it would avoid resorting to emergency works.
12.2-5	Reduction of maintenance costs up to 10%. 25% reduction of in-service failures.	If the stabilising measures were fully effective, the maintenance work of the line would be significantly reduced since the instabilities caused losses of levelling and geometry of the track. On the other hand, since there are no more problems in that section, there would be no temporary speed limits on the track that would cause delays in the train service.

Table 83: UC12.2 direct KPI impact

7.10.2.2. PI12.2-1 – Failure mode predictability

Short description

This PI hereby described focuses on determining the frequency and characteristic traces of failures that evolve over time (i.e., which undergo a degradation process), since these types of failures are those that, in principle, can be predicted by models.

How to compute PI12.2-1

Consider records from bridges and earthworks to develop methods for:

1. Automatic identification of systematic trends, and
2. Modelling degradation rate and making future projections.

The objective will be to have one model for earthworks and another one for bridges supporting the characterisation of two trends in each case, such as:

- Bridges: changes due to temperature and degradation of elements.

- Earthworks: changes induced by rainfall.

7.10.2.3. PI12.2-2 – Reduction of theoretical time per circulation by failures in the railway infrastructure

Short description

Predictive maintenance can significantly influence the reduction of speed restrictions on rail infrastructure by enabling early detection of potential problems before they become critical failures that may have an impact on circulation. These speed restrictions represent a reduction in the theoretical time lost for each circulation.

By analysing the information collected by the sensors, the predictive models to be developed will be able to detect patterns and anomalies that indicate potential problems before they become critical failures. This allows them to schedule maintenance before it is needed, helping to reduce unplanned downtime and improve the reliability and availability of rail infrastructure.

How to compute PI12.2-2

Speed restrictions caused by failures in POT bearings on bridges and slope movement problems will be quantified with the current corrective/preventive maintenance approach compared to the future predictive maintenance approach in which maintenance activities can be scheduled without affecting circulation. Time period will be determined based on the available data.

$$PI_{12.2-2} = \frac{TTLa}{TTLt} x\, 100$$

Where:

- TTLt: theoretical time lost for each circulation in the RFIG (Red Ferroviaria de Interés General) caused by problems in bridges and earthworks.
- TTLa: theoretical time lost for each circulation caused by failures in POT bearings on bridges and by problems of slope movements with current maintenance strategy.

The objective will be to reduce the delays (measured in time) due to speed restrictions by 8% to 10%.

7.10.2.4. PI12.2-3 – Cost reduction of instrumentation equipment for earthworks

Short description

The main objective of this PI is to check whether the reduction in costs involved in the implementation of the instrumentation necessary to monitor the hillside occurs. The installation of planned sensors will be low cost and will be compatible with the instruments already installed.

How to compute PI12.2-3

To calculate the cost reduction in slope instrumentation equipment, it is essential to know the cost

of previous monitoring instruments and, based on this data, see the evolution with the sensors of the current IoT network, that is, establish a comparison between both solutions.

Steps to follow:

- Obtaining the historical costs for conventional instrumentation devices of the hillside.
- Obtaining the costs associated with the network of low-cost sensors.

$$PI_{12.2-3} = \left(\frac{COSTS_{\ n} - COSTS_{\ n-1}}{COSTS_{\ n-1}}\right) x\ 100$$

Where:

- n = current monitoring IoT network sensors carried out in the FP3-IAM4RAIL project.
- n-1 =conventional monitoring prior to the FP3-IAM4RAIL project.

Finally, as an interpretation of the results, if the value of the PI12.2-3 indicator is negative, it means that costs with current IoT setwork sensors have been reduced compared to the previous monitoring.

7.10.2.5. PI12.2-4 – Reduction of costs in the pot bearings replacement

Short description

The application of this KPI aims to analyse the reduction in the cost of emergency works respect to a model based on predictive maintenance in which the works are planned through public tender. Indeed, emergency works are often more expensive than works through public tenders.

How to compute PI12.2-4

A comparison of the costs of a typical emergency work will be carried out with respect to the cost through an open public tendering procedure.

$$PI_{12.2-4} = \left(\frac{COSTEW - COSTPT}{COSTPT}\right) x100$$

Where:

- COSTEW: Cost Emergency Work to replace POT bearings.
- COSTPT: Cost Public tender to replace POT bearings + monitoring costs.

7.10.2.6. PI12.2-5 – Effectiveness of slope stabilisation measures

Short description

When severe instabilities occur in an earthwork, measures are designed in order to solve this stability issue. Sometimes, these stabilising measures are not fully effective, and problems continue to occur.

Therefore, the main objective of this PI is to measure the degree of effectiveness of these

stabilising measures that are executed on the hillside. This indicator can only be measured if the installation of the sensor network is carried out before the execution of the works.

How to compute PI12.2-5

The objective here is to verify of there are movements or deformations once the stabilisation measures have been executed. To do this, the trend of the data from the low-cost sensors installed before and after the stabilising measures will be studied.

$$PI_{12.2-5} = \left(\frac{\mathrm{Tb} - \mathrm{Ta}}{\mathrm{Tb}}\right) x100$$

Where:

- Tb: trend sensor data before measurements
- Ta: trend sensor data after measurements.

Interpreting the results, if the PI is equal to 100% it will mean that the stabilisation measures implemented have been correct and it will not be necessary to do any other type of action on the hillside.

7.11. UC12.3: Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels

The Infrastructure Manager's first mission is to guarantee the safety of the rail traffic, in particular by regularly checking the integrity of the platform, shallow subsurface and infrastructures (e.g., tunnel). Thus, the multi-scale diagnosis of the railway platform/structure concerns:

- The platforms to evaluate and control the mechanical state of the subgrade.
- The supporting soil to understand the phenomena of the appearance of disorders in the track, generated by a deterioration of the underlying cavity.
- The tunnels to control the integrity of the structure, identify the damages and monitoring and checking the convergence.

This task will contribute to the development of:

(1) Evaluation of mechanical properties of sub-ballast layers and subsoil in order to understand and apprehend the emergence of disorders in the subsoil by using the MASW method.

(2) High-efficiency tunnel inspection systems to automatically detect visual damage evolution and predictive maintenance for tunnels.

(3) An analysis of the use of passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems.

The use case has been defined and developed in WP12 subtask 12.3.3 "Monitoring of tunnel, sub-

ballast layers, subsoil and predictive maintenance for tunnels".
Following the installations and developments carried out in WP12, in WP13 subtask 13.3.3 "Tunnel monitoring and predictive maintenance", focuses on the development of: High efficiency tunnel inspection systems, based on different imagery systems, associated with software algorithms to automatically detect visual damages; Predictive maintenance for tunnels, i.e. development of algorithms, methodology and predictive maintenance numerical tools applied to tunnels and an analysis of the use of passive contactless magnetic microwire sensor arrays for high definition tunnel convergence monitoring systems.

7.11.1. Overall aim of the use case

7.11.1.1. Problem to be solved

Evaluation of mechanical properties of sub-ballast layers and subsoil
The design, regeneration and maintenance of railway lines require a regular assessment and control (both qualitative and quantitative) of the mechanical condition of the bedding structures and the supporting soil.
Thus, the multi-scale diagnosis of the railway platform concerns:

(1) The platforms to evaluate and control the mechanical state of the subgrade structures.
(2) The supporting soil to understand the phenomena of the appearance of disorders in the track generated by a deterioration of the underlying cavity.

This risk increases because there is not enough evidence of a disorder before the incident occurs. This risk is a major concern for SNCF Réseau, not only in terms of safety but also in terms of economic and social impacts. Emergency maintenance operations must be carried out by SNCF Réseau to ensure the continuity and safety of the traffic, which implies a temporary limitation of the speed, the stopping of the traffic, periodical surveys of the track geometry, permanent monitoring, filling and injection works, etc.
Objective: reach a predictive maintenance by developing and testing a new geophysical approach.

High-efficiency tunnel inspection systems and predictive maintenance for tunnels
Due to the difficult access conditions to these structures and the important interface with rail traffic, regular assessment and control (inspection) require the use of special trains during periods of traffic interruption. Even if tunnel inspections are successfully carried out, the cost is significant.
The recent development of new mobile inspection technologies is an opportunity to reduce these costs. These new technologies can also reduce the part of subjectivity of inspections (performed manually).
In addition, tunnel regeneration operations are very costly due to the specificity, complexity and important interface with rail traffic. Temporary speed restrictions are necessary. Sometimes, long-term traffic interruptions are also necessary. Defining the needs and planning these operations is a crucial issue for Infrastructure Managers.
Since 2006, SNCF Réseau has collected data on damages detected during inspections. The quotation reflects the state of the tunnel. All this data collected is an opportunity to develop algorithms to predict the degradation of tunnels in order to optimise the asset management (planning of maintenance).

Passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels

Railway tunnels are one of the essential assets of the rail transport infrastructure.
Convergence is a term that refers to the distance between the tunnel walls. If the convergence is too narrow, there may be a risk of collision or derailment, which can endanger the lives of passengers and train staff. In addition, convergence also affects the efficiency of the railway system in terms of time and costs.
Therefore, periodic measurement of convergence in railway tunnels is an essential part of ensuring that safety and efficiency standards are maintained in the railway system. Inadequate convergence in railway tunnels can be dangerous and costly.
The convergence sections make it possible to record the deformations of the element to be controlled (tunnel or section between screens), through the measurement of the length variations experienced by various representative chords. This distance measurement can be carried out with very different systems, such as strain gauges, high-precision total stations or laser systems for continuous measurement.
The design of the convergence must also consider factors such as tunnel width, ceiling height, degree of curvature and the maximum permitted speed in the tunnel. Consideration should be given to the characteristics of the trains that will use the tunnel and ensure that the convergence is adequate for their size and speed.
Currently, techniques are used to measure convergence in tunnels that do not allow automated inspections and are wireless to facilitate them.
To conclude, it is important that the convergence is carefully designed and complies with safety standards to avoid collisions or derailments. In addition, the convergence must allow trains to run without interruption and without having to reduce speed significantly and it is also important that monitoring methods are developed that are automatic and simple to set up.

7.11.1.2. Industry current position / baseline

Evaluation of mechanical properties of sub-ballast layers and subsoil

For mechanical characterisation of the sub-ballast layer and the sub-soil and to diagnose the risk of subsidence of the soil support, we use classical geotechnical and geophysical methods, which are punctual, in some cases not accurate and not compatible with the constraints of the railway. This work will help us to gain a better knowledge of our infrastructure, adapt it, reduce maintenance operations and better design the solution. Obviously, safety and economic benefits.

High-efficiency tunnel inspection systems and predictive maintenance for tunnels

Currently, regular tunnel inspections are led by human specialists using special trains without digital technologies. Damages are detected visually and by using a hammer.
New tunnel inspection systems have been developed in the last few years. These systems are mainly based on photography, lidar and infrared thermography technologies. They offer an opportunity to ensure a realistic and very high-definition representation of the tunnels in 2D and

3D. The latest technological developments also allow high-performance acquisition on mobile vectors.
The use of these new technologies for surveillance is an opportunity for SNCF Réseau to further improve its management processes and its asset knowledge. Several tests in operational situations have therefore been carried out with different systems to assess the potential of these new tools and to define their field application for SNCF Réseau structures. The initial feedback shows that these new tools can be a valuable help in identifying and characterising damage without replacing traditional inspections, which remain essential.
On the other hand, since 2006, SNCF Réseau has built digital data on damages detected during inspections (digital report and damages maps). The quotation reflects the state of the tunnel.
All this data will be used to create algorithms for predicting tunnel degradation.

Passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels
In tunnels, auscultation takes on particular importance since their design is generally based on empirical methods or theoretical calculations, according to complex and somewhat uncertain models. In addition, there are also major uncertainties in the properties and behaviour of the ground to be excavated, as well as in its homogeneity along the route, beyond the points where the surveys have been carried out.
Both methods, convergence tapes and topography, are used to provide a complete picture of the tunnel convergence. The frequency of monitoring depends on the complexity of the project and the geological conditions in the tunnel area.
Convergence tapes are devices that are fixed to the ceiling and the wall of the tunnel and measure the distance between them at different points along the tunnel. These measurements are used to calculate the convergence of the tunnel and detect any deformation or deviation from the desired alignment. High-precision convergence tapes have a very high measurement resolution and can detect even small deviations from the desired alignment.
Topography is another tool used for monitoring tunnel convergence. To measure the convergence of a tunnel with topography, control points are established on the ceiling and the wall of the tunnel on both sides. These points are measured using high-precision surveying instruments (theodolites and total stations). Periodic measurements of these control points are made to measure the convergence of the tunnel.
The convergence is calculated by comparing the XYZ coordinates of the control points at different points in time. Deformations and deviations in the tunnel alignment can be detected by comparing the measured values with the expected values.

7.11.1.3. Subproblem addressed by the use case and measurable objectives

Evaluation of mechanical properties of sub-ballast layers and subsoil
To characterise the mechanical behaviour of sub-ballast /sub-soil and monitor areas with sinkhole hazard we aim to:

- Develop a method of surface-active seismic surface waves and create a toolbox (methodology, equipment, software, etc.) that allows orienting the options in terms of design, monitoring and maintenance. This will be tested at specific sites on the high-speed line.

- Develop a passive seismic surface waves method to characterise the mechanical properties of the shallow subsurface, analyse the variation of the shear velocity due to a cavity in the subsurface and study the influence of hydrogeological context on the shear wave velocity analysis. This will be tested at conventional line with gypsum dissolution hazard context.

To reach this objective, we need to:

- Carry out in-situ geophysical tests, define measurement protocols, test processing routines, model physical phenomena of wave propagation in a railway context.
- Correlate the results with field data including geotechnics.
- Clarify expectations in the railway/industrial side for the exploitation of technical results and the expected adaptation in terms of maintenance and works.

<u>High efficiency tunnel inspection systems and predictive maintenance for tunnel</u>

The aim is to deploy new inspection technologies and to predict the evolution of the tunnel degradation.

The necessary tasks for the achievement of the objective of this demonstrator include:

- Concerning the utilisation of new inspection technologies:
  - Define specifications of the technologies to ensure a correct level of damage detection.
  - Define specifications of the measuring system.
  - Define the process and means of data processing and management.
  - Carry out tests in tunnels to verify performance and define limits.
- Concerning the prediction of the evolution of the tunnel degradation:
  - Develop algorithms for predicting the degradation of tunnels.
  - Evaluate the performance of these algorithms (comparison between predictions and reality).
  - Define the process and means of data processing and management.
  - Create an asset management tool based on prediction models

<u>Passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels</u>

The necessary tasks for the achievement of the objectives of this demonstrator include:

- To carry out all the laboratory tests to study the best direction of the microwires in order to obtain the most accurate and real information possible.
- To carry out all the laboratory tests to study the best way to carry out the set up.
- Carry out measurements and calculate the convergence on laboratory samples.
- Estimates of the time required to perform measurements in a relevant environment will be conducted, along with the economic estimates associated with the process.

7.11.1.4. Influence of the proposed innovation on the IM/RU problem

This work by Infrastructure Managers (SNCF and ADIF) will improve the approach to the following points:

- better quantify the disorders on sub-ballast and sub-soil, and anticipate the development of certain disorders;

- limit the number of emergency maintenance operations;
- propose an adapted design to the situation;
- check that the work has been carried out properly;
- optimise maintenance operations from a methodological and economic point of view;
- ensure the safety and operability of the tunnels.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
Monitoring of sub-ballast layers & subsoil	SNCF	France	Hattencourt Migennes Sarresburg
Tunnel inspection	SNCF	France	Abandoned tunnels
Prediction of tunnel degradation via AI	SNCF	France	NA
Magnetic microwires	Adif	Spain	Madrid

Table 84: Monitoring of tunnel, sub-ballast, subsoil & predictive maintenance for prototypes

7.11.2. UC12.3: Demonstrator's KPI

7.11.2.1. List of KPIs and related justification for the choice

The KPIs are intended to measure the reduction of maintenance time and cost of new technological methods for sub-ballast and sub-soil characterisation and monitoring, inspection and predictive maintenance of tunnel and tunnel convergence monitoring with Passive Contactless Magnetic Microwire Sensor.

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 85: UC12.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
12.3-1	Reduction of maintenance times	10 %
12.3-2	Reduction of the maintenance cost	10 %

Table 86: UC12.3 PIs

Relation to the FP3-IAM4RAIL's project KPIs

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP12	WHY
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	• Using and adapting the geophysical method combined with geotechnical data and site context; this will help us be more accurate in the diagnosis and anticipate/adapt the type of maintenance. • Using new inspection technologies and tunnel degradation prediction models. The new technologies should reduce inspection times and provide accurate damage records. Prediction models will use these data to predict the evolution of tunnel degradation and then plan repair

KPI ID	IMPACT IN WP12	WHY
VII	Infrastructure Operation: reduction of service failures (25% reduction)	operations with the greatest possible anticipation and accuracy. • Having an exact knowledge of the cost of the instrumentation equipment and knowing its degree of effectiveness in the measurements, a direct and concise preventive planning would be made that would reduce the maintenance cost since it would only act in what is necessary. • Developing an active seismic surface waves method and create a toolbox (methodology, equipment, software, …) allowing guide choices in terms of design, monitoring and maintenance. Site tests: high-speed line. Develop a passive seismic surface waves method to characterise the mechanical properties of the shallow subsurface, analyse the variation of the shear velocity due to a cavity in the subsurface and study the influence of the hydrogeological context on the shear wave velocity analysis. Site tests: conventional line with gypsum dissolution hazard context. • Using new inspection technologies and tunnel degradation prediction models. The new technologies should reduce inspection times and provide accurate damage records. Prediction models will use these data to predict the evolution of the tunnel degradation and then plan repair operations with the greatest possible anticipation and accuracy. • Utilising microwires for inspections, distances can be covered more quickly compared to traditional inspection methods. Instead of manually inspecting each section of the tunnel, the microwires can continuously collect data as they move through the tunnel. This accelerates the inspection process, enabling results to be obtained in less time.
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	
XIV	Cost reductions of the interventions (by at least 10%)	

Table 87: UC12.3 direct KPI impact

7.11.2.2. PI12.3-1 – Reduction of maintenance times

Short description

The main objective of this PI is to check whether the time needed to perform a measurement is able:

- To adapt the type/nature of maintenance and work for sub-ballast and sub-soil.
- To make tunnel inspections and the planning of repairs operations.
- To control the convergence of the tunnels can be reduced. For this purpose, sensors ("micro-wires") capable of providing accurate information on the convergence of the tunnels will be used. This factor is directly related to a correct preventive maintenance, by knowing in real time what data is being generated, this allows infrastructure managers to detect any changes in convergence early and take corrective action if necessary.

How to compute PI12.3-1

For the two first demonstrators' prototypes, which aim to reach the TRL 7, the estimation of the KPI1 for the two SNCF prototypes will adopt the following formula:

$$PI_{12.3-1} = \frac{Time_{traditional_method} - Estimated\ time_{new_method}}{Time_{traditional_method}} \times 100$$

Where:

- Traditional Method Time is the time required for maintenance and works, including investigations using the traditional method.
- Estimated time new method is the time required for maintenance and works, including investigations using the new method.

For the third demonstrator (microwire), as it has a low technological maturity level (TRL4), it will not be tested in a relevant environment, but will be tested in laboratories, **we can obtain estimates of the time it may take to perform the inspection** and compare it with traditional methods to establish the time saving ratio that could be achieved with the application of this technology.

To evaluate this PI we can use the following formula.

$$PI_{12.3-1} = \frac{Time_{traditional_method} - Estimated\ time_{new_method}}{Time_{traditional_method}} \times 100$$

Where:

- Traditional Method Time is the time required to perform an inspection using the traditional method.
- Estimated time new method is the time required to perform an inspection using the new method.

If PI12-3-1 is positive, the estimated time for the new method is less than the time required for the traditional method. In this case, a positive value indicates a time saving or reduced time needed to complete the task. However, if PI12.3-1 is negative, the estimated time for the new

method is greater than the time required for the traditional method. In this case, a negative value indicates that the new method would need more time than the traditional method.

7.11.2.3. PI12.3-2 – Reduction of the maintenance cost

Short description

The main objective of this PI is to check whether the reduction of maintenance cost is achieved by:

- Reducing the number and type of corrective maintenance operations and adapting the rehabilitation solution to the context, reducing the tunnel inspection times and number of repair operations per year, and implementing the necessary instrumentation to control the convergence of the tunnels.

For this purpose, sensors ("microwire") will be used, which are able to provide accurate information on the convergence of the tunnels. This factor is directly related to a correct preventive maintenance, by knowing in real time what data is being generated, this allows infrastructure managers to detect any changes in convergence early and take a corrective action if necessary.

How to compute PI12.4-2

For the two first demonstrators aiming to achieve TRL 7, the estimation of the PI14.2-2 for the two SNCFR demonstrators to be tested in a relevant environment will be done using the following formula:

$$PI_{12.4-2A} = \frac{Equ.cost_{t.m.} - Equ.Esti_{n.m.}}{Eu\ cost_{t.m.}} \times 100$$

Where:

- Traditional method cost is the cost required for maintenance and works, including investigation using the traditional method.
- Estimated new method cost is the cost required for maintenance and works, including investigation using the new method.

As it has a low technological maturity level (TRL4), it will not be tested in a relevant environment but in laboratories. **We can obtain estimates of the cost it may take to perform the inspection** and compare it with traditional methods to establish the cost ratio that could be reduced with the application of this technology.

To evaluate this PI we can use the following formula.

$$PI_{12.2-2B} = \frac{(Equ.cost_{t.m.} + Wf.cost_{t.m.}) - (Equ.Esti_{n.m.} + Wf.Esti_{n.m.})}{Equ\ cost_{t.m.} + Equ\ cost_{t.m.}} \times 100$$

Where:

- Equipment costs of the traditional method of an inspection ($Eq.cost_{t.m.}$): refers to the costs associated with the purchase, maintenance and calibration of the equipment necessary to carry out the inspection.
- Workforce cost of the traditional method of an inspection ($Wf.cost_{t.m.}$). This is the expenditure related to the time and human effort required to perform the inspection.
- Estimated equipment cost of new method of an inspection ($Eq.Esti_{n.m.}$): refers to the estimated costs associated with the acquisition, maintenance and calibration of the equipment necessary to carry out the inspection.
- Estimated workforce cost of a new method of inspection $Wf.Esti_{n.m.}$). This is the expenditure related to the time and human effort required to perform the inspection.

If PI14.2-2 is positive, it indicates that the estimated costs of the new method (n.m.) are lower than the total costs of the old method (t.m.). In this case, a positive value indicates an economic saving or a reduction in costs, but if the KP2 is negative, it indicates that the estimated costs of the new method are lower than the total costs of the old method (t.m.). If PI12.4-2 is negative, it indicates that the estimated costs of the new method (n.m.) are higher than the total costs of the old method (t.m.). In this case, a negative value indicates an increase in costs or a lack of economic savings in the new method.

7.12. UC12.4: Data Analysis for Condition Monitoring

Monitoring and inspection are generally performed over the whole railway network or at specific locations to have updated information about the condition of the railway assets. Inspections are also conducted for the assessment or final control of third parties performing specific fieldwork. The monitoring and inspection results support evaluating the quality of work, which is essential in competitive maintenance tendering processes.

The use case is developed in WP12 subtask 12.3.4 “Data analysis for condition monitoring”, and in WP13 subtasks 13.4.2 “Analysis of structural condition monitoring techniques”, 13.4.3 “Assessing embankment stability using train borne measurements” and 13.5.5 “Data analysis for condition monitoring demonstrator”.

7.12.1. Overall Aim of the use case

7.12.1.1. Problem to be solved

In this use case, the focus is on the monitoring of bridges and embankments. In the case of embankments, major attention is paid to locations with high rates of deformations, such as transition zones between tracks and bridges. The demonstrators in this use case are located in Norway and The Netherlands, considering test sites that, in spite of all technological advances in sensing, are not yet fully instrumented and for which manual monitoring or sporadic measurement campaigns are conducted at track level. Well-established techniques and instrumentation requirements are considered, with the aim of expanding their application and tailoring them to the local conditions while evaluating the business cases for exploitation that would justify their instrumentation, as today costs are more accessible for such sensing technologies.

For the baseline, manual monitoring is known to be time-consuming, not feasible in large-scale networks and subject to disturbances and subjectivity due to human intervention. Additionally, manual sensing activities through general mapping for small and large projects need track access, i.e., reduced up-time during the daytime or special access at night. High costs and time are required for systematic completions and commissioning tests of construction and development projects (e.g., “first-time runs”). Automated monitoring and inspection can collect the necessary data and minimise operations start delays while providing helpful information to construction teams through various measurements and checks (e.g., tunnel, catenary, track, substructure, earthworks) without necessarily requiring track access. Other challenges include avoiding subjective assessments, lack of rule-book standards (e.g., the definition of thresholds), and difficulty of verification (e.g., lack of data). Furthermore, manual control and inspection require a lot of manual work, and track access is relatively dangerous in confined spaces, especially around overhead electrifications.

Nowadays, sensing technologies allow the monitoring of large-scale railway infrastructures and critical civil structures (such as bridges and embankments) with data collection and processing times that can be achieved in real time and provide almost continuous updates. The technology is now more accessible and digital infrastructures (such as Digital Twins) can be used to find root causes and analyse problems, predict remaining useful life and other key information currently impossible to obtain due to a lack of data or resources to perform the necessary analysis manually. However, to enable the use of data, a consistency between the physical phenomena and an understanding of the advantages and limitations of the measuring technologies is required. For embankments and bridges, we observe that when Infrastructure Managers are not implementing sensing solutions, it is equivalent to missing great opportunities that digitalisation gives to have updated information about these railway components. A bridge reaching its nominal service life could require an early renewal to prevent sudden failures and minimise as many service disruptions as possible. Also, the investments for the complete replacement of a bridge could be postponed some years when the monitoring system indicates the safety conditions still allow it.

Norway: various bridges in Norway are near or over the designed life duration, and they are not instrumented, making it impossible to understand their current health condition fully. The local characteristics of the Norwegian bridges and infra manager operation create the need to implement state-of-the-art technologies for monitoring and assessment under local conditions. Renewal programs are costly, and better methods for RUL estimations are required. Various available data sources and the full instrumentation of a case study are considered in this project. A bridge in the iron ore line is selected due to its accelerated load-induced degradation. Numerical modelling with multibody software is also considered. Tentative bridge: Søsterbekk bridge.

Figure 15: Søsterbekk bridge on the Ofoten line in Norway

<u>The Netherlands</u>: the Dutch railways are highly occupied. Thus, it is difficult to perform manual monitoring without interrupting the service. Then, we evaluate technology based on onboard monitoring with trains in operations for embankment monitoring, relying on the capabilities of available technologies with high TRL levels to assess how much complementary information they can provide about their stability. Track geometry is proven and standard in the industry. We consider including dynamic measurements to update the track condition information with more frequent data under loaded conditions. Furthermore, additional data sources will be assessed to find complementary data to obtain better estimations of the embankment stability. We have analysed the line Dordrecht – Lage Zwalage and are now evaluating other lines, such as Delft-Schiedam.

Figure 16: Sites chosen for the embankment stability study in the Netherlands

7.12.1.2. Industry current position/baseline

Today's methods for monitoring and inspection are discipline-group specific, e.g., one group checks only overhead electrification (typically several people) and requires track access, while another group (at another time) checks superstructure and also requires track access. These methods for monitoring and inspection are subjected to variable data quality, often based on text and subjective judgments without clear evidence. Furthermore, in this use case, we compare current practices, such as manual monitoring, with the tailored implementation of new sensing

and data fusion technologies in the Norwegian and Dutch railway networks. The work in this use case relies on historical data for baseline definition and analysis.

7.12.1.3. Subproblem addressed by the use case and measurable objectives

Automated monitoring and inspection can give consistent and objective data quality using a combination of permanent and mobile instrumentation (acceleration, strain, optics, laser, thermography, ultrasound, etc.), augmenting expert judgment and providing data that can be subsequently analysed. A combination of mobile sensors, permanent sensors and a low-cost, lightweight measurement vehicle (multipurpose inspection robot) can efficiently collect the necessary data for regular and ad-hoc operations. The use case aims to automatise existing manual activities for data collection and analysis. In the Dutch railways, we use well-known technologies (axle box acceleration and track geometry measurements) to determine their relationship with the embankment stability. The full understanding of the complementary provided by new onboard data with historical data will allow the development of an indicator of stability issues. In the Norwegian railways, the analysis of high-danger areas focusing on bridges is considered. The final goal is to reduce costs by enabling condition-based maintenance through automated data collection, analysis and decision support. The use case will also enable the increase in the quality of results with respect to the verification of performed work, especially by third parties.

7.12.1.4. Influence of the proposed innovation on the IM/RU problem

Dutch and Norwegian infrastructure managers do not have the tools discussed in the use case locations that will be developed in this project. The significant renovation costs can be further optimised when the initiative to monitor embankments and bridges is successful. For instance, a well-informed priority list can be created to select which bridges should be renovated first, which require earlier renewal, and which can last beyond their expected useful life. A risk map based on embankment stability information developed in this project can be created for the major track works required. Hotspots and expected behaviour of the embankments can be integrated into current maintenance plans.

Søsterbekk - concrete bridge

Based on the outcome from ST12.3.4, the evaluation of a chosen method by numerical modelling of concrete bridge structures will allow to study methods and models for structural assessment management. The numerical model will allow the introduction and analysis of faults from train-based track measurements and artificial anomalies. Furthermore, anomaly detection algorithms will be developed using the model and will be applied based on measured data in the field. Modelling work will be performed using multibody software to assess the acceleration and behaviour of bridges with full and degraded structural integrity.

Structural assessment management of concrete bridges - More advanced calculations (e.g., nonlinear FE analysis) together with detailed inspections (Non-Destructive Inspections - NDI) and bridge monitoring measurements of the use case will be demonstrated to investigate the current load-bearing capacities and residual service life of the railway bridges made of concrete. Structural

assessment and modelling will identify failure modes in an earlier stage to increase the safety of infrastructure assets. A digital twin will be established to investigate the effects of known failure modes on concrete bridge structures and predict future structural degradation for maintenance and repair mitigation planning. The model will also be used to investigate possible higher load-bearing capacities and constitute a basis for upgrading/strengthening remedies if needed.

The methods developed from this use case could be used as a methodology for structural assessment on other railway concrete bridges and to improve bridge performance, reduce costs and make it possible to improve designs for better and longer lasting bridge designs. The general principle is to extend the life of large concrete structures instead of demolishing and building new ones. This has the potential to save Norwegian society and industry for at least NOK 100 billion. In addition, it can help to reduce the national greenhouse gas emissions by at least 10,000 tonnes over the next ten years.

Embankment stability – Transition zones

For the Norwegian railway, a numerical model of embankment stability will be established in a chosen transition zone on the Often line inspired by the project In2Track3 in Sweden. We will characterise the degradation mode and response of the system to the passage of different trains over time. Finite Elements model, discretisation of parts and connection in a transition zone will be evaluated to see the effect of modifications, to set boundary conditions for design and to monitor them. A numerical model will be established and used for track structure design in order to optimise the track structure dynamic stiffness in railway superstructure and substructure. There is a need for a smooth transition in track elasticity between open track and stiffer constructions, e.g., bridges, tunnels and culverts.

In the Dutch railways, we will analyse a very old railway line with known problems regarding embankment stability (Delft-Schiedam) and a line with mixed traffic (Dordrecht – Lage Zwalage). We will first analyse the relations between track geometry measurements and axle box acceleration (dynamic measurement) at transition zones and conventional tracks. Existing data sets (historical data) and new measurements are being considered using the TUDelft CTO train. Then, we will investigate the relationship between dynamic train loading and the geometry change rate to evaluate locations with excessive deformations. These locations will provide an overview of the affected areas that require further measurements and analysis to assess the root cause of their stability problems.

Finally, this use case will increase safety, improve track geometry and overall track quality, and also reduce degradation of track components and substructure/embankment and reduce maintenance and costs.

Progress in this demonstrator can be seen in the following documents, which acknowledge the FP3-IAM4RAIL project:

- A first step is the analysis of transition zones because these locations degrade faster, and they are places where a drastic change in the embankment design condition happens. We proved that dynamic measurements (ABA) can capture such abrupt change and that ABA allows a

condition estimation of the transition zones https://doi.org/10.1016/j.measurement.2023.112688. KPIs for the continuous monitoring of transition zones using ABA were proposed.

- The application of ABA in three different countries (The Netherlands, Sweden and Norway) for monitoring railway transition zones in various conditions was presented in TRA2024, https://repository.tudelft.nl/file/File_01b77a3e-9f59-4d36-b834-87eedd85fe71. The slides of the presentation are available at the following link: https://repository.tudelft.nl/file/File_f915338d-e193-4f01-bb5b-ba2c3ab24dd3.
- From the previous data-based analysis, we obtained responses in the ABA signals in a low-frequency range that appeared to be characteristics of transition zones. To validate and understand the physical meaning of those responses, we analysed the data obtained from in-situ tests in a bridge in Sweden (between Boden and Murjek), and the results were published at https://doi.org/10.1007/s13349-024-00766-0. The data-based approach indicated two important frequency ranges. In this work, using hammer test, falling weight and ABA, we identified these two frequency ranges. One of them was possibly to be characterised as full-track resonance (ballast-related). However, the other response in the frequency range below is most likely related to the embankment. Yet, the experiments only show the response in the ABA signal, probably due to the insufficient excitation of the traditional hammer and even from the newly designed falling weight experiment.

The efforts so far were focused on transition zones. Current work is focused on whole track condition monitoring, extending the findings from transition zones to other track locations. Finally, we are designing KPIs that combine both ABA and Track Geometry as we observed a relationship between excessive deformations from track geometry and dynamic train loading estimation from ABA measurements.

In addition, the following prototypes will be developed and deployed to achieve the expected results:

Prototype	Lead partner	Country use case	Use case location
Data gathering & analysis for condition monitoring	PRORAIL	Norway	Ofoten line
Data gathering & analysis for condition monitoring (embankments and transition zones)	PRORAIL	The Netherlands	Dordrecht Delft-Schiedam track

Table 88: Data analysis for condition monitoring prototypes

7.12.2. UC12.4: Demonstrator's KPI

7.12.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail demonstrator #4: "Asset Management & Infrastructure" and the related KPIs.

Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure Operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (increase by 25 %)	Little/indirect
IX	For repair: extension of remaining life (25%)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect

Table 89: UC12.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
12.4-1	Track condition monitoring	10 %
12.4-2	Detectability of incipient known failures	10 %

Table 90: UC12.4 PIs

<u>Relation to FP3-IAM4RAIL's project KPIs</u>

Considering the project pathways called the MAWP KPI, the concrete impacts for the described KPIs are the following:

KPI ID	IMPACT IN WP12	WHY
VI	Infrastructure Operation: reduction of maintenance costs (targeting 10% in specific use case)	The current baseline for track condition assessment solely relies on track geometry parameters. However, some limitations in utilising track geometry are indicated before. This use case considers ABA measurements, which can capture train-track interaction, as an additional source of information for track condition assessment. The preliminary results suggest that ABA measurements provide higher sensitivity than track geometry measurements, indicating a higher capability of ABA measurements in detecting track positions with poor embankment conditions, which can be called defects. In addition, due to higher sensitivity and more frequent monitoring operation of ABA measurements than track geometry measurements, an early warning detection framework for track embankment failures can be developed in the future. To compute the KPI, in this state, the KPI is developed to quantify the capability of ABA measurements in track condition assessment regarding the number of detected defects. A positive KPI value suggests that ABA measurements more effectively detect defects than the track geometry parameter measurements, indicating a higher capability for assessing track conditions, particularly in the embankment component. The predicted reductions associated with this KPI will be achieved by incorporating additional information collected during train passages. This approach will enhance the performance of embankment condition assessment, facilitate frequent monitoring, and enable early defect detection. Consequently, it provides valuable insights for maintenance decisions, reducing both maintenance costs and service failures.

KPI ID	IMPACT IN WP12	WHY
VII	Infrastructure Operation: reduction of service failures (25% reduction)	At baseline, incipient faults are either detected through regular inspections (noticed, reported and assessed by ad-hoc inspection) or, worst case, through failures if the fault is fully developed. Regular inspections may not capture all relevant faults at a sufficiently early stage, e.g., due to accessibility or due to long periods between inspections. Early detection will increase safety and give time to plan and execute maintenance actions at a lower cost without compromising safety. If successful, the numerical model, coupled with data from continuous monitoring instrumentation, will enable the description of the properties and behaviour of the bridge and transition zones in much greater detail than what can be provided by instrumentation. This will provide an insight into the link between the measurements and the degradation mechanisms. Defects and damage may also be introduced to study their impact on the bridge response. This allows for the earlier prediction of failure. However, it is important to note that predictions made by a simulation must be understood within the context of a model's validity and assumptions. The KPI will be computed based on a statistical comparison of performance on the detectability of known incipient faults compared with regular baseline inspection (manual inspection). The main failure cases targeted will be: 1. Loss of prestress in tendons, 2. Loss of stiffness in transition zones. The KPI will be calculated individually for the two failure cases. The reduction predicted with this KPI is going to be achieved thanks to the superior performance of an automated analysis of data gathered during a train passage from the bridge itself compared to the manual inspection performed without traffic.

Table 91: Sites chosen for the embankment stability study in the Netherlands

7.12.2.2. PI12.4-1 - Track condition monitoring

Short description

The current baseline for track condition assessment solely relies on track geometry parameters. However, some limitations in utilising track geometry are indicated before. This use case considers ABA measurements, which can capture train-track interaction, as an additional source of information for track condition assessment. The preliminary results suggest that ABA

measurements provide higher sensitivity than track geometry measurements, indicating a higher capability of ABA measurements in detecting track positions with poor embankment conditions, which can be called defects. In addition, due to higher sensitivity and more frequent monitoring operation of ABA measurements than track geometry measurements, an early warning detection framework for track embankment failures is allowed to be developed in the future.

How to compute PI12.4-1

Therefore, in this state, the PI is developed to quantify the capability of ABA measurements in track condition assessment regarding the number of detected defects, as follows.

$$PI_{12.4-1} = \frac{(\text{defect}_{\text{ABA}} - \text{defect}_{\text{TG}})}{\text{defect}_{\text{TG}}} \times 100$$

Where:

- $\text{defect}_{\text{TG}}$ is the number of defects regarding track geometry measurements, from location $x = 1$ to $x = n$. In this case, a longitudinal level at location x, $LL(x)$, is a considered track geometry parameter. Defects must provide a higher longitudinal level than the established limit value, $\widehat{LL}$.
- $\text{defect}_{\text{ABA}}$ is the number of defects regarding ABA measurements, from location $x = 1$ to $x = n$. To identify defects, the SAWP (ABA energy) at location x, $SAWP(x)$, is considered. Defects must provide higher SAWP than the minimum SAWP at locations with a longitudinal level equal to the limit value.

A positive PI value suggests that ABA measurements more effectively detect defects than track geometry parameter measurements, indicating a higher capability for assessing track conditions, particularly in the embankment component.

7.12.2.3. PI12.4-2 – Detectability of incipient known failures

Short description

At baseline, incipient failures are either detected through regular inspections (noticed, reported and assessed by ad-hoc inspection) or, in the worst case, through failures if the failure is fully developed. Regular inspections may not detect all relevant faults at a sufficiently early stage, for example, due to accessibility or due to long periods between inspections. Early detection will increase safety and give time to plan and execute maintenance actions at a lower overall cost without compromising safety. If successful, the numerical model, coupled with data from continuous monitoring instrumentation, will enable the description of the properties and behaviour of the bridge and transition zones in much greater detail than what can be provided by instrumentation. This will provide insight into the link between the measurements and degradation mechanisms. Defects and damage may also be introduced to study their impact on the bridge response. This allows for the earlier prediction of failure. However, it is important to note that predictions made by a simulation must be understood within the context of a model's validity and assumptions.

How to compute the KPI

The PI will be calculated based on a statistical comparison of performance on the detectability of known incipient failures compared to regular baseline inspection (manual inspection). The PI will be calculated using this formula:

$$\mathrm{PI}_{12.4-2} = \frac{n_{mon}}{n_{mon} + m_{ins}} \times 100$$

Where:

- n_{mon} is the number of failures detected by the monitoring system deployed in this project.
- m_{ins} is the number of failures detected by inspection or other means without first being detected by the monitoring system.

The main failure cases targeted will be:

1. Loss of prestress in tendons,
2. Loss of stiffness in transition zones.

The PI will be calculated individually for the two failure cases.

8. Cluster E - Railway Digital Twins

This group of developments focuses on the implementation of railway Digital Twins across the rail sector (WP14 and WP15), relative use cases are listed in Table 92.

UC ID	Title	Relevant WP/DO
15.1	Decision support systems for railway station asset management	WP14/15/DO5
15.2	Blockchain for certification management of railway infrastructure	WP14/15/DO5
15.3	Track Condition data fusion in Point Clouds	WP14/15/DO6
15.4	Point Machine Digital Twin simulation	WP14/15/DO6
15.5	Demonstration of automatic track visual inspection by unmanned means (drones)	WP14/15/DO6
15.6	BIM model as support to communicate and populate the Station's Asset Management System	WP14/15/DO6

Table 92: Cluster E use cases

8.1. UC15.1: Decision support systems for railway station asset management

The implementation of this use case shall provide a modular and expandable instance of data driven decision support using among the others BIM and Digital Twins.
The proposed decision support system in station management will help to combine various data from different areas and concerning various processes (main and auxiliary) that take place at the station and which can be managed.
Data from disparate sources will be included in the data lake structure, that will allow accessing information on multiple levels of decision making, offering support in such decisions like (but not limited to): predictive maintenance, cleanness maintenance, KPI tracking, structural health monitoring and real estate management.
Modular structure of decision support will allow adaptation to different levels of organisational structure.
The use case is developed in WP14 subtask 14.1.1 "Use cases and operational services" and subtask 14.1.3 "Data-driven services for station management" and interfaces with subtask 14.1.2 "BIM modelling for station management".
The use case is demonstrated as part of the WP15 subtask 15.4.1 "Station asset management integrated demonstrator, verification and preparatory works for the second call".

8.1.1. Overall aim of the use case

8.1.1.1. Problem to be solved

There are multiple layers of decision making in different organizations, but certain aspects are common. These multiple layers of decision support require services for each of them, with different levels of interaction with BIM or DT.

Decision support system shall provide modular option extending applications to different levels and needs of particular organisations keeping a simple integrated structure and data exchange.

8.1.1.2. Industry current position/baseline

Decision Support Systems (DSS) for railway stations are software platforms that provide tools and information to help station managers make informed decisions related to station operations. These systems use data analytics and modelling to help station managers analyse complex scenarios and make decisions that are optimised for operational efficiency, safety and passenger experience. Some examples of DSS for railway stations include:

1. Capacity planning tools: capacity planning tools are used to optimise the use of station facilities and resources, such as platforms, ticketing systems and waiting areas. These tools use data analytics and modelling to help station managers understand passenger flows, predict demand and optimise the allocation of resources to meet demand.
2. Incident response systems: incident response systems provide information on incidents that may occur at the station, such as accidents, security breaches or system failures. These systems use data from various sources, such as CCTV cameras, sensors and passenger feedback, to help station managers quickly respond to incidents and minimise disruptions to station operations.
3. Predictive maintenance systems: predictive maintenance systems use data analytics and machine learning algorithms to predict equipment failures and schedule maintenance activities proactively. These systems help station managers optimise maintenance schedules, reduce downtime and improve the reliability of station equipment.
4. Customer feedback analysis tools: customer feedback analysis tools help station managers understand the passenger experience and identify areas for improvement. These tools use data analytics and sentiment analysis to analyse customer feedback from various sources, such as social media, surveys, and customer service interactions.
5. Performance monitoring systems: performance monitoring systems provide information on station operations, such as train schedules, passenger flows and equipment performance. These systems help station managers identify potential issues and make informed decisions to optimise station operations and improve passenger experience.

Overall, decision support systems for railway stations are essential tools for station managers to make informed decisions and optimise station operations to provide a safe, efficient and comfortable passenger experience.

However, the decision support systems for railway stations are used mainly by large stations. Large stations, such as London Paddington Station, Madrid Atocha Station and Berlin Hauptbahnhof Station have more complex operations and larger passenger flows, making decision support systems more necessary to manage and optimise their operations. These stations have more resources to invest in advanced Decision Support Systems as can be the use of technologies like artificial intelligence and machine learning to improve efficiency, safety and passenger experience. For example, the Control Period 6 (CP6) Decision Support System used by Network Rail at London Paddington Station employs machine learning algorithms to predict train delays and improve the accuracy of train timetables. The "Railway Integrated Supervision Platform" used by China Railway Corporation at Shanghai Hongqiao Station also employs AI techniques such as machine learning and image recognition to analyse video feeds from CCTV cameras and detect safety hazards such as people on the tracks or foreign objects on the rail lines. The "Central Control System" used by Sydney Trains at Sydney Central Station employs predictive algorithms to anticipate the arrival and departure of trains and to detect potential conflicts or delays before they occur. The system also uses computer vision technology to monitor passenger flows and congestion patterns within the station and to provide information to station staff. It analyses video feeds from CCTV cameras to detect these patterns.
Overall, AI techniques such as machine learning and image recognition are increasingly being used in decision support systems in railway stations to improve efficiency, safety and passenger experience. However, the available solutions are not scalable to multiple stations and are not focused on municipal level. Moreover, they are characterised by:

- High cost: decision support systems often require significant investment in hardware, software and training. This can be a barrier to adoption, especially for smaller stations with limited resources.
- Limited flexibility: decision support systems are designed to perform specific tasks and may not be easily adaptable to changing operational needs.

8.1.1.3. Subproblem addressed by the use case and measurable objectives

One of the elements considered for the railway station asset management system is the intelligent analysis of videos recorded by CCTV camera recordings. In particular, it will be used to support the cleaning process (detection of rubbish, dirty surfaces, detection of overflowing bins, etc.). The work will utilise state-of-the-art virtual reality simulation technologies to create a digital 'station model', serving as a source of data for learning and testing vision algorithms, including those based on deep neural networks. This approach facilitates the acquisition of a diverse set of training data (to simulate various situations), as well as to carry out initial testing of the system. Moreover, assessing the gap between simulation and reality and developing methods to reduce it, will also be part of the proposed work. The digital model created can also be used in other elements of the system, e.g., for highlighting maintenance issues.

The process of managing the station infrastructure is a complex issue, especially regarding the data used in them. The data comes from different sources and have different formats. Therefore, currently the best solution for storing and analysing them would be to use a data lake, which is a centralised repository that allows large volumes of structured, semi-structured and unstructured

data to be stored and managed at scale. It is designed to store data in its raw, native format, and can hold data from various sources, such as databases, social media, web analytics and sensors. Unlike traditional data warehouses, which require data to be structured before it can be stored, data lakes store data in its original format, making it more flexible for analysis.

A data lake typically uses a distributed file system, to store and manage data across multiple servers or nodes. Data can be ingested into the data lake from various sources using batch processing, streaming or real-time data ingestion technologies. Data can also be accessed from the data lake using a variety of tools and technologies, such as SQL, machine learning, data visualisation and business intelligence tools. Data ingested into the DSS platform will be sourced from existing IT systems utilised by railway station operators. To facilitate this process, a detailed specification for a data acquisition interface will be designed, leveraging the APIs of operator-provided systems. On the data lake side, integration will be implemented using an ETL/ELT pipeline to streamline data extraction, transformation and loading. This solution facilitates the interoperability and integration of heterogeneous existing IT systems with the system architecture developed for the project.

One of the primary benefits of a data lake is that it allows organisations to store and process large volumes of data from various sources in a cost-effective manner. It also enables organisations to perform advanced analytics, such as predictive analytics and machine learning, on the data. Additionally, because the data is stored in its raw format, data scientists and analysts have more flexibility to explore and analyse the data in different ways.

The process of managing the station infrastructure is also an important issue in the context of economic issues.

From the perspective of process management station management, the main goal is to define key performance indicators (KPIs) related to the main process (it is assumed that they will be universal for most stations in the area of interest). The main process KPIs will be based on data collected in the data lake from various sources and formats.

Ultimately, these indicators should determine both economic efficiency and the level of passenger satisfaction, which seems to be the most important from the point of view of the main process. Each main process has auxiliary processes that are supposed to support the main process. The project provides for the creation of KPIs for auxiliary processes - in the case of these auxiliary processes, KPIs should focus mainly on economic efficiency, remembering that they are not superior to the KPIs of the main process.

Predictive maintenance systems have the potential to revolutionise railway stations, particularly in their everyday usage devices such as elevators, door openers, escalators and lighting. By utilising advanced analytics and real-time data, these systems can proactively identify and address maintenance needs, reducing downtime, increasing efficiency and improving passenger experience. For example, predictive maintenance can detect potential issues in escalators or elevators before they result in breakdowns, allowing for timely repairs or replacements. Similarly,

it can optimise lighting systems to reduce energy consumption and improve overall sustainability. However, integrating predictive maintenance systems with decision support systems in railway stations also presents challenges. This includes data integration from multiple sources, ensuring data accuracy and reliability, managing the complexity of multiple devices and systems and developing effective algorithms for predicting maintenance needs. Additionally, overcoming budget constraints and addressing cybersecurity concerns are also key factors that need to be addressed to fully realise the potential of predictive maintenance systems in railway stations.

Final subproblems that will be addressed by decision support systems are:

- Automatic trash detection using video data;
- KPI monitoring dashboards;
- Predictive maintenance dashboards.

8.1.1.4. Influence of the proposed innovation on the IM/RU problem

The proposed Decision Support System for station management will help integrate various data from different areas processes (both main and auxiliary) that occur at the station and can be managed.

Identifying and analysing station processes will allow for the recognition of significant KPIs related to the strategy and the implemented strategic goals. The proposed innovation will primarily consist of identifying new KPIs that have not been noticed or have been overlooked so far, as well as the possibility of a real impact on the management of station assets through continuous monitoring of the level of KPIs and skilful decision-making to improve economic, strategic and organisational efficiency.

What will the improvements be?
Linking various information and identifying key KPIs will improve the station asset management system.

- KPIs will help reduce the information overload to a small number of key data,
- Information will be clear and specific,
- KPIs will be a kind of control tool to check whether the assumed goal is being achieved,
- KPIs allow tracking the progress or decline in the results of a given goal,
- Continuous monitoring will enable effective response to KPIs levels and faster decision in the event of alarming trends or changes in KPIs levels,
- KPIs will be considered in a structure where the main focus will be the KPIs of the main process.

KPIs provide knowledge that enables quick decisions and prioritisation of activities in the implementation of processes. Knowing which elements of our activity function properly and which do not bring results, we can improve and refine the development strategy or the way the station operates.

The proposed decision support system in station management can help in assessing and improving the economic efficiency and efficiency of processes.

8.1.2. UC15.1: Demonstrator's KPI

8.1.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4Rail Demonstrator #5: Asset Management & Digital Twins" and the related KPIs. In addition, it also contributes to the overarching demonstrator #4 "Asset Management of Infrastructure Operation" as well as its KPIs.
Specifically, the FP3-IAM4Rail Grant Agreement connects the DO4 and the DO5 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by the Digital Twin (Increase by 25 %)	High/direct

Table 93: UC15.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.1-1	Number of assets covered by predictive maintenance	25 %
15.1-2	Number of accessibility assets covered by predictive maintenance	50 %
15.1-3	Average time of cleanliness incident detection	25 %

Table 94: UC15.1 PIs

8.1.2.2. PI15.1-1 - Number of assets covered by predictive maintenance

Short description
One of the main functionalities of the decision support system is the implementation of predictive maintenance strategies across assets within railway stations. The PI focuses on measuring the growth in the implementation of predictive maintenance strategies across assets within an organisation. Predictive maintenance involves using data analysis, machine learning and other advanced technologies to anticipate potential asset failures and schedule maintenance proactively, maximising equipment uptime and reducing costly unplanned downtime.

The goal of this PI is to achieve a 25% increase in the number of assets covered by predictive maintenance. By expanding the use of predictive maintenance practices, the demonstrator aims to improve asset reliability, optimise maintenance schedules, increase operational efficiency and reduce overall maintenance costs.

How to compute PI15.1-1

$$PI_{15.1-1} = \frac{N}{M} \, x \, 100$$

Where:

- N is the total number of assets covered by predictive maintenance: this indicator measures the number of assets in the organisation that are actively monitored and maintained using predictive maintenance techniques.
- M is the total number of assets identified in the project to be supported by predictive maintenance.
- Percentage of assets under predictive maintenance: this indicator calculates the percentage increase in the number of assets under predictive maintenance compared to the baseline or previous reporting period.

Target value N = M*0.25

8.1.2.3. PI15.1-2 - Number of accessibility assets covered by predictive maintenance

Short description

Accessibility improvements at railway stations are crucial because they promote inclusivity and ensure that transport services are available to all individuals, regardless of their physical abilities. By making railway stations more accessible, people with disabilities, seniors, parents with strollers and those with temporary injuries can use public transport with greater ease and independence. These enhancements may include installing ramps, elevators, tactile paving and clear signage, which not only accommodate diverse needs but also foster a more inclusive and compassionate society.

Integrating predictive maintenance systems into the accessibility improvements of railway stations offers significant advantages that extend beyond traditional infrastructure. These systems can be instrumental in ensuring the continued functionality and safety of accessibility features. By deploying data analytics on ramps, elevators and other accessibility-specific elements, authorities can proactively monitor the condition of these facilities in real-time. This enables them to detect signs of wear, potential malfunctions or emerging issues before they escalate into critical problems.

As a result, maintenance teams can be alerted to address these concerns promptly, minimising downtime and ensuring that essential accessibility features remain operational for passengers who rely on them. Such predictive maintenance practices not only improve the overall passenger experience but also demonstrate a commitment to inclusivity and accessibility by providing a

seamless and reliable journey for all railway users.

How to compute PI15.1-2

$$PI_{15.1-2} = \frac{N_a}{M_a} x\ 100$$

Where:

- N_a - Total number of accessibility assets covered by predictive maintenance: this indicator measures the number of assets in the organisation that are actively monitored and maintained using predictive maintenance techniques.
- M_a – Total number of accessibility assets identified in the project to be supported by predictive maintenance.
- Percentage of assets under predictive maintenance: this indicator calculates the percentage increase in the number of assets under predictive maintenance compared to the baseline or previous reporting period.

Target value $N_a = M_a*0.50$

8.1.2.4. PI15.1-3 - Average time of cleanliness incident detection

Short description.
Benefits of the decision support system would be:
The PI focuses on measuring the improvement in detecting cleanliness incidents within a common passenger area at railway stations. Cleanliness incidents may include spills, dirt, debris or foreign objects that can impact the cleanliness and safety of the monitored space. The PI aims to reduce the time it takes to identify such incidents by introducing advanced technology solutions, such as continuous video monitoring and automatic object recognition using machine learning algorithms. The goal of this PI is to decrease the average time it takes to detect cleanliness incidents within the monitored area by 25%. By leveraging continuous video monitoring, machine learning-based automatic recognition and based on this analysis decision support system, the organisation seeks to respond more quickly to incidents, improve cleanliness standards, mitigate potential safety risks and enhance overall operational efficiency.

How to compute PI15.1-3

$$PI_{15.1-3} = \left(1 - \frac{\hat{T}_{dss}}{\hat{T}}\right) x\ 100$$

Where:

- $\hat{T}_{dss}$ – average time from event occurrence till detection of cleanliness event via decision support system in hours

- $\hat{T}$ – average time from event occurrence till detection of cleanliness event via standard procedures

Target value of PI15.1-3 = 25%

8.2. UC15.2: Blockchain for certification management of railway infrastructure

This use case constitutes the core feature of an envisioned framework for the railway infrastructure certification that exploit the possibilities offered by blockchain and Digital Twin technologies.
Within the framework, this use case provides the technology and the methods to track the exchanges between the actors involved in the life cycle of the certificates for the infrastructure and to access the related data.
The use case is developed in WP14 subtask 14.4.2 "Blockchain system development" and WP15 subtask 15.3.2 "Blockchain system implementation".
The use case is demonstrated as part of the WP15 subtask 15.4.2 "Virtual Certification Framework integrated demonstrator".
By relying on asset data exposed in a Common Data Environment (CDE), accessible via Federated Data Space and Conceptual Data Model (CDM) and organised as infrastructure Digital Twin, this use case exemplifies the advantages of asset management based on Digital Twins. In this sense this use case supports the demonstrator #5 in GA: Asset Management & Digital Twins (DO5).

8.2.1. Overall aim of the use case

8.2.1.1. Problem to be solved

The Virtual Certification Framework (VCF) aligns different initiatives that address the basic needs of the Infrastructure Manager through the use of Digital Twins. This use case, as part of the VCF, deals with **Certificate issue and management**.
Railway companies need to issue, manage and verify a huge number of certificates from stakeholders, to certify that a product, system or process complies with industry, legal and regulatory standards, safety requirements and specifications. This is necessary to obtain authorisation for placing in service of vehicles and structural subsystems and authorisation to use generic applications, generic products and components.
Where changes are made to the product, system or subsystem, the extent of the changes must be analysed, and a new conformity assessment must be provided if required. When multiple suppliers are involved in manufacturing a product or completing tasks, additional oversight and effort are needed to monitor and ensure compliance. The certification process, according to European regulations, can take many months and cost up to several million euros as in the case of new rolling stock[1].

[1] CEP COM(2013) *"Proposal for a Regulation of the European Parliament and of the Council on the European Union Agency for Railways and repealing Regulation (EC) No. 881/2004"* – 2013, Centres for European Policy Network (CEP): https://www.cep.eu/eu-

To improve this process, the two major challenges are cost reduction and time reduction without compromising the safety, performance and compatibility of the railway.
Among the many factors affecting the performance of the certification process, the following are addressed by the technologies included in the use case:

1. Asset data collection -including evidence of conformity-, organisation and sharing among the actors (IM/RU, maintainers, contractors, validators): this is a time-consuming activity due to multiple sources of information, non-standard data formats and the lack of common data environment. Inconsistency and missing informative elements can lengthen the overall process duration.
2. Certificate retrieval, analysis and update: where paper certificates are used, they can be easily damaged, forged or lost; certificate storing -for both paper and digital certificates- typically relies on heterogeneous archive methods. This leads to inconsistencies and inefficiencies in information management, such as validating how the certificate was created, who, when and how it is stored, distributed and updated during its lifetime.
   Certification consistency and efficient management is critical for timely asset commissioning, maintenance of the conformity assurance, especially when upgrades involve partially overlapping certificate, and liability tracing (e.g. for litigation in case of untimely identification of non-conformity).
3. Certificate issue: achievement of an acceptable degree of confidence of asset conformity for technical requirements that are difficult to verify extensively.
   European and national norms specify the requirements for conformity assessment, although validators have some discretion in identifying evidence of conformity.

For asset subject to physical or scheduling constraints at validation, or for asset validated against requirements on emergent properties (e.g. RAM and safety), validators may need to accept a limited degree of confidence.
This may expose the IM to the risk of partial conformity or undetected non-conformity. Alternatively, asset delivery time and costs may increase in the efforts to overcome such limitations. Asset simulation is expected to alleviate this condition.

8.2.1.2. Industry current position/baseline

Certification Management: with reference to the before mentioned factors affecting the performance of the certification process, best practices in place are as follows:

1. Asset data sharing: information is document-based, closed format and, for a significant part, not machine-readable (without the application of advanced AI algorithms). Access from a party usually requires formal request issued and processed manually. If needed, access rights must be explicitly granted manually on assignment basis. Depending on the context, users of asset data may replicate data locally with consequent problem of consistency: no common data environment is used. Both the data collection and the data processing suffer of these limitations.

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topics/details/4th-railway-package-european-railway-agency-directive.html; UIC eNews Nr 156 *"Focus on TrioTRAIN Project (Total Regulatory Acceptance for an Interoperable Network)"* – 2009 – UIC: https://www.uic.org/com/enews/nr/156/article/focus-on-triotrain-project-total?debut_articles=0&page=thickbox_enews&utm_source=chatgpt.com.

2. Certificate retrieval, analysis and update: existing systems for certification management are heterogeneous, limited in terms of availability, dependent on third parties and time-consuming. Processing is manual.
3. Achieving confidence of conformity: design-based verifications are extensive and routinely make use of asset behavioural simulation for -and limited to- well known critical asset elements and O&M conditions. These verifications are on per-subsystem basis. Verification of the behaviours of integrated systems is postponed to physical works testing prior to commissioning and emergent properties are tentatively captured and measured only during trial operation: the cost of late resolution of non-conformances -or unexpected behaviour- is much higher.
   Moreover, circumstances do exist when it is not possible to test stated equipment performance prior the handover to the IM (e.g. when running train is required but testing schedule cannot accommodate the run before the handover of the equipment), thus forcing the IM to manage possible non-conformities in later stages and with the limited contractual support.

8.2.1.3. Subproblem addressed by the use case and measurable objectives

The VFC extends over all the processes for the certificate management in its life cycle and all the actors involved down to a certain appropriate level of the supply chain.
Processes resulting in an operation on the certificate (issue, checks, update and withdraw, etc.) proceed as sequence of data exchange between actors and data processing within the actors.
Regardless of the specific process, task, data and actors involved, the exchange can be generalised in the form of a request from one party to another and the subsequent response (for the sake of clarity, the applicant for a certificate, e.g. a manufacturer, and a validator, e.g. a conformity assessment body).
This use case addresses how to trace such exchanges and enables access to the related data.
The measurable objectives of UC15.2 are centred on the performance improvements of the certification management processes provided by the blockchain-based solution, as reducing the number of operational steps required for a certification request-response cycle with a suitable system response time.
The non-measurable objectives include improved consistency and reliability of the processes (issue, validity checks, update & withdraw, traceability along the supply chain, etc.), the availability and readiness of the data, the reduction of time in certificate processing and consequent cost savings. For those objectives, both the improved performance and the baseline given by to the current practices are strongly variable depending on the specific context and on difficult statistical analysis.

8.2.1.4. Influence of the proposed innovation on the IM/RU problem

Use of **blockchain** for certification process tracing and certificate management: digitising information is not sufficient to increase efficiency, productivity and quality if the workflow in which digitalised information is managed is inefficient.
Blockchain is a distributed ledger technology that can address these problems due to its ability to

provide traceability, immutability, transparency and verifiability. Historical data such as additions or modifications can be easily traced, and asset data can be easily appended or referred to their certificates to suit stakeholders' needs. Certificates become easier to access as well as to share. Blockchain is expected to optimise the entire certification management process in terms of cost reduction, time reduction, easy distribution, productivity enhancement and quality improvement, going beyond IM's/RU's internal process optimisation.
Use of a **Digital Twin**: address the problem of data accessibility and sharing. It provides a conceptual data model to integrate asset data from a variety of sources and to relate heterogeneous asset models. As shared trough a common data environment, the technology natively regulates access rights. It is an enabling technology supporting the general improvement of all workflows build upon it. For the specific use case of certification management, once certifications are included within the perimeter of the Digital Twin, a change in the data - representing a modification of the real asset which has already happened, or it is planned to be made- can be processed to check for the validity of certifications and related compliance. This enables automatic verification processes, ensuring that any changes to the real asset or its digital counterpart are consistently aligned with the certification requirements. If the modification impacts the validity of the certifications, the system can trigger alerts or initiate workflows to update or revalidate the necessary certifications, thereby maintaining regulatory compliance and asset integrity within the Digital Twin environment.
In general terms, we propose to alleviate all the IM problems considered above by making digitalisation pervasive in the workflows. Currently, the number of assets managed by the Digital Twin, intended as the collection of models and up-to-date asset data for use by the digital processes, is very limited and reduce the possibility to fully exploit the advantage of the proposed solutions.

8.2.2. UC15.2: demonstrator's KPI

8.2.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #5: Asset Management & Digital Twins" and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO5 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect
VII	Infrastructure operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by the Digital Twin (increase by 25 %)	High/direct

Table 95: UC15.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.2-1	System Response Time	≤ 10 sec

Table 96: UC 15.2 PIs

8.2.2.2. PI15.2-1 - System Response Time

Short description

This PI measures the average time taken by the blockchain system to process and respond to a certification request.

How to compute PI15.2-1

Measure the elapsed time from the initiation of a certification request to the system's response. This excludes the time required for data processing.

$$PI_{15.2-1}\ (\text{System Response Time}) = \frac{\sum_{i=1}^{n}(response_time_i)}{n}$$

Where:

- **Response_Time**$_i$ is the time taken for the i-th request-response cycle measure as difference of:
  1. **End Time**: the timing ends when the blockchain system generates and sends the response (e.g., the issued certificate or a status update) back to the requester.
  2. **Start Time**: the timing begins when the certification request is submitted by the requester (e.g., an Infrastructure Manager (IM) or a Notified Body (NoBo)) into the blockchain system.

  Delay due to processing of the data for internal processes (e.g. NoBo verification of conformity) is not counted.

- n is the total number of request-response cycles measured.

8.3. UC15.3: Track Condition data fusion in Point Clouds

The use case proves the use of the Digital Twin to improve different critical asset management processes, such as unlinked database and data silos, lack of merging between Point Clouds and raw data condition and extracted features and digitised assets detached from diagnostic information.

The implementation of this use case will support remote track inspection and verification of the condition of the infrastructure by providing a unique web-based environment that will bridge Point Cloud insights with Track Diagnostic information, digitised assets and railway corridor.

For the collection of the required data streams, various technologies will be used. Namely:

1. Air-borne systems for the acquisition of the orthophotos and the digital terrain models.
2. Train-borne systems with Lidar for the acquisition of Point Cloud.
3. Diagnostic systems with Track Geometry and Overhead Line Geometry systems for the acquisition of condition data.

The geo-referenced digitised assets and mobile surveying data will be synced with the diagnostic data based on GPS coordinates as shown in Figure 1. The visual fusion of the data will occur in a Web-based platform that will use a micro-frontend and micro-services architectural framework that tallows standalone modules to be developed and concurrently linked to each other.

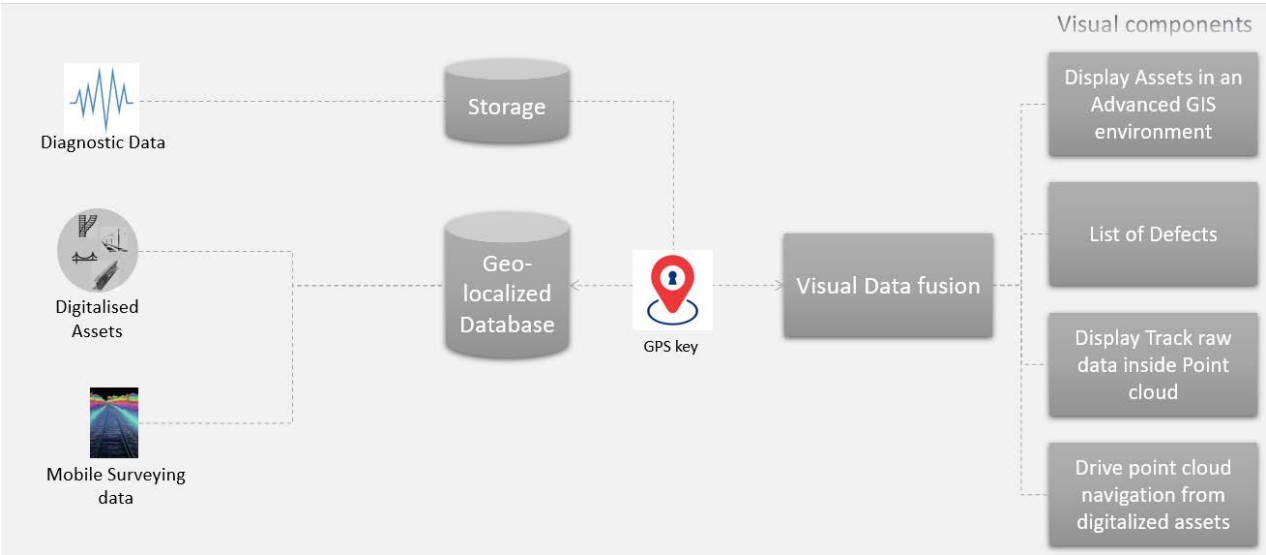


Figure 17: Data fusion process

The outcomes of this use case will support the remote inspection of the Track and Overhead Line geometry, verification of the relative exceedances and improvement of the preparation for maintenance and renewal works in the field by remotely verifying the surrounding environment and sequentially increasing safety by decreasing the so-called “boots-on-track".

The use case is developed in WP14 subtask 14.2.1” Data requirement specifications and architecture definition” and WP15 subtasks 15.1.1 “Data collection for the demonstrated track”, 15.1.2” Implementation, installation and deployment of a Web-based platform for Point Cloud navigation and fusion with track condition and Asset Inventory data information” and 15.1.3 “Implementation of unmanned track data acquisition and evaluation”.
The use case is demonstrated as part of the WP15 subtask 15.4.2 “Virtual Certification Framework integrated demonstrator”.

8.3.1. Overall aim of the use case

8.3.1.1. Problems to be solved

The first problem addressed in this use case relates to the provision of a unique access point for the different data streams that result from asset mobile surveying and diagnostic services. The digitalisation of the railway corridor produces several data streams that, in most cases, sit in different databases and systems, creating data silos. Such data silos block the correlation of the information across different departments, the monitoring of track's condition, and finally, the planning of the maintenance works based on objective data.

Though the use of mobile mapping and the representation of the railway corridor with Point Cloud becomes more and more popular and commonly used by Infrastructure Managers, it remains detached from the raw data condition information collected by the diagnostic systems. Henceforth, embedding raw measurement data inside Point Cloud environment will improve the perception of the track's condition with respect to the surrounding area's characteristics.

Equivalently detached from the raw data diagnostic information are the assets resulting from the digitalisation and feature extraction process of mobile survey mapping. A web-based environment that supports the visual correlation of the digitalised assets with track's raw data condition monitoring outputs will further support the root-cause analysis of the events and drive objectively the decision-making process.

8.3.1.2. Industry current position/baseline

The evolution and development of sensors and diagnostic systems introduce by default a degree of misalignment between the collected data streams but also between the existing historical condition and asset inventory data. Moreover, the outputs of the mapping services conducted as part of the definition and generation of the railway corridor Digital Twin often does not coincide with the existing asset inventory databases across the different departments. Misalignments have been observed in terms of localisation and asset typology. In other cases, asset records are not updated sufficiently after the completion of track and asset renewal works.

Due to the different nature of the data, infrastructure managers use different software environments and tools for their visualisation and assessment. This significantly increases the effort for reviewing the information and makes it difficult to interpret and more importantly, to translate the data into actionable outputs. In addition, the lack of integration leads to increased operational costs and reduced lifespan of the infrastructure.

8.3.1.3. Subproblem addressed by the use case and measurable objectives

The specific use case addresses the following challenges:

- Verification of existing asset databases with the outputs of digitalisation mapping services;

- Integration of surveying outputs such as orthophotos, digital terrain models and cartography maps with digitalised assets;
- Visual synchronisation of multidisciplinary data streams;
- Enriching Point Clouds with track condition raw data measurements;
- Supporting the remote inspection of the track corridor;
- Definition of the software architecture that supports the visual correlation of the different data streams;
- Common localisation among the different data streams.

The virtual track inspection will be improved by the introduction of the track geometry and overhead line geometry measurement points inside the Point Cloud. Similarly, by navigating to the digitalised asset of interest, IMs can obtain additional insights of the surrounding area and can support further the assessment of the overall condition of the specific asset. The following layers of information will be accessible from a single user interface:

- Point Cloud data of the railway corridor
- Track Geometry and Overhead Line Geometry raw data and defects
- Digitalised assets
- Orthophotos of the railway corridor
- Digital Terrain Models of the railway corridor
- Cartography maps of the railway corridor

8.3.1.4. Influence of the proposed innovation on the IM/RU problem

With the proposed innovation, IMs can benefit at two levels; the first level relates to the impact on the revision of the diagnostic information with the fusion of Point Cloud and condition data; the second level relates to the use of single and unique web-based environment that will serve as the unique access point for all these additional data streams.

The fusion of the condition data inside Point Clouds and their sequent inclusion into a web-based environment alongside with other equally important data streams will allow IMs to:

- Increase the quality, accuracy and completeness of the asset infrastructure;
- Provide a holistic view of the track condition that can lead to accurate assessments and prescription of works;
- Improve the overall decision-making process;
- Increase safety by supporting the remote inspection of the track;
- Save operational costs and increase the lifespan of the infrastructure.

8.3.2. UC15.3: Demonstrator's KPI

8.3.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-

IAM4RAIL Demonstrator #5: Asset Management & Digital Twins" and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO5 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VII	Infrastructure operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by the Digital Twin (increase by 25 %)	High/direct

Table 97: UC15.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.3-1	Number of data anomalies found in asset digitalisation	>25%

Table 98: UC15.3 PIs

8.3.2.2. PI15.3-1 - Number of data anomalies found in asset digitalisation

Short description

The construction of the single Digital Twin of the railway infrastructure will increase quality of the asset information compared to the asset information that are currently present in different system SILOs. These data anomalies that are detected during the digitalisation process improve overall the quality and precision of the Asset inventory database. Any anomalies detected during this phase compared to the original state of the infrastructure will indicate increase in the precision, quality and integrity of the asset inventory.

How to compute PI15.3-1

The following formula is used to calculate the PI15.3-1:

$$PI_{15.3-1} = \sum aA^{UC}$$

Where:

- UC, means use case scenario.
- aA, means asset Anomalies detected during the digitalisation process.

8.4. UC15.4: Point Machine Digital Twin simulation

This use case constitutes the core feature of an envisioned framework for the railway infrastructure certification that exploits the possibilities offered by blockchain and Digital Twin technologies.
Within the framework, this use case provides the technology and the methods to track the exchanges between the actors involved in the life cycle of the certificates for the infrastructure and to access the related data.
The use case is developed in WP14 subtask 14.4.2 “Blockchain system development” and WP15 subtask 15.3.2 “Blockchain system implementation”.
The use case is demonstrated as part of the WP15 subtask 15.4.2 “Virtual Certification Framework integrated demonstrator”.
By relying on asset data exposed in a CDE, accessible via Federated Data Space and CDM and organised as infrastructure Digital Twin, this use case exemplifies the advantages of asset management based on Digital Twins. In this sense, this use case supports the demonstrator #5 in the GA: Asset Management & Digital Twins (DO5).

8.4.1. Overall aim of the use case

8.4.1.1. Problem to be solved

Railway companies need to issue, manage and verify a huge number of certificates from stakeholders, to certify that a product, system or process is in compliance with industry, legal and regulatory standards, safety requirements and specifications, and to obtain authorisation for placing vehicles in service and structural subsystems and authorisation to use generic applications, generic products and components.
When changes are made to the product, system or subsystem, the extent of the changes must be analysed, and a new conformity assessment must be provided if required. When many suppliers are hired to manufacture a product or complete tasks, additional oversight and effort is needed to monitor and ensure compliance. The certification process, according to European regulations, can take many months and cost up to several million euros.
Especially during Test & Commissioning, when a product is replaced, a new certificate of conformity needs to be issued. This is where a Digital Twin can greatly support in reducing the overall costs of issuing conformity.

1. During T&C to increase confidence in conformity
    a. as the IM/Contractor’s method to produce evidence of conformity
    b. as the Validator’s method to verify the evidence of conformity

    E.g. virtual testing under various operational conditions, even beyond those strictly required by the norm/std/contractual requirements, possibly including weather conditions.
    The standards on V&V method for Validator’s accreditation may be updated to include these methods.
    It may be used by the IM to accept asset takeover from the Contractor pending completion

of full on-site testing (e.g. impractical arrangements for dynamic testing; statistically unreliable RAM monitoring performance; etc.).

Next during Operations & Maintenance, when a decision is made to modify the infrastructure, rolling stock or O&M model (e.g., increasing traffic with the same train), even if these changes do not appear to affect the conditions of the existing certification, it may still be beneficial to assess the potential impact by simulating the assessor.

2. This includes identifying elements that could forecast a decline in performance (even if within safety limits, such as increased maintenance costs) to modify the extent of the change or plan maintenance activities on those components (e.g. replacement).
   As a result, a re-evaluation of the impact of these changes on current certifications may be necessary. The Digital Twin helps to reduce the efforts of onsite examination.

   For asset subject to physical or scheduling constraints at validation, or for assets validated against requirements on emergent properties (e.g. RAM and safety), Validators may need to accept a limited degree of confidence.

   This may expose the IM to the risk of partial conformity or undetected non-conformity. Alternatively, asset delivery time and cost may increase in the effort to overcome such limitations. Asset simulation is expected to alleviate these conditions.

8.4.1.2. Industry current position/baseline

The Digital Twin today is not yet mature enough to be used for conformity assessments. The requirements shall be defined by assessors or IMs to gain higher confidence in asset performance before Test & Commissioning of the Digital Twin characteristics that can be allowed to be considered.

The current idea is to use a Digital Twin of a Point Machine:

- A switch point contains several point machines.
- Each point machine, as well as the track, is monitored by certain number of sensors to feed into the Digital Twin. For the current demonstrator purpose, one single point machine shall be created digitally and connected to a physical one.
- Data is transmitted to a remote server via a communications gateway using System Pillar defined protocols. For example, SDI and using OPC-UA.
- The server analyses the data received and interprets it with the help of FMUs. In case of multiple computing environments where data collection and algorithms are separated, we plan to use Federated Data Spaces to securely share data between different environments.

- The tester can simulate additional scenarios in a Co-Simulation environment with the help of the Digital Twin using a Web Interface.
- Maintenance managers can visualise the status of Point Machine performance in Digital Twin as if the Point was operated in a real-life scenario.
- The Digital Twin is visualised from a Web UI providing real time data and collaboration.

Such a Digital Twin enables the assessor and maintainer to analyse the functioning remotely without the need for a physical visit. There are still several questions to be answered, such as which Infrastructure Manager will support with the real point machine to replicate as a Digital Twin, and who will own which data, etc.

8.4.1.3. Subproblem addressed by the use case and measurable objectives

The VFC extends over all the processes for the certificate management in its life cycle and all the actors involved down to a certain appropriate level of the supply chain. The Digital Twin assists the VFC.
The measurable objectives of UC15.4 are centred on the performance improvements of the certification management processes provided by the blockchain-based solution, such as reducing the number of operational steps required for a certification request-response cycle with a suitable system response time. The same can be enabled by the Digital Twin by reducing the number of physical visits during analysing the functional tests of Point Machine.
The non-measurable objectives would be the improved consistency and reliability of the processes (issue, validity checking, update & withdraw, traceability along the supply chain, etc.), the availability and readiness of the data and the reduction of time in certificate processing, resulting in cost savings. For those objectives, both the improved performance and the baseline given by to the current practices are strongly variable depending on the specific context and of difficult to statistical analysis.

8.4.1.4. Influence of the proposed innovation on the IM/RU problem

The use of a **Digital Twin**: addresses the problem of data accessibility and sharing. It provides a conceptual data model to integrate asset data from a variety of sources and to relate heterogeneous asset models. As shared through a common data environment, the technology natively regulates the access rights. It is an enabling technology supporting the general improvement of all workflows built upon it. For the specific use case of certification management, once certifications are included within the perimeter of the Digital Twin, a change in the data - representing a modification of the real asset which has already happened or is planned to be made- can be processed to check for the validity of certifications and related compliance. This enables automatic verification processes, ensuring that any changes to the real asset or its digital counterpart are consistently aligned with the certification requirements. If the modification impacts the validity of the certifications, the system can trigger alerts or initiate workflows to update or revalidate the necessary certifications, thereby maintaining regulatory compliance and asset integrity within the Digital Twin environment.

In general terms, we propose to alleviate all the IM problems considered above by making digitalisation pervasive in the workflows. Currently, the number of assets managed by the Digital Twin, intended as the collection of models and up-to-date asset data for use by the digital processes, is very limited and reduces the possibility to fully exploit the advantages of the proposed solutions.

8.4.2. UC15.4: Demonstrator's KPI

8.4.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #5: Asset Management & Digital Twins" and the related KPIs.
Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO5 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure operation: reduction of service failures (25% reduction)	High/direct
VIII	Number of assets managed and monitored by the Digital Twin (increase by 25 %)	High/direct
IX	For repair: extension of remaining life (25%)	Little/indirect

Table 99: UC15.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.4-1	Number of tests enabled	NA

Table 100: UC15.4 specific PIs

8.4.2.2. PI15.4-1 - Number of tests enabled by Digital Twins

Short description
This PI measures the number of conformity tests carried out using Digital Twins vs traditional.

How to compute PI15.4-1
It is an enumeration measure as observed by the assessor in a given situation. In the current demonstrator, our objective is to use Point Machine Digital Twin as an example.
The list of tests carried out by an onsite assessor for the Point Machine functioning before Test & commission are prepared. Among this list, the assessor shall confirm how many can be carried out virtually, without visiting onsite. This forms the basis for the number of tests carried out using a

Digital Twin.

8.5. UC15.5: Demonstration of automatic track visual inspection by unmanned means (drones)

The objective of the use case is to develop an integrated solution for major technical challenges of drone surveillance of railway infrastructure, especially signalling assets by performing the following actions:

- Integration of mission planning and execution: a web-based controlling interface connected to an on-board computer for streamlined office-based waypoint definition and mission planning.
- Extension of regulatory approval for flying beyond line of visibility: safe and secure communication and additional safety measures for the drone.
- Extension of operational range by automatic recharging in intelligent mobile airports.
- Data processing and integration into a Digital Twin: a generalised data model for signalling assets and track, linking reference visual data, used by algorithms to detect failures and clearance envelope violations.

The use case is developed in WP14 subtask 14.2.3 “Unmanned track inspection data and models” and WP15 subtask 15.1.3 “Implementation of unmanned track data acquisition and evaluation”
The use case is demonstrated as part of the WP15 subtask 15.4.3 “Demonstration of track visual inspection by unmanned means (drones)”.

8.5.1. Overall aim of the use case

8.5.1.1. Problem to be solved

Although modern sensors and telemetry offer various ways to remotely detect problems with railway assets, a final visual inspection is often necessary to determine the required nature of maintenance steps and their urgency. Traditional visual inspections by personnel dispatched to the field can be time-consuming, costly, detrimental to normal operations and sometimes hazardous. Drones, with their ability to capture high-quality images, video footage and data from LiDAR and other sensors, can provide a solution to this problem.
However, from the point of view of an Infrastructure Manager (IM), operational deployment of drones presents various challenges. To achieve efficiency savings, the drone needs to fly over a substantial portion of the track, likely passing beyond the operator’s line of visibility. This is an obstacle for getting permission from the civil aviation authority in many jurisdictions and requires communication and control technologies not yet commercially available. Drone operations should be automated as much as possible to enable frequent replicable data acquisition on demand by the Infrastructure Manager, without specialist drone pilots for each mission.
To achieve higher cost effectiveness, the IM needs algorithms for the processing of visual and other data from drones to match them to existing infrastructure models and identify new anomalous states of assets. These algorithms need to be trained on large amounts of data with

the same parameters, including the vantage points.
In short, the IM needs drones that can fly mostly automatically with limited supervision, communicate efficiently with the control post, recharge quickly in the field, and feed data to algorithms that can then automatically match it with integrated models of the infrastructure.

8.5.1.2. Industry current position/baseline

Infrastructure Managers currently combine (1) online remote monitoring of assets by non-visual automatic sensors with (2) periodic visual inspections and (3) on-demand dispatches of personnel to identify problems signalled by (1). In some cases, permanent visual supervision is achieved by fixed-point cameras aimed at particularly vulnerable assets such as boom gates at level crossings. The non-visual sensors (e.g. impedance or current measurements) generally only identify the presence of an unspecified problem with the monitored asset but give little information about which exact part is affected and how. A repair then needs to proceed in two steps, with one field trip for detailed inspection, identification of the necessary replacement part, etc., followed later by another trip for the actual repair. When the affected location is not reachable from roads, the need to travel by rail and obtain track use authorisation for each trip introduces additional delays and costs.
Fixed-point collection of visual data, although a great improvement, has its own drawbacks and associated costs, including the need to continuously send large amounts of data and to maintain the related field equipment, which is vulnerable to theft, vandalism and environmental damage.
The baseline thus offers many opportunities to increase the amount of fully monitored assets by the deployment of unmanned periodic or on-demand supervision from the air.

8.5.1.3. Subproblem addressed by the use case and measurable objectives

Although drones have been available for more than a decade and used for railway asset monitoring since at least 2019 (see e.g. the solutions developed by the British company Plowman Craven) (Plowman Craven, 2023), their routine deployment for the inspection of railway assets still presents various challenges that need to be addressed:

1. Use beyond line of visibility (BEVLOS) when communicating via 5G or 4G mobile networks,
2. Desktop-based mission planning and operation,
3. Reliable processing of collected data to adapt them to other digital infrastructure models and provide input for infrastructure management decision making,
4. Extension of operational range by semiautomatic recharging or battery replacement at mobile “airports”.

The objectives of the use case are to develop an integrated solution that will achieve measurable progress in all these areas. Specifically for item 1, a web-based controlling interface connected to an on-board computer, will enable flexible extension of operational range – this will need to be assessed by the civil aviation authorities. For item 2, the same web-based interface will be integrated with digital maps of the infrastructure to allow streamlined waypoint definition and mission planning. For item 3, a generalised data model will be prepared in WP14 and implementation algorithms developed. For item 4, a prototype of a mobile airport with charging capabilities and protection for the recharging drone will be built.

The demonstrator will be deployed as a TLR6 prototype on AZD-operated test tracks in the Czech Republic.

8.5.1.4. Influence of the proposed innovation on the IM/RU problem

The use of drones for visual inspection will remove many obstacles to frequent and timely identification of defects and significantly reduce costs, risks and the environmental impact of these inspections. Savings calculated by Plowman Craven in 2023 for the related use case of surveying include 20% savings in time, 30% savings in costs and 85% savings in CO_2 emissions compared to traditional methods. Surveying is generally more labour intense and costly than on-demand inspection of suspected defects, but on the other hand, the drone solution discussed in (Plowman Craven, 2023) is not as fully automated as the use case discussed here. Additionally, drones can offer visual inspection of the track surroundings not readily visible from the track itself, e.g. of slopes with landslide risks or areas behind fences with fire hazards, etc.
The use of fully automated drone solutions for visual inspections of railroads is now gaining increasing traction in Asian countries (Harbin Tielu, 2023) (AMP News, 2020). Although there have been attempts by European start-ups to provide similar services (UFlySystems, 2021), the level of integration is currently not satisfactory. The deployment of drone solutions is crucial for achieving the objectives of Europe Rail's Flagship Area 3 "Intelligent & Integrated asset management", specifically "Cost-effective asset management addressing short, mid and long-term interventions widely supported by digital (diagnosis) technologies and data analytics." (EU-Rail Governing Board, 2022, str. 34).

8.5.2. UC15.5: Demonstrator's KPI

8.5.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #5: Asset Management & Digital Twins" and the related KPIs. In addition, it also contributes to the overarching demonstrator #4 "Asset Management of Infrastructure Operation" as well as its KPIs.

KPI (GA)	Description	Impact
VI	Infrastructure operation: reduction of maintenance costs (targeting 10% in specific use case)	High/direct
VII	Infrastructure operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by the Digital Twin (increase by 25 %)	High/direct
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect
XV	Societal impact: support to rail workers - Exoskeletons are used to perform strenuous tasks, such as safely moving heavy loads.	Little/indirect

Table 101: UC15.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.5-1	Number of assets managed and monitored by Digital Twins	15 %
15.5-2	Reduction of maintenance costs	10 %

Table 102: UC15.5 PIs

8.5.2.2. PI15.5-1 - Number of assets managed and monitored

Short description

The focus of the overarching demonstrator is to drive design, maintenance, upgrade and renewal interventions by Digital Twins, digital models of the infrastructure so detailed and realistic that can be directly used for simulations, planning and optimisation of processes. The role of the use case in this objective is twofold:

1) to provide high-volume, high-resolution data for baseline modelling of the infrastructure (both visual and in the form of point-clouds from LiDAR surveying), and

2) to quickly detect precise nature of deviations from the reference state, which allows further use of the Digital Twin for the maintenance workflow without additional field trips.

The KPI must be interpreted in a way that accounts for the current baseline of, strictly speaking, zero monitoring of assets by Digital Twins. In this case, we take the equivalent baseline to be up-to-date visual data about the infrastructure, evaluated over an extended time, e.g. over three months. In such a setup, there would typically be three single routine field visits by the Infrastructure Manager to each part of the track, plus continuous visual streams from fixed-point cameras at level crossings, etc. The use case can, on the one hand, extend the routine visual streams over the entire length of the monitored track, with special focus on assets such as signals or turnout elements which it is currently impractical to monitor visually. On the other hand, it can increase the frequency of visual inspection of the track without increasing associated costs.

How to compute PI15.5-1

The KPI will be computed using the formula:

$$PI_{15.5-1} = \frac{VMTF_{UC} + \sum_{AC} k_{ACi} VMAF_{ACi_{UC}}}{VMTF_B + \sum_{AC} k_{ACi} VMAF_{ACi_B}} - 1,$$

Where:

- VMTF = frequency of visual monitoring of track
- $VMAF_{ACi}$ = frequency of visual monitoring of asset class *i*
- k_{ACi} = coefficient of asset class *i* relative to the track
- UC = use case scenario
- B = Baseline scenario

The coefficients for the different asset classes express the relative importance and cost of monitoring them compared to the track itself. They also consider relative density of the asset class on the track. The assumption is that the frequency will increase relative to baseline while achieving PI2, i.e. overall cost reduction.

8.5.2.3. PI15.5-2 - Reduction of maintenance costs

Short description

The objective of the overarching demonstrator #4 is to integrate on field and on-board systems with central platforms capable of managing Big Data to enable prescriptive interventions, minimising dangerous situations and service disruptions during operation. The use of unmanned visual inspection aims at precisely this objective while reducing overall costs.

This includes costs of the repairs themselves (primarily by reducing the amount of in-person transport and staff time required to carry them out), but also the cost of the disruption which the repair addresses (degraded speed and/or track capacity), and the cost of the monitoring required under traditional conditions (e.g. fixed-point cameras and routine in-person inspections). In particular, the reduction in average repair time translates into direct savings for the Infrastructure Manager.

How to compute PI15.5-2

The PI will be assessed using three components according to the formula:

$$PI_{15.5-2} = 1 - \frac{MRC_{UC} + MDC_{UC} + MMC_{UC}}{MRC_B + MDC_B + MMC_B},$$

Where:

- MRC = mean repair cost (all inclusive)
- MDC = mean disruption cost given the mean repair time
- MMC = mean monitoring cost

- UC = use case
- B = Baseline

For the purpose of validation, identical defects will be simulated and solved in the baseline and use case scenario. Their average weight will be determined by expert assessment and historical data.

8.6. UC15.6: BIM model as support to communicate and populate the Station's Asset Management System

The implementation of this use case will contribute to the creation of an accurate Digital Twin for the demonstrator DO5. To achieve this, the BIM model must contain all the geometric and structured asset data to be used by the asset management system and the DT solution. The principle is to get information for the configuration of the Asset Management and DT from the BIM model of a station trough a standard interface (IFC 4), and also to use this BIM File to build a 3D representation of the Station and animate the status (real or simulated) of equipment.

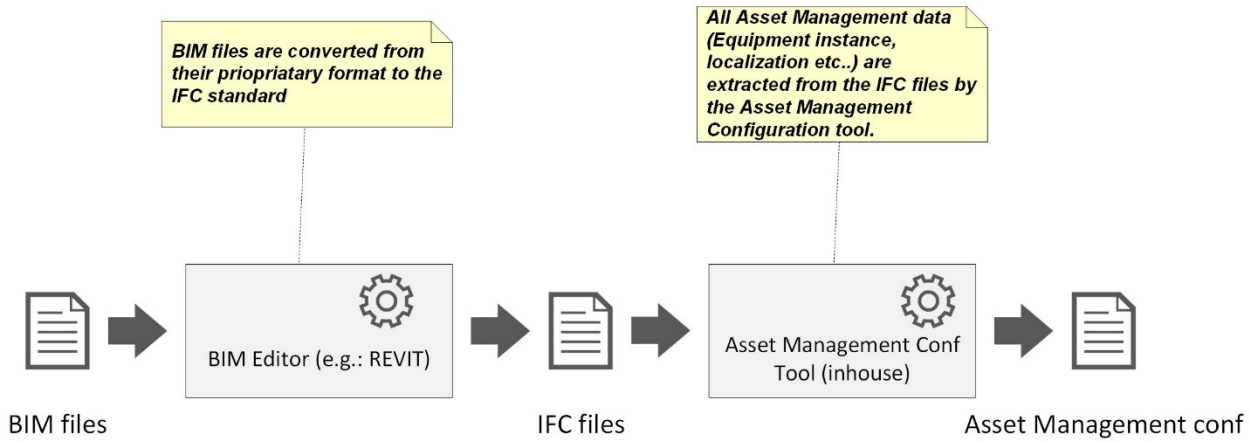


Figure 18: Conversion of BIM files into Asset Management elements

An Asset Management System refers to a structured and integrated approach used by property owners or Infrastructure Managers to monitor, control and optimise the maintenance of their assets throughout their lifecycle.
The use case is developed in WP14 subtask 14.1.2 "BIM modelling for station management".
The use case is demonstrated as part of the WP15 subtask 15.4.1 "Station asset management integrated demonstrator, verification and preparatory works for the second call".

8.6.1. Overall aim of the use case

8.6.1.1. Problem to be solved

There are many problems in terms of the operation and maintenance. Most of the time the information is not complete or structured to be able to be used immediately. To use this information correctly, the Infrastructure Manager wastes a lot of time sorting, organising and capturing information to create a useful data base. Additionally, several times the information is not located in the same place, and there is poor interoperability. One of the most important problems to be solved with the help of this use case is to have a functional station and a global digital solution that concentrates all the information of the station, connecting with real-time data the interaction with the physical world.

To ensure the functionality of station building, the Infrastructure Manager needs information for decision-making and interventions. The availability of information is very important for the planning of maintenance interventions.

In a BIM approach, most of the information is created in the design and construction phases but that information is not necessarily used or updated in the other phases. The current use of BIM is under development, but it is not clear how to implement it, what information should be included and how to structure the information so that it is usable for station management.

This use case will define what type of information must be delivered and used by the operator to ensure the sustainability of the station/building inside a BIM model. It will also define the methodology to create a Digital Twin able to communicate with the assets in the physical world using a BIM model as a source of data regarding assets.

The main problem to be solved is to gain in efficiency at all the stages of the asset life cycle (from the first commissioning up to the asset's end of life) to reduce operation and maintenance costs.

8.6.1.2. Industry current position/baseline

This use case proposes an integrated approach that combines BIM and asset management methodologies to optimise the performance and longevity of infrastructure assets. We will define a process, the technologies to use and the stakeholders.

By leveraging the comprehensive data-rich environment provided by BIM, asset management strategies can be implemented more effectively and efficiently. This integration allows for enhanced decision-making processes, improved asset maintenance and operation, reduced lifecycle costs and increased sustainability.

The integration of BIM and asset management facilitates the transfer of data between the BIM model and the asset management system, ensuring accurate and up-to-date information.

Specialists in the real estate sector globally estimate the annual maintenance cost of a building at 5% of its construction cost. Over time, the cost of maintaining and operating a building can

represent up to 80% of the total cost, with the cost of construction ultimately representing only 20%. It must, therefore, be considered that over the total life of a building, which can be estimated to be between 60 and 80 years, the overall cost will be equal to three or four times the initial construction cost (source: Use of building information modelling technology in the integration of the handover process, 2014).

The Infrastructure Manager can spend six months organising the site's information after delivery. According to The National Institute of Building Sciences (NIBS) costs can reach between 23,000 and 36,000 euros (Freeman 2009). Experience has shown that the earlier reliability and maintainability are considered in a construction project, the better. These should be specifically addressed from the design stage of a project.

One of the biggest challenges during information handover is managing, assessing and validating the handover information quality by the asset management system integrator. The handover documentation often consists of various parts, different types of documents and asset information such as drawings, datasheets, etc. which are available as PDF's, native, files and images. Managing the handover of data and documentation from projects to operations is especially a waste of time because the information is unstructured and not stored in a common environment.

The data's volume is vast and can contain hundreds of thousands of documents and millions of individual data items. Additionally, documents are often delivered with missing, incorrect or inconsistent data. The Infrastructure Manager has the responsibility to ensure that only correct and validated data is loaded into the asset management system. Data handover can account for 1 to 2% of total CAPEX costs.

Currently, it is not clearly described what should be transferred to an IM after the realisation phase. The information specification should be specified according to what information is needed and in what sort of format. This means it is important to filter the needed information for the IM. Secondly, it is still unknown how to transfer the information and how this information can be assimilated into asset management systems. When information about assets is clear and accurate after the handover, a focus can be set on the desired performance of the assets during maintenance at the lowest possible costs. Through using correct information, real-time insights about assets will be possible and predictions can be made. This data can be derived from the BIM, after it is validated. This will result in a more efficient maintenance of the assets.

An innovation in the station's construction industry which is currently growing is called BIM. Building Information Management (BIM) is used more and more in the industry. A BIM Model can work as a database able to hold all the information needed by the IM. The figure below shows how the information is received (unstructured) and the time that is spent to structure the data as needed to be used and integrated in an asset management system.

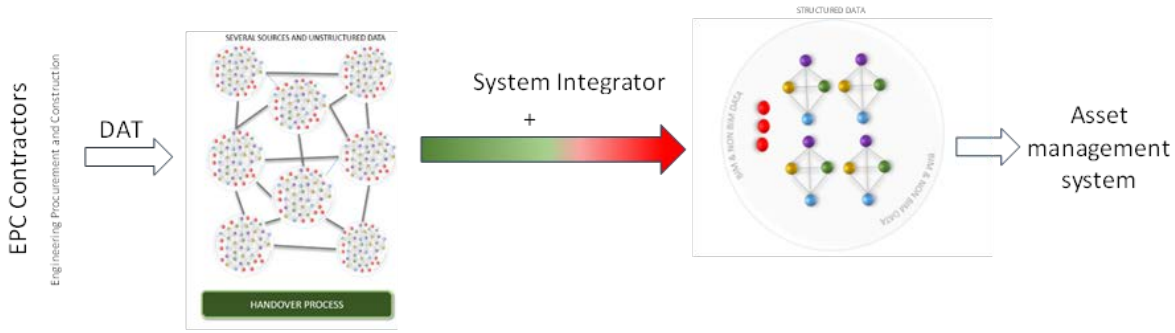


Figure 19: Transformation of Unstructured Data for Asset Management Integration

There may be other stakeholders who can provide more information, making the process even more complex.

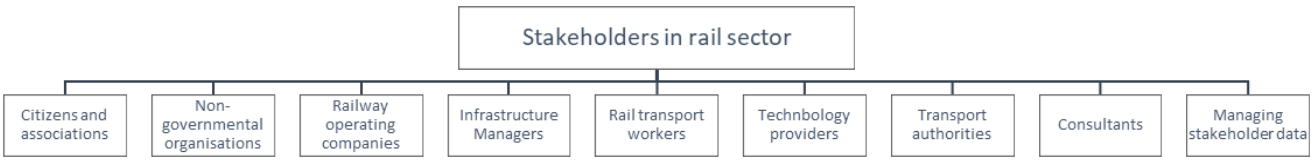


Figure 20: Stakeholders in the Information process

The current asset management process has many shortcomings from the early stages of implementation, which result in increased maintenance costs and reduced equipment life. It is very important to improve this process by using new methods and technologies.

In conclusion, the use case proposed must answer the following questions to improve our current state:

- Which information does an IM need for digital maintenance and what should be handed over after the construction phase?
- How should this information be handed over to the asset manager according to open standards?
- How can the IM validate this as-built information or how can the station manager suffice on the requirements set by the company?
- How can WP14 process this as-built information into their own asset management systems?
- What is the added value for asset management and how can this value be captured during this process?

8.6.1.3. Subproblem addressed by the use case and measurable objectives

Asset management is an important and necessary activity and having an inefficient asset management system can have significant negative impacts on an organisation's efficiency, financials and overall operations.

This inefficiency can also be caused by an inaccurate inventory because the system is not adapted to see the discrepancies between physical assets and the database. As a result, equipment failures may occur more frequently and produce higher maintenance costs due to emergency repairs.
When assets are not adequately managed, employees may waste time searching for tools or equipment, reducing overall productivity and efficiency.

The lack of visibility and control in traditional solutions can represent an additional problem. Rapid advancements in technology can render existing equipment or systems obsolete, making it necessary to invest in upgrades or replacements to maintain efficiency and safety.

The main objectives are to create a Digital Twin using BIM models to:

- Have up-to-date building data "As-built", to reduce maintenance costs, reduce intervention times and increase user satisfaction.
- Identify the process and information required in the BIM Model for asset management interventions.
- Deploy a methodology for updating BIM information.
- Identify the technology needed to develop a BIM-AIM working method and a Digital Twin.
- Establish a methodology for the exchange of information between the asset management system, the Digital Twin and the BIM Model.

The uncertainties introduced by working at TRL6 instead of TRL8/9 will be:

- Not being able to support the full set of equipment's types.
- Not covering the full set of data injection into the BIM files.

In a nutshell, working at TRL6 will prevent us from taking full benefit of the use of a Digital Twin&BIM file.

8.6.1.4. Influence of the proposed innovation on the IM/RU problem

The Infrastructure Manager can have a significant positive impact on the overall operations and performance of a station. Using an efficient and effective Digital Twin solution can influence the management strategy.

If the measurable objectives of the project are successfully attained, the utilisation of a Digital Twin in conjunction with Building Information Modelling (BIM) has the potential to improve the

Infrastructure Manager's process by saving time and having more accurate information for better decision making. The IM will adopt better asset management practices to increase productivity and extend the useful life of the equipment. He will optimise the use of resources, including materials and energy with important cost savings, he will be able to operate the station more efficiently reducing time waste.

As mentioned before, the use of a Digital Twin can facilitate the data-driven decision-making, and a robust management solution can provide access to real-time data and performance metrics. Infrastructure Managers can use this data to make informed decisions, identify trends and implement continuous improvements. An important influence on the IM is that a Digital Twin provides a virtual representation of the physical asset, and it can have access to a detailed 3D models and simulations, allowing it to visualise the equipment's components and behaviour. He can remotely access data and analytics from sensors and other monitoring devices attached to the physical asset. This capability allows IM to diagnose issues from a distance, reducing the need for physical inspections and saving time.

A very important influence will be the collaboration and sharing knowledge among IMs. This collaboration approach enhances problem-solving capabilities and fosters a culture of continuous improvement within the maintenance team.

8.6.2. UC15.6: Demonstrator's KPI

8.6.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #5: Asset Management & Digital Twins" and the related KPIs. In addition, it also contributes to the overarching demonstrator #4 "Asset Management of Infrastructure Operation" as well as its KPIs.

KPI (GA)	Description	Impact
VI	Infrastructure operation: reduction of maintenance costs (targeting 10% in specific use case)	Little/indirect
VII	Infrastructure operation: reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by the Digital Twin (increase by 25 %)	High/direct

Table 103: UC15.6 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following specific PIs are proposed for this use case:

PI	Description	Target value
15.6-1	Number of assets managed and monitored by Digital Twins	25 %
15.6-2	Data quality treated in the Digital Twin	NA
15.6-3	Time reduction to create a data base for asset management	NA

Table 104: UC15.6 PIs

To refer to PRIME, those new PIs can be placed in 2 scorecard dimensions: Financial and Delivery

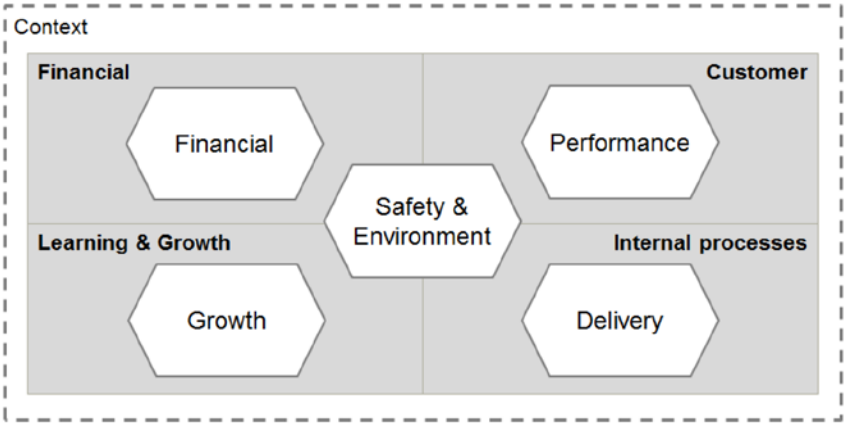


Figure 21: PRIME Scorecard Dimensions

- Delivery – the effectiveness of the IM's internal processes and management of the IM's assets and provision of a fit for purpose network, including the delivery of contractors and suppliers.
- Financial – the financial performance of the IM, including its cost effectiveness and revenues, including track access charges.

Those PI are not listed in the PRIME PI catalogue, and they can impact directly and indirectly different categories like capacity, condition and cost. That means that we can improve other PRIME's PIs results listed in the catalogue. In the images below, we can see the different areas of the PI's impact:

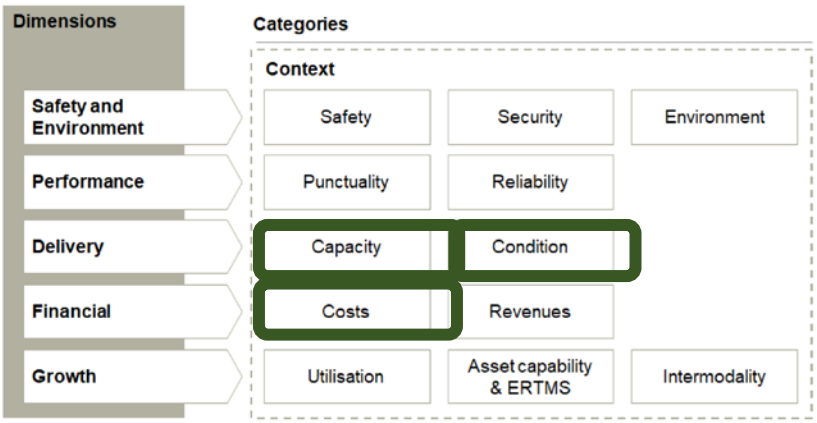


Figure 22: PRIME PI categories aligned to scorecard dimensions

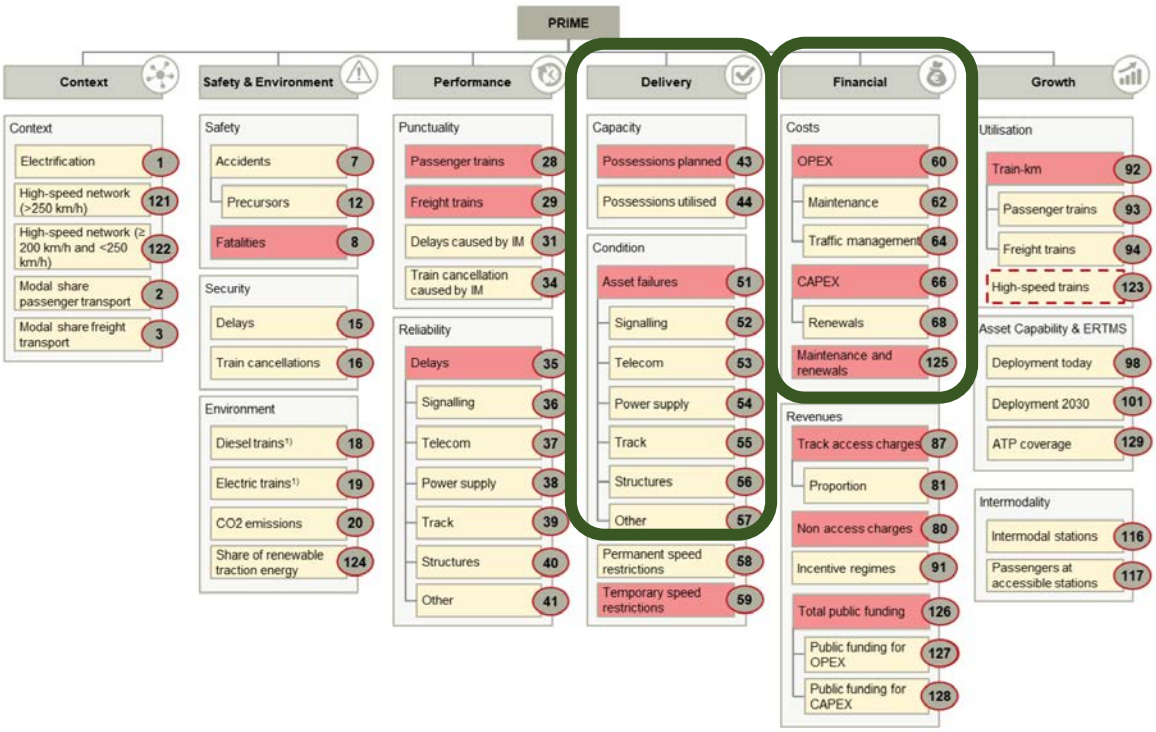


Figure 23: Detailed PRIME categories for architecture design

8.6.2.2. PI15.6-1 - Number of assets managed and monitored by Digital Twins

Short description

The PI indicates that there has been a 25% growth in the monitoring ***of assets*** compared to the actual assets monitoring by using the Digital Twin.

How to compute PI15.6-1

The following formula allows to measure the number of assets managed and monitored by Digital Twin:

$$PI_{15.6-1} = \frac{(\text{TNA} * \text{ANIA}) + \text{AAIAA}}{\text{AAIAA}}$$

Where:

- TAM: determine the total number of type of assets being managed and monitored in the existing architecture (SoA) (in existing projects of Thales), that is called Total Asset Monitored (TAM).
- TNA: Determine the total number of types of new assets in station that can be managed and monitored in Digital Twins, that we will call Total New Assets (TNA).
- AINA: Determine the Average of Instances in the New Assets (AINA).
- TAA: Determine the Total of Ancient Assets (TAA).
- AAIAA: Determine the Average of Ancient Instances in Ancient Assets (AAIAA).

8.6.2.3. PI15.6-2 - Data quality treated in the Digital Twin

Short description

The PI "Data quality treated in a Digital Twin" measures the effectiveness and accuracy of data treatment processes within a Digital Twin system. Data quality is crucial in ensuring that the Digital Twin accurately represents its physical counterpart, as the virtual model's performance and insights depend on the quality and reliability of the data being utilised. This PI2 will also measure the conformity of the BIM model according to the requirements of the BIM Execution Plan.

How to compute PI15.6-2

- Create a documentary base to compare the required information against the information actually delivered (define the Data standards).
- Create a check list of all the information that must be controlled.
- Recover the IFC BIM model to analyse all the structured information inside the model (LOD and LOIN) (Audits)
- Create a satisfaction report to see the percentage of conformity. (Data validation)

Poor	Unsatisfactory	Satisfactory with reserves	Excellent
0%-20%	**21%-65%**	**66%-80%**	**81%-100%**

Table 105. PI15.6-3 conformity table

- Feedback from stakeholders and continuous improvement

8.6.2.4. PI15.6-3 - Time reduction to create a data base for asset management

Short description

The PI "Time Reduction to Create a Database for Asset Management" measures the efficiency and effectiveness of the process to create a comprehensive database for managing assets. This PI focuses on reducing the time required to collect, collate and organise asset-related data into a centralised and structured database, which is critical for the creation of a Digital Twin, and to populate the asset management system.

How to compute PI15.6-3

- Establish baseline data to have a reference. How many days to create a Station Database.
- Analyse the common process of data treatment to identify inefficiencies.
- Implement a process that utilise technology an automation based in BIM and Digital Twins.
- Analyse the new process and compare with the common process.
- Benchmark to compare the results vs industry results.
- Create a graph to compare the Process Vs Time in hours.
- Example of how the KPI tracking results will be presented.

Figure 24: Time reduction to create a data base

9. Cluster F - Environment, User and Worker Friendly Railway Assets

Cluster F has the objective of creating environment, user and worker friendly railway assets addressing environmental and cost-effective lines (WP16), new processes for the repair of railway infrastructure and the manufacture of spare parts using additive manufacturing (WP17), robotic platforms for railway interventions (WP18) and Augmented Reality and exoskeletons to support railway maintenance (WP19); Cluster F uses cases are reported in Table 106.

UC ID	Title	Relevant WP/DO
16.1	Green Turnout	WP16/DO6
16.2	Innovative Sleeper System	WP16/DO6
16.3	Maintenance Reducing Squat Resistant Rail	WP16/DO6
16.4	Bridge Dynamics	WP16/DO6
16.5	Platipus	WP16/DO6
16.6	Diagn'eau	WP16/DO6
16.7	Geogrids	WP16/DO6
17.1	In-situ AM repair machine for rails, switches and crossings	WP17/DO6
17.2	AM repair machine for wheels	WP17/DO6
17.3	In situ repair of track metallic assets	WP17/DO6
17.4	Stationary solution for AM repaired turnout crossings using WAAM technology	WP17/DO6
17.5	Additive Manufacturing of large interior flame-retardant polymer spare part	WP17/DO6
17.6	Digital Warehouse	WP17/DO6
18.1	Light and Flexible on-track inspection	WP18/DO7
18.2	Automated installation of ERTMS balises and axle counters	WP18/DO7
18.3	Disinfection of trains and small stations	WP18/DO7
18.4	Train Underbody Inspection	WP18/DO7
18.5	Automated fixed crossing repair	WP18/DO7
19.1	Upper-body exoskeleton for worker's support in railway industry	WP19/DO7
19.2	Augmented Reality tools to help and guide railway workers in maintenance operations	WP19/DO7

Table 106: Cluster F use cases

9.1. UC16.1: Green turnout

This use case spans Task 16.1 “Sustainable tracks and turnouts” and subtask 16.1.1 “Track”.

9.1.1. Overall aim of the use case

Railway transportation is the most environment friendly form of transportation but has high emission of CO2 during production and operation. Optimisation of design solutions, production and maintenance of the railway could significantly reduce the environmental impact in these areas as well as increase the availability in track. Key challenges targeted in the use case are ballast destruction for track and turnouts.

9.1.1.1. Problem to be solved

The use case considers the whole life cycle of a turnout, starting with the design process of a turnout, and ending with its operation in track. In many of those phases, the emission of CO2 can be reduced.

9.1.1.2. Industry current position/baseline

To maintain serviceability of the railway system all sub-systems need to function in various weather conditions and ideally 24/7. Due to the green deal, also railway supply industry will reduce the emission of CO2 during to the whole lifetime of single components and assemblies. This first step should be done with the green turnout.

Another research point of this use case is the development of geothermal heating system. For switches and crossings with movable parts, a heating system is essential in cold conditions. Conventionally turnout heating consumes up to 5 MWh per year and turnout or up to 2.250 kg CO2 per turnout and year. The use of geothermal energy in turnout heating has the potential to significantly reduce the CO2 consumption.

9.1.1.3. Subproblem addressed by the use case and measurables

Railway transport is environmentally friendly compared to other means of transport, but in addition to the huge technological advantages of railways, there are still some essential side processes that heavily rely on conventional energy technologies. Maintaining the serviceability of infrastructure assets in adverse situations is one of the key requirements regarding meeting the required availability of the system. For example, during cold weather conditions, the freely movement of all movable parts of a turnout must always be ensured to guarantee any kind of operational functionality. This is conventionally done via turnout heating that consume up to 5 MWh per year and turnout or up to 2.250 kg CO2 per turnout and year. Geothermal turnout heating that meets the railway-related demands in terms of safety, robustness or reliability holds the potential of significantly reducing the remaining CO2 footprint of the railway sector.

9.1.1.4. Influence of the proposed innovation on the IM/RU problem

Reduce the emission of CO2 during all phases of a turnout during its lifetime. This is going to be demonstrated with the green turnout.

The development of a geothermal turnout heating system that combines existing technologies with the very special demands in the railway sector will be performed. In a second step, the geothermal technology will be validated via installing a turnout which is equipped with the geothermal heating system at the yard track of voestalpine Zeltweg. Special attention is paid to monitoring the correct operation of the system. In order to succeed there are still some remaining technical key challenges related to this still young technology that must be solved.

9.1.2. UC16.1: Demonstrator's KPI

9.1.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	Little/indirect
X	Time reduction (from design to manufacturing) (20%)	High/direct
XI	Design and Manufacturing: Cost reduction (20%)	Little/indirect

Table 107: UC16.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
16.1-1	Time reduction	20%
16.1-2	Extension of remaining lifetime	20%
16.1-3	Reduce maintenance cost	20%

Table 108: UC16.1 PIs

9.1.2.2. PI16.1-1 – Time reduction

Short description

Compared to the current state of the art the developed use cases will contribute to 20% time reduction from design to manufacturing of railway assets and maintenance operations in track.

How to compute PI16.1-1

To calculate PI16.1-1, the time needed with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the formula below:

$$PI_{16.1-1} = \frac{Time_{traditional_method} - Time_{new_method}}{Time_{traditional_method}} \times 100$$

A positive PI16.1-1 indicates that the estimated time for the new method is less than the time required for traditional methods.

9.1.2.3. PI16.1-2 – Extension of remaining lifetime

Short description

Compared to the current state of the art the developed use cases will contribute to 20% extension on of remaining lifetime in track.

How to compute PI16.1-2

To calculate PI16.1-2, the lifetime of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the time of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.1-2} = \frac{Lifetime_{traditional_method} - Lifetime_{new_method}}{Lifetime_{traditional_method}} \times 100$$

A positive PI16.1-2 indicates that the estimated time for the new method is bigger than the time required for traditional methods.

9.1.2.4. PI16.1-3 – Reduce maintenance cost

Short description

Compared to the current state of the art the developed use cases will contribute to 20% reduction of maintenance costs in track.

How to compute PI16.1-3

To calculate PI16.1-3, the maintenance costs of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the costs for maintenance of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.1-3} = \frac{Cost_{traditional_method} - Cost_{new_method}}{Cost_{traditional_method}} \times 100$$

A positive PI16.1-3 indicates that the estimated costs for maintenance for the new method are less than the time required for traditional methods.

9.2. UC 16.2: Innovative Sleeper System

9.2.1. Overall aim of the use case

This use case spans Task 16.1 “Sustainable tracks and turnouts” and subtask 16.1.2 “Turnout”.

9.2.1.1. Problem to be solved

Increased traffic on railway tracks while reducing in track maintenance possibilities, requires highly available and resistant tracks and components. Very high emissions of CO2 during the production of concrete sleepers.

9.2.1.2. Industry current position/baseline

Railway is the means of transport that emits less CO2, because many countries, companies and people shift their way of transport to the train. Due to that, the traffic increases and the time for maintenance gets reduced. So new components that need less maintenance need to be developed. Concrete is a common material on railways, e.g. for sleeper systems, although it is harmful to the climate because cement production consumes a lot of energy and also produces high carbon dioxide content. The cement industry is responsible for about 8% of global carbon dioxide emissions, which is more than double compared to those from airplanes or ships. Current cement type commonly used, has a high CO2 content and Global Warming Potential (GWP). Replacing the cement type would result in a significant reduction in CO2 during sleepers’

production.

9.2.1.3. Subproblem addressed by the use case and measurables

The total lifespan of infrastructure subsystems (e.g.: turnouts) can be limited by one single component. Regarding turnouts, the limited lifespan of ballast beds can be crucial and the related maintenance processes are additional major cost drivers for railway infrastructure companies and reduce the availability in track.

Furthermore, the settlement processes occurring with conventional turnout systems are very unequal in regarding their special distribution which makes turnouts especially prone to need maintenance in the form of tamping or a change of their ballast bed before the estimated product lifespan has ended. Therefore, vaRS can offer the innovative sleeper concept, which could be transferred during the project to the track proposal. This track proposal contains an optimised track/sleeper system with tight fixing systems, where the protection of the ballast is a focus point. The system can be evaluated on the track through several measurement campaigns and then with a standard track.

9.2.1.4. Influence of the proposed innovation on the IM/RU problem

Especially system-critical railway infrastructure in congested areas around highly populated cities, would enormously benefit if a newly developed system improved these weak points of currently used standard products. As a result, overall maintenance downtimes of track and turnout systems could be lowered significantly and the availability of the rail lines would increase at the same time and life cycle costs would be reduced.

The objective is to develop concrete sleepers which have an optimised bearing area in order to distribute loadings from the rolling stock most equally in comparison to standard solutions. Also, the settlement processes shall be minimised. The settlement processes occurring in turnouts shall be distributed much more homogeneously over the whole turnout than with standard solutions to preserve the initial installation levels for as long as possible.

The new sleeper concept is meant to be used for tracks as well as for turnouts and should require none or very little tamping operations through its entire product lifetime, which would increase for the entire turnout as well. Developed sleepers has an optimised bearing area, a minimised settlement process, and a reduced need for tamping operations through the entire product lifetime.

9.2.2. UC16.2: Demonstrator's KPI

9.2.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	Little/indirect
X	Time reduction (from design to manufacturing) (20%)	High/direct
XI	Design and Manufacturing: Cost reduction (20%)	Little/indirect

Table 109: UC16.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
16.2-1	Time reduction	20%
16.2-2	Extension of remaining lifetime	20%
16.2-3	Reduce maintenance cost	20%

Table 110: UC16.2 PIs

9.2.2.2. PI16.2-1 – Time reduction

Short description

Compared to the current state of the art the developed use cases will contribute to 20% time reduction from design to manufacturing of railway assets and maintenance operations in track.

How to compute PI16.2-1

To calculate PI16.2-1, the time needed with traditional methods for designing and manufacturing of relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The

PI can be evaluated using the formula below:

$$PI_{16.2-1} = \frac{Time_{traditional_method} - Time_{new_method}}{Time_{traditional_method}} \times 100$$

A positive PI16.2-1 indicates that the estimated time for the new method is less than the time required for traditional methods.

9.2.2.3. PI16.2-2 – Extension of remaining life

Short description

Compared to the current state of the art the developed use cases will contribute to 20% extension on of remaining lifetime in track.

How to compute PI16.2-2

To calculate PI16.2-2, the lifetime of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the time of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.2-2} = \frac{Lifetime_{traditional_method} - Lifetime_{new_method}}{Lifetime_{traditional_method}} \times 100$$

A positive PI16.2-2 indicates that the estimated time for the new method is bigger than the time required for traditional methods.

9.2.2.4. PI16.2-3 – Reduce maintenance cost

Short description

Compared to the current state of the art the developed use cases will contribute to 20% reduction of maintenance costs in track.

How to compute PI16.2-3

To calculate PI16.2-3, the maintenance costs of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the costs for maintenance of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.2-3} = \frac{Cost_{traditional_method} - Cost_{new_method}}{Cost_{traditional_method}} \times 100$$

A positive PI16.2-3 indicates that the estimated costs for maintenance for the new method are less than the time required for traditional methods.

9.3. UC 16.3: Maintenance Reducing Squat Resistant Rail

9.3.1. Overall aim of the use case

This use case spans Task 16.1 “Sustainable tracks and turnouts” and subtask 16.1.2 “Turnout”.

9.3.1.1. Problem to be solved

Reduce the need for maintenance caused by squats.

9.3.1.2. Industry current position/baseline

Today’s railway standards prescribe several different mechanical tests to ensure rail properties. However, all of this concerns the virgin railway material, e.g. the properties before any rolling contact fatigue loading occurs. It does not consider the potential drastic properties changes in the rail head, thus does not reflect the real conditions in the railway. Squats are common rail surface defects which usually are found in late stages of deterioration and can consume over 70% of track maintenance budget. The repair of squat defects also causes higher effort in workload compared to other defects.

9.3.1.3. Subproblem addressed by the use case and measurables

In the highly trafficked railway network, proactive maintenance actions are crucial and an important factor to keep the availability of the whole system high. Within the various rail defects, the squat is especially a defect type that causes problems. This operational defect is a sub-surface crack under the running band with a V-shaped surface appearance that is detected in late stages of development. The repair of squat defects causes high efforts in workloads which needs to be detected and estimated early to minimise maintenance cost and increase reliability in the railway. To deal with the problem of squats, the squat staircase needs to be considered, which is summarising the crucial factors for squat formation. Voestalpine is working on longer lasting steel grades or even new material compositions for rails in tracks and turnouts. The material development is one focus to avoid issues with squats.

Railway standards prescribe several different mechanical tests to ensure rail properties but does only consider the properties before any rolling contact fatigue loading occurs. In operation, the rail head properties can change drastically due to successive plastic deformation on rolling contact loading. The gradually increasing accumulated strain creates anisotropy and gradients of

behaviour in both plastic properties and fracture properties. The insufficient knowledge of material behaviour under such complex loading scenarios hinders predictions of cracking and wear, which could be useful for steering maintenance. The lack of post-break-in requirements also makes a fair comparison between different rail materials difficult before an extensive in-field evaluation. Initial experiments and modelling of fatigue cracking in pre-deformed rail steel has been done but require further analysis and method development.

9.3.1.4. Influence of the proposed innovation on the IM/RU problem

Development of new steel grades for railway operation will contribute significantly to eliminate the problem of squats. Deep analysis of the root causes of squat development will identify a proper approach to successfully tackle the problem which is manifold and complex according to case studies. Influencing factors are improper rail maintenance and aggressive rail grinding, white etching layers and other rail surface defects as well as high concentrated rail loading caused by unpropitious rail-wheel profile combinations. A new steel grade will show sufficient resistance towards squat formation under these boundary conditions. The solution will demonstrate the effectiveness in respect to the potential to reduce maintenance costs caused by squat defects and reduce squat building likelihood by more than 75%.

The activities will build on existing knowledge and further develop test methods and material models that could be of use for judging the behaviour under more field-like conditions. The objectives are to enable to speed up the process of predicting the in-field behaviour of new materials, and to provide valuable input for a more resource efficient maintenance. Additionally, complementing railway standards with property requirements after run-in could help in the design and homologation of new railway materials.

9.3.2. UC16.3: Demonstrator's KPI

9.3.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	Little/indirect
X	Time reduction (from design to manufacturing) (20%)	High/direct
XI	Design and Manufacturing: Cost reduction (20%)	Little/indirect

Table 111: UC16.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
16.3-1	Time reduction	20%
16.3-2	Extension of remaining lifetime	20%
16.3-3	Reduce maintenance cost	20%

Table 112: UC16.3 PIs

9.3.2.2. PI16.3-1 – Time reduction

Short description

Compared to the current state of the art the developed use cases will contribute to 20% time reduction from design to manufacturing of railway assets and maintenance operations in track.

How to compute PI16.3-1

To calculate PI16.3-1, the time needed with traditional methods for designing and manufacturing of relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the formula below:

$$PI_{16.3-1} = \frac{Time_{traditional_method} - Time_{new_method}}{Time_{traditional_method}} \times 100$$

A positive PI16.3-1 indicates that the estimated time for the new method is less than the time

required for traditional methods.

9.3.2.3. PI16.3-1 – Extension of remaining life

Short description

Compared to the current state of the art the developed use cases will contribute to 20% extension on of remaining lifetime in track.

How to compute PI16.3-2

To calculate PI16.3-2, the lifetime of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the time of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.3-2} = \frac{Lifetime_{traditional_method} - lifetime_{new_method}}{Lifetime_{traditional_method}} \times 100$$

A positive PI16.3-2 indicates that the estimated time for the new method is bigger than the time required for traditional methods.

9.3.2.4. PI16.3-3 – Reduce maintenance cost

Short description

Compared to the current state of the art the developed use cases will contribute to 20% reduction of maintenance costs in track.

How to compute PI16.3-3

To calculate PI16.3-3, the maintenance costs of a turnout in track with traditional methods for designing and manufacturing relevant railway assets in the work package, as well as maintenance operations, will be estimated and compared to the project result. Manufacturers and infrastructure managers will provide estimated values for traditional methods and use case values for the new methods. The PI can be evaluated using the costs for maintenance of the turnout in track with the new developed method divided by the traditional methods.

$$PI_{16.3-3} = \frac{Cost_{traditional_method} - Cost_{new_method}}{Cost_{traditional_method}} \times 100$$

A positive PI16.3-3 indicates that the estimated costs for maintenance for the new method are less than the time required for traditional methods.

9.4. UC16.4: Bridge dynamics

This use case spans Task 16.2 “Resilient and sustainable lines” a subtask 16.2.1 “Improved dynamic amplification factors” and subtask 16.2.2 “Bridge resonance”.

9.4.1. Overall aim of the use case

9.4.1.1. Problem to be solved

The use case will provide a more realistic understanding of dynamic effects on bridges and will allow existing bridges to be upgraded in order to support higher allowable axle loads without reinforcing or replacing them. This will also allow for more cost-effective design of new bridges.

9.4.1.2. Industry current position/baseline

Bridge dynamics
Recent research suggests that current values given in standards for bridge resonance and dynamic amplification factor (DAF) are overly conservative. There is a potential for some existing bridges to allow for 20% more load than in current requirements.

9.4.1.3. Subproblem addressed by the use case and measurables

Higher payload by improved DAF
Dynamic effects from passing trains are often accounted for by a DAF, e.g. in EN 1991-2 Annex C. Part of the dynamic effects are often attributed to the wheel-rail contact forces and highly depend on the track irregularities and the vehicle suspension system. Recent research suggests that the current values may be over-conservative, especially for short- and medium span bridges.

Bridge resonance
For railway bridges on high-speed lines, dynamic analyses are often performed to ensure that no adverse effects occur due to passing trains at a high speed, e.g. due to resonance. The current limit criteria are given by EN 1990/A2. The main criteria are related to the vertical bridge deck acceleration, for ballasted tracks related to instability of the ballast at excessive vibrations and for non-ballasted tracks related to the risk of derailment, e.g. due to wheel-rail contact loss. Both criterions are based on limited previous studies and are likely over-conservative or potentially physically inaccurate.

9.4.1.4. Influence of the proposed innovation on the IM/RU problem

Higher payload by improved DAF
The project aims to develop train-track-bridge interaction models for realistic estimates of dynamic effects on bridges. The models will be improved by using bridge response data from dynamic monitoring and available data of recorded track irregularities. It is expected that the results will allow for improved dynamic assessment, especially for short and medium span railway

bridges. For a well-maintained track, initial studies on freight train application suggest that the current dynamic effects may be reduced by up to 20%. As a result, existing bridges may be upgraded to higher allowable axle loads without needing to be reinforced or replaced and new bridges may be designed more cost-efficiently.

Bridge resonance

The project aims to increase the understanding of the behavior of bridges with ballasted tracks under dynamic loading. Different levels of refined simulations will be compared with experimental data, both from a full-scale bridge tested in laboratory and previously tested in-situ bridges. The models will also be compared with the test data from the current limit criterion. It is expected that the developed models will allow for an improved limit criterion for ballast acceleration on railway bridges. The models will also be used to better describe the load distribution in ballasted tracks and dynamic soil-structure interaction to allow for more accurate bridge models in dynamic analysis. Recommendations for modelling will be developed.

9.4.2. UC16.4: Demonstrator's KPI

9.4.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
X	Time reduction (from design to manufacturing) (20%)	Little/indirect
XI	Design and Manufacturing: Cost reduction (20%)	High/direct

Table 113: UC16.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
16.4-1	Cost reduction	20%

Table 114: UC16.4 PIs

9.4.2.2. PI16.4-1 – 20% Cost reduction

Compared to the current state of the art, it is believed that the developed use cases will contribute to 20% cost reductions in the design of railway bridges. Recent studies have shown that the current DAF may be over-conservative, especially for short and medium span bridges. The use case will

provide a more realistic understanding of dynamic effects on bridges and will allow existing bridges to be upgraded to support higher allowable axle loads without strengthening or replacement. This will also allow for more cost-efficient design of new bridges.

9.5. UC16.5: Platipus

This use case spans Task 16.2 “Resilient and sustainable lines” and subtask 16.2.3 “Scour-Flood tools”.

9.5.1. Overall aim of the use case

9.5.1.1. Problem to be solved

The French National Rail Network (RFN) has 10,000 infrastructures with crossing-water foundations (FSA), directly located in watercourse environments or in their immediate vicinity. The management of these critical infrastructures takes on a special dimension due to the inherent complexity of assessing the condition of submerged foundations and the growing impact of climatic hazards, particularly intense rainfall, which can lead to flooding and scouring.

Current approaches to monitoring and maintenance, based on visual inspections and empirical methods, are limited in terms of effectiveness, accuracy and applicability.

The PLATIPUS project aims to overcome these challenges through technological innovation. Its main objective is to develop a predictive maintenance tool based on the use of innovative technologies such as artificial intelligence (AI) and connected surveillance, with a view in particular to optimising and improving the surveillance of crossing-water foundations and its infrastructures, effectively and sustainably over time.

9.5.1.2. Industry current position/baseline

Monitoring of structures with FSAs is currently mainly based on visual inspections and empirical methods defined in MT01253 ‘Rules for monitoring engineering structures and related maintenances. These inspections, which are carried out at varying frequencies depending on the condition of the structure and its exposure to hazards, enable deterioration to be identified and the general condition of the foundations to be assessed.

Structures are classified according to their vulnerability, linked in particular to the nature and condition of the foundations (presence of wooden piles, existing damage), the conditions of the watercourse (lowering of the bed, instability of the banks) and the history of past events (flood, scour and reparation, etc.).

For structures located in watercourses with high water levels or significant water depths, as well as those considered to be particularly exposed to passage of high flows, tidal range, etc., specific monitoring is carried out on 6% of the FSA engineering structures, including underwater

inspections (carried out by specialised divers) and precision levelling measurements on bridge decks and piers.

Exceptional floods can cause major damage to the foundations of structures exposed to run-off (see also IN02085). The VIGICRUES platform can be used to identify critical thresholds for assessing risk situations. Consequently, a special exceptional surveillance action will be initiated in response to a VIGICRUES Red alert.

This exceptional special surveillance consists of inspecting the foundations and parts of the structure concerned. It should be noted that while waiting for these interventions in the watercourse, for structures with a particularly exposed foundation, it is necessary to carry out, as soon as possible after the flood, comparative precision levelling measurements to gather information on the bearing capacity of the supports.

During intense bad weather, particularly in the event of heavy rain or flooding, the structures listed in the Storm Warning System are monitored by means of special rounds or visits carried out by track team operatives.

The purpose of these rounds or visits is to check that there is no danger in train movements and in taking any necessary protective measures.

9.5.1.3. Subproblem addressed by the use case and measurables

Climate change is putting increasing pressure on the old foundations of engineering structures. It amplifies existing problems and introduces new ones. The main consequences are linked to changes in hydrological regimes:

- Lowering of low-water levels: the reduction in low-water flows during dry periods results in prolonged exposure of foundations, particularly timber piles, accelerating their deterioration through rotting.
- Increase in the intensity and frequency of floods: extreme events, such as violent floods, cause high water levels and flow speeds, which can lead to scouring, erosion and displacement of materials around foundations. These phenomena weaken structures through loss of bearing capacity of the foundations and increase the risk of failure.
- Lowering of the riverbed: the urbanisation and the intensification of human activities increase rainwater run-off, which increases the intensity and speed of flooding, thereby reinforcing the effects described above.

These changes in the hydrological regime have a direct impact on the foundations of engineering structures:

- Scouring
- Degradation of materials
- Decrease in soil bearing capacity

Climate change is an aggravating factor for the condition of the old foundations of engineering structures. It is therefore essential to take these impacts into account in strategies for monitoring, maintaining and rehabilitating these structures.
Taking climate change into account means that monitoring methods will have to evolve, as current methodologies are unable to accurately assess the impact of climate change on the stability of structures and to implement appropriate preventive measures.

Special monitoring, coupled with digital AI models to simulate changes in hydraulic conditions, may prove necessary to anticipate risks and implement appropriate protection measures.
Maintenance and prediction of scour risks in the infrastructure needs to be enhanced to ensure the conditions of the railway network and safe train operations.

9.5.1.4. Influence of the proposed innovation on the IM/RU problem

The PLATIPUS project aims to significantly improve the safety, reliability and performance of the infrastructure of the French national rail network, while optimising maintenance costs and integrating the challenges of adapting to climate change (ACC) in order to strengthen the sustainability and resilience of the rail network face of extreme climatic events.

The PLATIPUS project is expected to deliver a number of benefits:

- At the operational level, it is planned to improve the identification of the most sensitive crossing-water infrastructures, monitor them in real time during seasonal floods and adapt monitoring in the event of exceptional weather conditions.
- In terms of monitoring and supervision, it is planned to develop tools to assist monitoring and automatically trigger alerts if thresholds are detected or predicted to be exceeded.
- In terms of identifying work requirements and scheduling investments, the plan is to prioritise regeneration operations, improve the direction of investments and increase the reliability of maintenance budgets for this type of structure.
- The objective is to maintain the infrastructure from the risk of scour and prevent train operations from derailing. A database of crossing-water infrastructure considering various parameters will be developed. To evaluate the sensitivity of the structures, scour risk prediction will be generated by machine learning. Real-time monitoring during flooding will alert and stop train movement in time.

9.5.2. UC16.5: Demonstrator's KPI

9.5.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	High/direct
IX	For repair: Extension of remaining life (25%)	Little/indirect

Table 115: UC16.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
16.5-1	Extension of remaining life	10%
16.5-2	Reduction of maintenance costs	10%

Table 116: UC16.5 PIs

9.5.2.2. PI16.5-1 – Extension of remaining life

Short description

The aim is to extend the lifespan of the infrastructure by implementing predictive maintenance. This involves selecting and adapting structures that need protection and maintenance to prevent premature failure and reduce the cost of replacements.

How to compute PI16.5-1

While the precise computation is not detailed, the evaluation involves measuring the reduction in emergency interventions by detecting weaknesses early and planning regeneration works. A detailed analysis of long-term data on maintenance costs before and after implementing PLATIPUS, comparing the longevity of the structures, would be necessary for precise computation.

9.5.2.3. PI16.5-2 – Reduction of maintenance costs

Short description

This PI focuses on reducing the costs associated with infrastructure maintenance. By implementing proactive monitoring and leveraging innovative technologies such as AI, maintenance operations become more efficient, reducing the overall financial burden.

How to compute PI16.5-2

Calculating PI16.5-2 would involve analysing maintenance costs over several years to determine cost savings. The project should show cost savings through reduced emergency interventions and optimised maintenance schedules, comparing maintenance costs before and after implementing

the PLATIPUS system, as well as assessing train regularity and infrastructure availability indicators.

9.6. UC16.6: Diagn'eau

This use case spans Task 16.2 "Resilient and sustainable lines" and subtasks 16.2.3 "Scour-Flood tools" and 16.2.4 "Embankment reinforcement using geogrids".

9.6.1. Overall aim of the use case

9.6.1.1. Problem to be solved

The use case includes enhanced decision-making in track infrastructure considering climate change impact.

9.6.1.2. Industry current position/baseline

With a view to ensuring a satisfactory level of service during flood events, the SNCF has developed some guidelines to be used during the management of significant flood events: flood risk resilience plans built on predicted and historic water levels to help operational staff anticipate problem areas on the network. The tool has limitations such as the fact that the vulnerability of all railway assets has not been integrated into the tool and that knowledge of asset vulnerability is often limited to water level due to lack of data at scale.

9.6.1.3. Subproblem addressed by the use case and measurables

Water related natural hazards that impact railway infrastructure and its exploitation can impact all sub-systems such as earthworks, tracks, signalling, electrification, stations and bridges. Railway infrastructure can be impacted during extreme floods but can also be significantly affected by more frequent events. Measures need to be taken to maintain safety excellency in the railway system during environmental impact as well as preserve infrastructure, limit financial damage, improve the ability for the railway system to recover from a crisis and ensure the highest possible level of services.

9.6.1.4. Influence of the proposed innovation on the IM/RU problem

<u>Help to build operational activity management</u>

With the actual tool it's possible to:

- Collect on the tool already analysed buildings or tracks sections (embankments) to build the business continuity planning.
- The level of exposure or impact is shown with the colour of the asset.
- Store all the analysis previously made and the future ones.

Analyse assets that are new but known to be in a potentially flood-prone area, but with some

limits:

- Only the direct impact (i.e. loss of the installation, such as the signalling system) is shown and not the impact on rail traffic (suspended or limited) and the affected area (i.e. from station A to station B).
- It's not possible to identify an asset in a flooded area unless it is with the use of visualisation of flood data. It's not a dynamic and user-friendly tool.

With the upgraded tool it will be possible to:

- Visualise the indirect impact of a flooded asset on the rail traffic (the information will have to be filled in) to have the full system impact of a flood on an area or an asset.
- Extract all the information: direct and indirect impact and origin of the flood (river, hydrometric measure station, and for some flood data, the height of the hydrometric measure station).
- Improve the identification of potentially flood-prone assets.

Integrate the flood risk on projects

With the actual tool it's possible to:

- Analyse a building or an asset which is known to be in a flooded area and potentially impacted.
- Two different methods for:
    - Substations, signalling system, ...
    - Embankments and bridges.

But with some limits:

- It's not possible to automatically identify asset in a flooded area or to search the flood data on a location.
- The displayed flood data is not automatically updated. It's a static data and with no interactions possible with the users.
- The infrastructure database is not automatically updated.
- Non existing buildings cannot be easily analysed.

With the upgraded tool it will be possible to:

- Analyse a building or an asset which is known to be in a flood-prone area and potentially impacted in the same way as the actual tool but with a guaranty of updated data and more scenarios available.
- For each asset the flood data existing on the area will be automatically linked.
- Display the impacted asset on a map for different flood scenarios and extract the data for a specified region or area.
- Access all the documentation linked to risk analysis on this asset.

- For new projects (non-existing asset): obtain the flood data on the localisation of the project: flood area, flood type and water height and thus make the proper protections on the asset: heightening, waterproof doors and ducts...
- For embankments modification of the risk exposure matrix to make it more easily used for non-experts' people: use of an elevation profile measuring with the display of water height.

Determine flood alerts thresholds

With the actual tool it's possible to:

- Identify for each property impacted by flooding – the river causing the flooding and the closest measure hydrometric station (Vigicrues).
- Look on the state website Vigicrues which threshold to choose and integrate it into the alerting system with the national meteorological company (METEO FRANCE).

But with some limits:

- Limited to two scenarios: 10-year flood or 100-year flood either too low to have a high impact on the asset or too high with a strong impact and no possibility to have intermediate levels.
- The Vigicrues data is not automatically updated.

With the upgraded tool it will be possible to:

- Identify for each property impacted by flooding – the river causing the flooding and the closest measure hydromectric station (Vigicrues) with the guaranty of updated to data and more scenarios.
- With the use of specific data called ZIP ZICH for «Potential Flooded Area» and «Potential Flood Heights» that are directly linked to a height on the Vigicrues station with more intermediate levels (i.e. identify the impact on the asset for each of this flood level).
- Help to determine intermediate thresholds:
    - Level 1: alerting to prepare the crisis and start monitoring.
    - Level 2: monitoring of critical assets or deployment of protections measures (sandbags, aqua barriers).
    - Level 3: suspend circulations or decrease speed.

9.6.2. UC16.6: Demonstrator's KPI

9.6.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
V	Tools which provide at least 3 possible strategies of long term management (with an accuracy (as defined by ISO) improvement of 10%)	High/direct

Table 117: UC16.6 KPIs on a FP level from the Grant Agreement

As the project primarily deals with a tool, the following PI is the most suited for Diagn'eau:

PI	Description	Target
16.6-1	Infrastructure long-term Asset Management	30%

Table 118: UC16.6 PIs

9.6.2.2. PI16.6-1 – Infrastructure long-term asset management

Short description of the PI16.6-1
This description of this PI is specific to Diagn'eau: it is based on the estimation of the number of assets entered in the tool and that will be used in large-scale projects (refurbishments, etc.) to control flood risk.

How to compute
No formula is possible to use during the duration of the project. Calculating this PI would involve analysing project strategies over several years (post ERJU) to determine the improvement in asset resilience and the projects that have benefited from the developed tool (or, in other words, "the rate at which the tool is used").

Improve integration of flood risk in design or regeneration projects with a target of at least 30 % of assets registered in the tool. This target value would not be attained during ERJU but afterwards after a prolonged duration of tool use.

9.7. UC16.7: Geogrids

This use case spans Task 16.2 "Resilient and sustainable lines" and subtask 16.2.4 "Embankment reinforcement using geogrids".

9.7.1. Overall aim of the use case

9.7.1.1. Problem to be solved

The use case includes enhanced decision-making in track infrastructure considering climate change impact.

9.7.1.2. Industry current position/baseline

Geogrids are rarely used in the track bed network as a solution to reduce the impact of the reinforcement works by decreasing the depth of excavation and thus the cost of the project. A huge range of geogrids exists with different shapes and manufacturing techniques that need to be researched for the purpose of the project.

9.7.1.3. Subproblem addressed by the use case and measurables

Track exploitation efficiencies are partially linked to the presence of disorders in the track bed. To prevent such consequences, renewal is sometimes needed. However, these works are sometimes poorly considerate because of their cost and their low yields. Thus, innovative solutions are needed to ensure the perfect productivity of the considered line.

9.7.1.4. Influence of the proposed innovation on the IM/RU problem

A huge range of geogrids with different shapes and manufacturing techniques will be investigated to find the best products considering the project objectives. New configurations of geogrids will be proposed to reduce the thickness of the sub-ballast layer and potentially reduce the thickness of the capping layer. This is expected to lead to reduction of the cost of the works and increase the yield, thus, decrease the environmental impact. To apply this methodology in the rail network requirements such as the railway environment, dimensioning, costs and efficiency needs to be considered.

9.7.2. UC16.7: Demonstrator's KPI

9.7.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
X	Time reduction (from design to manufacturing) (20%)	Little/indirect
XI	Design and Manufacturing: Cost reduction (20%)	High/direct

Table 119: UC16.7 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
16.7-1	Time reduction	30%
16.7-2	Cost reduction at the track bed renewal scale	30%
16.7-3	Cost reduction in terms of maintenance	20%

Table 120: UC16.7 PIs

9.7.2.2. PI16.7-1 – Time reduction

Short description

By using geogrids, we expect a decrease in the thickness of the track bed structure and, correlatively, a decrease in the excavation depth. Compared to the current state of the art we will contribute to 30% time reduction of the works.

How to compute PI16.7-1

To calculate this PI, the time needed with traditional methods is compared with a planned geogrid solution (according to other railway infrastructure managers).

A positive PI16.7-1 indicates that the estimated time for the new method is less than the time required for traditional methods.

9.7.2.3. PI16.7-2 – Cost reduction at the track bed renewal scale

By using geogrids, a reduction of the amount of material needed to build the track bed is expected.

This reduction is correlated with:

- A decrease in the costs linked to the purchase of sub-ballast and capping layer materials
- An increase in the performance of the works
- A decrease in landfill costs (by reducing the depth of excavation)

The impact of the use of geogrids also occurs at the project level (by reducing the depth of the drainage system associated with the track bed, for example).

Short description

Compared to the current state of the art we will contribute to 30% cost reduction of the works.

How to compute PI16.7-2

To calculate the PI, the cost of renewal with traditional methods is compared with an expected cost with the geogrid solution (according to other railway infrastructure managers).

A positive PI indicates that the estimated time for the new method is less than the time required for traditional methods.

9.7.2.4. PI16.7-3 – Cost reduction for maintenance

If track beds are renewed if needed, a cost reduction in terms of maintenance is expected.

Short description
Compared to the current state of the art we will contribute to a 20% cost reduction of the works.

How to compute PI16.7-3
To calculate the PI, the cost of the life of a line with track bed disorders (tampings, etc.) is compared to the cost of track bed renewal cost.

A positive PI indicates that the estimated cost of the track bed renewal using geogrid is less than the cost of maintenance operations at the scale of the life of a line with track bed disorders.

9.8. UC17.1: In-situ AM repair machine for rails, switches and crossings

A machine for in-situ repair of rails, switch or crossings using AM technology is developed. The machine integrates several subsystems to remove material before the repair, add material using Laser-DED powder, remove material to reach final dimensions and measure final dimensions.

This use case spans Task 17.5 “AM Integrated demonstrators” and subtask 17.5.1 “In-situ repair machine for rails, switches and crossings”.

9.8.1. Overall aim of the use case

9.8.1.1. Problem to be solved

Some of the damages caused by the use on the active surfaces of the metallic elements of the track can be remedied by regenerating its dimensions, until reaching those they originally had, by depositing and grinding a steel to provide characteristics similar to those of the one that integrates the damaged element, a procedure that receives the name of electric arc recharge repair. Currently, when a metallic asset, for example, a frog in a crossing, is detected as deteriorated, a recharge is carried out. However, currently this process is carried out manually, not only on-site, but also in the workshop. It is considered important to find automatic methods to carry out these maintenance works, so as to improve the safety and efficiency of the process.

9.8.1.2. Industry current position / baseline

Currently, the most used repair technique for repairing rails, crossings and points is electric arc welding, which is a rather laborious technique with very little automation.
This method consists of depositing filler steel to form an electric arc between the supplying fuse element and the rail to be repaired, followed by subsequent grinding. This allows the damaged elements to be joined to the new ones by fusing the materials together, creating a solid and strong bond that restores the integrity of the track.
There are two variants of the method of repairing defects in track elements by electric arc

surfacing. The first one is applicable to rails where, in order to avoid hardening, it is necessary to keep their temperature in the range of 350-420 °C for those made of 700, 900 and even 900 hard class steel, or between 380-400 °C for those made of 1100 steel. The second variant is used for manganese steels for switches and crossings, where prolonged heating and raising their temperature above 200 °C is not possible without changing their structure.

9.8.1.3. Subproblem addressed by the use case and measurables

The repeatability and quality of the repairs will be improved through three lines of research:

1) Automation of manual repair operations: since human errors are inevitable, implementing automated repairs minimises errors increasing accuracy and consistency. This results in a much more efficient repair, which ultimately leads to an extension of the repaired component service life.
2) Repairs carried out by AM are expected to be of better quality than those carried out by welding.
3) The development of new repair materials specially designed for AM will contribute to improve the repair performance.
4) To demonstrate TRL6 a repair of a rail or switch&crossings element will be performed: a repair will be performed using the developed repair system which integrates at least the following operations: grinding, surface measuring and repair by additive manufacturing. For this purpose, a relevant environment consisting of a track box with at least slippers, damaged track element (rail or switch&crossings part) with the corresponding fasteners and ballast will be installed at CEIT facilities.

9.8.1.4. Influence of the proposed innovation on the IM/RU problem

The in-situ repair for an AM repair process of rails, switch&crossings elements will result in a speed up and cost saving of the entire operation, as well as quality improvement and reproducibility of results in total.

9.8.2. UC17.1: Demonstrator's KPI

9.8.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	High/direct

Table 121: UC17.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
17.1-1	Extension of remaining life of the railway asset repair	25%

Table 122: UC17.1 PIs

9.8.2.2. PI17.1-1 – Extension of remaining life of the rail

Short description

The service life of these components is primarily reduced by wear and tear. Therefore, the wear rate will be used to quantify the potential extension of their service life. By decreasing the wear rate through the proposed repairs, it will extend their service life. Additionally, the reduction of human error associated with manual interventions will be quantified, as the objective is to eliminate such errors by automating all manual operations involved in the repair process.

How to compute PI17.1-1

Comparison of the wear rate of railway rails and turnout elements using the current repair build-up welding process versus the wear rate achieved with the AM repair Laser-DED process, taking into account the reduction of human error:

$$PI_{17.1-1} = \frac{WearRate_{baseline_solution} - WearRate_{I4R_solution}}{WearRate_{baseline_solution}} \times 100 + \frac{ErrorRate_{I4R_solution}}{ErrorRate_{baseline_solution}} \times 100$$

Where:

- $WearRate_{I4R_solution}$ is the wear rate of a component repaired by additive manufacturing.
- $WearRate_{Baseline_solutiuon}$ is the wear rate of component repaired by the traditional repairing build-up welding process.
- $ErrorRate_{I4R_solution}$ is the error rate of the automated system by reducing the human error rate in the repair process. This error will be quantified through characterisation of 5-10 AM repairs to assess repeatability.

- $ErrorRate_{baseline_solution}$ is the error associated with all the manual operations conducted during a conventional repair, such as insufficient grinding and inadequate control of preheating, which can result in defects in the final repair, including porosity, heterogeneous hardness, and cracks. This error will be quantified through ADIF historical data and characterisation of 5-10 conventional repairs to assess repeatability.

In addition, the results of laboratory tests such as impact and tensile tests specified in deliverable 17.1. will also be used to assess the quality of the repairs and the adhesion of the repair material to the base material (rail or turnout element). If a lack of adhesion is observed, the repair will not be considered valid regardless of the wear values obtained.

9.8.3. Synergies/risk of duplication of work

There are no synergies with other flagship projects or with other WPs within Flagship Project 3-IAM4RAIL. Therefore, no risk of duplication of work is foreseen either.

9.9. UC17.2: AM repair machine for wheels

This use case spans Task 17.5 “AM Integrated demonstrators” and subtask 17.5.2 “Repaired metallic components: rolling stock and infrastructure”.

9.9.1. Overall aim of the use case

9.9.1.1. Problem to be solved

Wheels are one of the most important consumables of the train in terms of cost and weight. To recover the wheel and trying to avoid side and risk operations like disassembly and assembly of the axle from the wheel, we want to study the use of the AM methods to “remanufacture” the wheel.

9.9.1.2. Industry current position / baseline

Wheels are one of the main running costs of maintenance, hence of the TCO of the train. In addition, operation of disassembly a press-fit wheel-axle subassembly could damage both with consequence of lack of availability at train level due to the lack of axle stock in extreme cases.
No alternatives considered right now in RU level. Well stablished and standard process for manufacturing the wheels.

9.9.1.3. Subproblem addressed by the use case and measurables

Alternative solution to return in services the wheels by using AM. At least two different AM technologies, cold spray and Laser-DED will be tested to study the technical viability of the solution and parameters to be used (materials, conditions, dimensions, etc.). In later stages, the AM repair machine will be implemented to ‘remanufacture’ worn wheels.

9.9.1.4. Influence of the proposed innovation on the IM/RU problem

To establish additive manufacturing (AM) methods as a viable alternative to the current state of the art, we must first address the technical uncertainties associated with using non-conventional manufacturing methods for safety-critical components, such as wheels. This involves employing a manufacturing approach that is not currently included within the scope of the standard EN 13262, which pertains to railway applications—specifically, wheelsets and bogies, and the product requirements for wheels.

To do that, an intensive characterisation campaign of mechanical properties achieved using different technologies will be needed to assure the different steps in the development based on a safety approach. The idea is to follow and assess the requirements, as much as possible, from the wheel standard EN 13262.

Finally, On-bench testing of wheels repaired by AM resembling running conditions. The test results should identify the best combination of process and material for wheel repair. Once technical feasibility is assured, the next step is to work on the cost-effective solution, where to install the repair machine, etc.

9.9.2. UC17.2: Demonstrator's KPI

9.9.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
IX	For repair: Extension of remaining life (25%)	High/direct

Table 123: UC17.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
17.2-1	Extension of remaining life of a wheel repair	25%

Table 124: UC17.2 PIs

9.9.2.2. PI17.2-1 – Extension of remaining life

Short description

The service life of these components is primarily reduced by wear and tear. Since they are not currently repaired, applying additive manufacturing techniques to add material for their repair will directly increase their service life. This increase will be determined by comparing the wear rate of the AM-repaired wheel to that of a new wheel.

How to compute PI17.2-1

Comparison of the wear rate of a new wheel versus the wear rate achieved with the Laser-DED additive manufacturing repair process, considering that no repairs are currently being conducted.

$$PI_{17.2-1} = 1 + \frac{WearRate_{I4R_solution}}{WearRate_{baseline_solution}} \times 100$$

Where:

- $WearRate_{I4R_solution}$ is the wear rate of a wheel repaired by additive manufacturing.
- $WearRate_{baseline_solution}$ is the wear rate of a new wheel.

In addition, the results of laboratory tests, including measurements of residual stresses and tensile tests as specified in deliverable 17.1, will be used to assess the quality of the repairs and the adhesion of the repair material to the base material (wheel). If a lack of adhesion or the presence of residual tensile stresses is observed, the repair will be considered invalid, regardless of the wear values obtained.

9.9.3. Synergies/risk of duplication of work

There are no synergies with other flagship projects or with other WPs within Flagship Project 3-IAM4RAIL. Therefore, no risk of duplication of work is foreseen either.

9.10. UC17.3: In situ repair of track metallic assets

Repair and reinforcement by laser technology of rails and turnout elements.

This use case spans Task 17.5 “AM Integrated demonstrators” and subtask 17.5.2 “Repaired metallic components: rolling stock and infrastructure”.

9.10.1. Overall aim of the use case

9.10.1.1. Problem to be solved

Rails and switches are two of the most sensitive elements of the railway infrastructure, which suffer from different types of defects, such as wear, deformation, spalling, slipping, etc. These

important components are usually recovered whenever possible on the track itself, in situ, following mainly economic and safety criteria. This work is normally carried out at night, taking advantage of the hours when there is little rail traffic, and involves a compromise/balance between the speed of the maintenance operation and the durability of the repair.

One of the most widespread methods is manual hard-facing operations using arc welding technology. This conventional welding technology, assisted by other tools such as grinders, allows the rail components to be recovered quickly. However, these methods are not a definitive solution, as they have several drawbacks. They tend to generate high thermal stress in the treated regions, deformations and generally low or medium durability recoveries. In addition, the associated equipment and the techniques used are very difficult to handle and require a great deal of experience, as well as risks to the health and safety of the workers who carry them out, which means that highly qualified operators are required.

9.10.1.2. Industry current position/baseline

The most common technologies used for on-track recovery are so-called alumina-thermic and electric arc welding. The latter is the most traditional and widespread for the repair of small defects.

In fact, the use of electric arc welding equipment for surfacing or adding material to damaged or defective track elements is very common in on-site track maintenance operations. This equipment is based on a robust, mature and, at the same time, relatively inexpensive technology, given that it is used in different sectors. Moreover, given the flexibility and speed they offer, they are able to solve different problems avoiding the replacement of the defective crossing or rail and extending its life.

However, the method is not without its drawbacks. In addition to the very low degree of automation, the recovery procedure is tedious, given the large number of more or less precise stages involved, such as cleaning, roughing, heating, hard-facing, grinding, etc., with the hard-facing process being the most important and the one that most conditions the rest.

The arc hard-facing technique generates a considerable energy input on the treated region of the component, which commonly results in excess temperature and microstructural defects in the material, residual stresses, cracking, porosity, as well as deformations. In addition, the process is not very energy efficient and involves the input of a large amount of material, which forces more time to be spent on subsequent operations to condition the geometry of the component.

In fact, given the particularities of the technology, the arc hard-facing process is difficult to operate and control and therefore requires highly specialised personnel who are very accustomed to carrying out its different operations, as well as rigorous control during the preparation of the work and throughout its development. The quality of the repaired geometry is therefore highly dependent on the skill and experience of the operator.

9.10.1.3. Subproblem addressed by the use case and measurables

The main objective is to develop new maintenance operations based on laser technology applied to the recovery of railway rail components and elements. The particular objectives are summarised below:

- Design and manufacture of specific tooling and nozzles for laser recovery operations and in accordance with the geometries to be recovered from the use cases.
- Determine the best conditions of parameters, strategies and trajectories of the laser reloading process for the recovery of the defined components.
- Generation of recovery and refurbishment procedures for each component and type of defect.
- To demonstrate TRL6 a repair of a rail or switch&crossings element will be performed: To demonstrate TRL6 field tests will be performed in order to validate the parameter conditions and strategies obtained in the project together with the recovery procedures and stages defined by introducing the new technology.

9.10.1.4. Influence of the proposed innovation on the IM/RU problem

The in-situ repair for an AM repair process of rails, switch&crossings elements will result in a speed up and cost saving of the entire operation, as well as quality improvement and reproducibility of results in total.

9.10.2. UC17.3: Demonstrator's KPI

9.10.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	High/direct

Table 125: UC17.3 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
17.3-1	Extension of remaining life of a railway asset repair	25%

Table 126: UC17.3 PIs

9.10.2.2. PI17.3-1 – Extension of remaining life

Short description

The service life of these components is primarily reduced by wear and tear. Therefore, the wear rate will be used to quantify the potential extension of their service life. By decreasing the wear rate through the proposed repairs, it will extend their service life.

How to compute PI17.3-1

Comparison of the wear rate of railway rails and turnout elements using the current repair build-up welding process versus the wear rate achieved with the AM repair Laser-DED process.

$$PI_{17.3-1} = \frac{WearRate_{baseline_solution} - WearRate_{I4R_solution}}{WearRate_{baseline_solution}} \times 100$$

Where:

- $WearRate_{I4R_solution}$ is the wear rate of a component repaired by additive manufacturing.
- $WearRate_{baseline_solution}$ is the wear rate of component repaired by the traditional repairing build-up welding process.

In addition, the results of laboratory tests such as impact and tensile tests specified in deliverable 17.1. will also be used to assess the quality of the repairs and the adhesion of the repair material to the base material (rail or turnout element). If a lack of adhesion is observed, the repair will not be considered valid regardless of the wear values obtained.

9.10.3. Synergies/risk of duplication of work

There are no synergies with other flagship projects or with other WPs within Flagship Project 3-IAM4RAIL. Therefore, no risk of duplication of work is foreseen either.

9.11. UC17.4: Stationary solution for AM repaired turnout crossings using WAAM technology

The focus of this use case is on an AM repaired turnout crossings using WAAM (Manual Metal Arc Welding) technology. The developed AM repair process features an ideal distribution of specific metal alloys according to the specific position in the complex internal structure of a crossing to

meet local stress situations and individual material resistance requirements (wear, fatigue, plastic deformation).

The overall goal of the first call is the development of an AM repair process for turnout crossings as stationary solution in the workshop and the demonstration of a crossing repair together with the project partners in the laboratory (TRL 4).

This use case spans Task 17.5 “AM Integrated demonstrators” and subtask 17.5.2 “Repaired metallic components: rolling stock and infrastructure”.

9.11.1. Overall aim of the use case

9.11.1.1. Problem to be solved

For the repair of railway crossings, MMAW is widely spread. The significant amount of manual work and the small number of the available filler metals are characterising for the actual situation. Also considering the track closure time, the manual repair welding process itself and the necessary preparatory and post-processing work, the repair welding of fixed crossings is a time-consuming and costly process. Due to the ideal distribution of specific metal alloys to the necessary position on a crossing, it will be possible to consider the local stress situations with an individual material approach to improve the resistance requirements.

9.11.1.2. Industry current position/baseline

The repair of a railway crossing by build-up welding is a time and cost consuming process, but essential for the infrastructure management to extend the lifetime of the crossing in track and lower the LCC. The goal of automating this process offers the possibility of cost reduction, procedure acceleration and quality improvement, among others. To extend the lifespan of a railway crossing more than by normal repair welding due to using a specific distribution of customised material concepts, will strongly influence the LCC.

9.11.1.3. Subproblem addressed by the use case and measurables

The repair welding of railway crossings is a challenging process that requires a lot of expertise. The state-of-the-art process is characterised by a significant amount of manual work and a small number of the available filler metals for the repair welding of a railway crossing. The development of a functional WAAM repair welding process for crossings and the use of specific material concepts will allow to affect the LCC in a positive way. These features will be demonstrated in a laboratory (TRL 4) and this will lay the foundation for an AM repair process for railway crossings.

9.11.1.4. Influence of the proposed innovation on the IM/RU problem

The stationary solution for a repair welding process of fixed crossings will result in a speed up and cost saving of the entire operation, as well as quality improvement and reproducibility of results

in total. The possibility to use customised material concepts, depending on the local load situation, will lead to an increase of the lifespan and will therefore strongly influence the LCC.

9.11.2. UC17.4: Demonstrator's KPI

9.11.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
IX	For repair: Extension of remaining life (25%)	High/direct

Table 127: UC17.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
17.4-1	For repair: extension of remaining life	25%

Table 128: UC17.4 PIs

9.11.2.2. PI17.4-1 – For repair: extension of remaining life 25%

Short description

Through the use of specific metal alloys and their ideal distribution to meet local stress situations and individual material resistance requirements, the life of the crossing can be noticeably extended compared to a usual repair. The service life of these components is primarily reduced by wear and tear as well as RCF and plastic deformation. Therefore, the wear rate will be used to quantify the potential extension of their service life. By decreasing the wear rate through the proposed repairs, it will extend their service life.

How to compute PI17.4-1

Comparison of the wear rate of railway turnout elements using the current repair build-up welding process versus the wear rate achieved with the AM repair Laser-DED process.

$$PI_{17.4-1} = \frac{WearRate_{baseline_solution} - WearRate_{I4R_solution}}{WearRate_{baseline_solution}} \times 100$$

Where:

- $WearRate_{I4R_solution}$ is the wear rate of a component repaired by additive manufacturing.
- $WearRate_{baseline_solution}$ is the wear rate of component repaired by the traditional repairing build-up welding process.

In addition, the results of laboratory tests such as tensile tests specified in deliverable 17.1. will also be used to assess the quality of the repairs and the adhesion of the repair material to the base material (turnout element). If a lack of adhesion is observed, the repair will not be considered valid regardless of the wear values obtained.

9.11.3. Synergies/risk of duplication of work

In relation to this UC, "Stationary solution for AM repaired turnout crossings using WAAM technology", vaRS will carry out parallel but independent activities in WP17 and WP18. For clarification purposes, the following table shows the activities to be carried out in the different WPs:

Topics	WP17	WP18
Notation in proposal	Repair of metallic assets and spare parts for vehicles using Additive Manufacturing	Robotics Platform
Goal vaRS	Development of an AM repair welding process for turnout elements (especially focused on fixed crossings)	Methodology development for the automation of the repair welding process for fixed crossings
Focus vaRS	Focus clearly on the process side: - Selection of optimal filler materials and process parameters -Optimisation of the filler materials if necessary	Development of a functional welding platform with the functions of geometry detection and welding path generation as well as monitoring of intermediate layer temperatures
Realization	Stationary solution in the workshop. Demonstration in the lab.	Functional welding platform can be combined with other automation solutions in and out of the track. Demonstration in the lab

Table 129: Activities to be carried out in WP17 and WP18.

Therefore, there are synergies with WP18 within Flagship Project 3-IAM4RAIL, but no risk of duplication of work is foreseen.

9.12. UC17.5: Additive Manufacturing of large & flame-retardant polymer spare parts

The demonstrator is a large and flame-retardant polymer component. The component must follow the EN-45545-2 standard and reach up to R1-HL2 requirements. The dimensions of the part will be about 1m. The component can be, for example, a driver's cab desktop, a command panel or a buffet car component. External fairings will be also considered as a backup option. This option aims to enlarge the variety of components, to ensure a proper component is found.

This use case spans Task 17.5 "AM Integrated demonstrators" and subtask 17.5.3 "AM of large interior flame retardant polymer spare parts".

9.12.1. Overall aim of the use case

9.12.1.1. Problem to be solved

The RU maintains a large number of trains in operational conditions which requires thousands of spare parts references. This maintenance means a wide variety of components and small quantities needs compared to other industries. Suppliers often require large quantity orders which leads to high-cost physical storage. In some cases, spare parts are no longer produced by suppliers. Transforming the physical stock in a digital storage becomes a strategic objective for the RU.

9.12.1.2. Industry current position/baseline

Printing spare parts using additive manufacturing has been identified by RUs as a powerful tool to transform maintenance process and increase performances. Additive processes for plastic and metal materials have been investigated for several years now to provide a portfolio of potential processes and materials that fit railway needs. The present use case focuses on polymer parts and deals with two crucial needs of polymer components: large dimensions and flame retardancy. Currently, very few flame-retardant polymer materials for 3D printing exist on the market and the dimensions of printed parts are limited by the capacities of printers. The capability of large printers needs to be demonstrated and compared to railway specification and standards.

9.12.1.3. Subproblem addressed by the use case and measurables

Flame retardancy – Increase the portfolio of polymers for 3D printing following the railway flame-retardant standard for materials: EN 45545-2. Reduce the cost of printing flame retardant materials.
Large dimensions – Increase the scope of available processes to print flame-retardant large railway parts.

9.12.1.4. Influence of the proposed innovation on the IM/RU problem

The use-case proposes new flame-retardant materials which increases the use of additive manufacturing to make spare parts and accelerate the storage digitalisation. The cost of these new materials will meet the railways needs, < 100€/kg. The use case brings additive manufacturing for large parts. The use case increases the number of available processes and suppliers to make one component making the supply chain more resilient.

9.12.2. UC17.5: Demonstrator's KPI

9.12.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
X	Time reduction (from design to manufacturing) (20%)	High/direct
XI	Design and Manufacturing: Cost reduction (20%)	High/direct

Table 130: UC17.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
17.5-1	Time reduction (from design to manufacturing since ordering)	30%
17.5-2	Cost reduction in parts and assets	30%

Table 131: UC17.5 PIs

9.12.2.2. PI17.5-1 – 30% Time reduction (from design to manufacturing)

Short description

The use of additive manufacturing for spare parts enables to produce quicker when compared to traditional processes, increasing train fleet availability. For example, a component such as a door socket tip produced by a conventional process can be delivered in 6 months. This lead time is to be divided by 6 with additive manufacturing processes.

How to compute PI17.5-1

For the demonstrator, the lead time between conventional and additive processes will be compared:

$$PI_{17.5-1} = \frac{Time_{baseline_method} - Time_{I4R_method}}{Time_{baseline_method}} \times 100$$

Where:

- $Time_{I4R_method}$ is the effective time to deliver the demonstrator including the design modifications time.
- $Time_{Baseline_method}$ is the time given by the supplier to deliver the demonstration part produced by conventional process based on new or existing offers.

A positive PI indicates that the estimated time for the new method is less than the time required for traditional methods.

9.12.2.3. PI17.5-2 – 30% Cost reduction in parts and assets

Short description

The use of additive manufacturing for large polymer spare parts enables to produce on-demand small quantities of components. In conventional processes, suppliers usually require large quantity orders. Thus, additive manufacturing can reduce physical storage, train assets and consequently maintenance costs. For example, on old rolling stock, a speedometer component costs about 4k€ in conventional processes and 30€ in additive manufacturing. The objective is to be less than 100€ for material costs.

How to compute PI17.5-2

The demonstrator costs produced by conventional process and additive manufacturing will be compared:

$$PI_{17.5-2} = \frac{Cost_{baseline_method} - Cost_{I4R_method}}{Cost_{baseline_solution}} \times 100$$

A positive PI indicates that the estimated cost of the new method is less than the cost of traditional methods.

9.12.3. Synergies/risk of duplication of work

In relation to this UC, “Additive Manufacturing of large & flame-retardant polymer spare part”, separate activities involving the use of additive manufacturing of rolling stock components will be carried out in WP17 within FP3-IAM4RAIL and in WP16 within FP4-Rail4Earth. By way of clarification, in FP4 WP16 the additive manufacturing activities address the design of running gears and new component design from the maintenance point of view to develop new lightweight solutions and new architectures of running gears.

However, FP3 WP17 will focus on Scouting and testing different commercial polymer materials, coatings if it's necessary and associated AM technologies to up to R1 HL2 requirement for manufacturing large interior spare parts defined by EN-45545-2.

There are synergies with other flagship projects or with other WPs, but no risk of duplication of work is foreseen.

9.13. UC17.6: Digital warehouse

The Digital Warehouse will focus on methods and technologies railway operators can use it to procure or manufacture spare parts on-demand.

This use case spans Task 17.5 "AM Integrated demonstrators" and subtask 17.5.4 "Digital Warehouse case study".

9.13.1. Overall aim of the use case

9.13.1.1. Problem to be solved

The procurement and provision of spare parts for maintenance is a crucial task for a Railway operator. Railway operators face the problem of a wide variety of parts needed, low annual demands compared to other industries and very few providers with minimum order quantities available which results in high stocks of spare parts and low annual turnovers of stocks. Under these conditions railway operators face long lead times, a high capital bounding in stock of spare parts and obsolescence of spare parts.

On-demand manufacturing methods like additive manufacturing have shown big potentials in the railway market and have been used since 2015. European Railway operator currently identifies parts for additive manufacturing bottom-up from suggestions of their employees and struggle to identify parts for additive manufacturing from their existing ERP systems. The vision to procure spare parts on-demand by printing is hampered by the labour-intensive bottom-up approach and missing technical data in the ERP system to use currently available solutions to identify parts for additive manufacturing. Methods and processes are needed to identify spare parts top down from the existing ERP systems of railway operators.

9.13.1.2. Industry current position/baseline

Additive manufacturing of spare parts is currently introduced into the railway sector. Operators test and scale the use of additive manufacturing through internal project teams which identify parts for additive manufacturing bottom-up. A check of feasibility and selection of an additive manufacturing technology is carried out manual by experts. Data Generated during the process of making a part printable (CAD-files etc.) are not carried back to existing ERP systems.

Railway manufacturer slowly starts to introduce additive manufacturing for the manufacturing of spare parts, and it's used for serial parts.

9.13.1.3. Subproblem addressed by the use case and measurables

Methodologies to identify spare parts – Document the bottom-up process to identify spare parts and develop methods of the top-down identification of spare parts.

Methodologies to evaluate AM materials and technologies – Create a systematic overview where materials and additive manufacturing technologies can be used in the railway sector. Integrate knowledge of the overview as input of the identification process.

9.13.1.4. Influence of the proposed innovation on the IM/RU problem

The use case shall demonstrate operators which already use additive manufacturing methods to scale and systemise the use of additive manufacturing. The use case shall show operators which do not use additive manufacturing yet, to be able to use additive manufacturing using the proposed methods. The aim of the use case is to enable operators to use additive manufacturing on a large scale, to tackle current hurdles in the procurement of spare parts.

9.13.2. UC17.6: Demonstrator's KPI

9.13.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #6: Design and Manufacturing and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO6 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
X	Time reduction (from design to manufacturing) (20%)	High/direct
XI	Design and Manufacturing: Cost reduction (20%)	High/direct

Table 132: UC17.6 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
17.6-1	Time reduction (from design to manufacturing)	30%
17.6-2	Cost reduction in parts and assets	30%

Table 133: UC17.6 PIs

9.13.2.2. PI17.6-1 – 30% Time reduction (from design to manufacturing)

Short description

The digital storage of the digital 3D-Models of spare parts, allows railway operators to quickly adjust spare parts geometry when necessary and enables the usage of on-demand manufacturing methods like additive manufacturing. The time reduction has two elements:

- Reduction of the in-house process time to specify and gather all necessary information to procure a spare part (e.g., an obsolete spare part).
- Reduction of the lead time in which a part can be delivered after an order due to the on-demand production.

How to compute PI17.6-1

For the demonstrator the time reduction is calculated by comparing the process time in days from spare part request to the date the first part is delivered for the traditional process $t_{traditional}$ route with the route of a digital warehouse $t_{digital\ warehouse}$. The calculation is done by comparing samples with similar characteristics.

$$PI_{17.6-1} = t_{saving} = \frac{t_{traditional} - t_{digital\ warehouse}}{t_{traditional}}$$

9.13.2.3. PI17.6-2 – 30% Cost reduction in parts and assets

Short description

The digital warehouse allows for a cost reduction in parts and assets by reducing the total cost of ownership for a spare part. Elements of the total cost of ownership are:

- Procurement cost per part.
- Storage cost over the expected average storage live until all parts of an order batch are used.
- Opportunity savings due to reduced lead times, etc.

How to compute PI17.6-2

$$PI_{17.6-2} C_{total} = \frac{C_{spare\ part\ order}}{N_{parts\ in\ order}} + \frac{C_{spare\ part\ order}}{2} * \left(\frac{i+l}{100}\right)^{\frac{N_{parts\ in\ order}}{D_{yearly\ average\ demand}}} - C_{oppertunity\ savings}$$

The cost between a standard order with classical minimum order quantities will be compared to a reduced order quantity enabled by a digital warehouse.

9.13.3. Synergies/risk of duplication of work

There are no synergies with other flagship projects or with other WPs within Flagship Project 3-IAM4RAIL. Therefore, no risk of duplication of work is foreseen either.

9.14. UC18.1: Light and flexible on-track inspection

The multi-functional inspection robot on rail was developed specifically for this purpose. It does not yet necessarily cover the entire spectrum of useful inspection (due to technical and budgetary constraints), but it will be able to integrate future inspection needs.

This use case spans Task 18.4 “Use cases related tasks” and subtask 18.4.1 “On rail multipurpose inspection robot”.

9.14.1. Overall aim of the use case

9.14.1.1. Problem to be solved

The overall Problem to be solved by the Infrastructure Manager (IM) or the Railway Undertaking (RU) with an on-rail multipurpose inspection robot is to ensure the safe and efficient operation of the railway system. The inspection robot can be used to detect and assess potential risks, defects or damage to the railway infrastructure, such as the track, signals, infrastructure, bridges, and tunnels. On some small or remote lines (due to the availability of the measurement systems or due to the difficulties to transport them at the right location) the traditional means of inspection (measuring trains...) cannot be mobilised or not in such a flexible way as required to carry out particular surveillances. IMs are looking for lighter and more flexible means of inspection which can cover multiple inspection tasks.

The inspection robot must be able to locally navigate the railway system, to collect data and information, to identify potential hazards or issues and adapt it behaviour. The IM or RU must then use this information to plan and prioritise maintenance and repair activities to ensure continued safe and reliable operation.

The ultimate goal of the on-rail multipurpose inspection robot is to prevent accidents, reduce downtime and ensure the highest level of safety for passengers and freight transport. By using advanced technology to automate the inspection process, the IM or RU can improve the efficiency and accuracy of inspections, leading to significant cost savings and increased reliability of the railway system.

9.14.1.2. Industry current position/baseline

Inspections that cannot be covered by measuring machines or commercial machines are covered by walking tours. These rounds are tedious for the operators. The probability of not detecting a defect is not negligible.
Currently, the IM or RU mainly relies on human inspectors or large inspection vehicles to inspect the railway infrastructure.
For example, some railways may use track geometry cars or trains equipped with sensors to collect data on the condition of the track and other infrastructure. These methods can provide valuable information but are also costly to operate and require track-access.

The manual inspection process also has a high risk of error and oversight, which can result in potential hazards or issues going unnoticed.

9.14.1.3. Subproblem addressed by the use case and measurables

Catenary inspection poses challenges in terms of efficiency, accuracy and safety when performed manually. However, a small on-rail inspection robot equipped with a LiDAR (Light Detection And Ranging) sensor, colour camera and thermal camera provides an advanced and automated solution. This robotic system streamlines various aspects of catenary inspections, improving overall efficiency and reducing risks associated with human presence in hazardous environments. The LiDAR sensor accurately measures catenary wire position, alignment and sag, while the colour camera captures high-resolution images for precise defect detection. Additionally, the thermal camera plays a crucial role in identifying faults through temperature patterns, including overheating and variations along insulator surfaces. By collecting valuable data from these sensors, the robot enables comprehensive inspection reports that facilitate data-driven decision making, optimise maintenance activities and result in long-term cost savings. This integrated approach revolutionises catenary inspections, providing a proactive and accurate solution for maintaining a reliable and safe railway infrastructure, while also detecting defects early and preventing larger repairs or disruptions.

Other electrical infrastructure will also benefit from the capabilities of the inspection robot. The robot's advanced technology enables efficient and accurate inspection of various components such as overhead line equipment, power substations, signal and communication systems and traction power systems. Leveraging its ability to detect abnormal temperature patterns, the robot effectively identifies and alerts to a wide range of anomalies, faults and loose connections.

Railway tunnel clearance profiles are vital to ensure the safety and efficiency of train operations, especially in restricted access tunnels. These tunnels differ from standard railway systems, characterised by narrow widths, low heights, irregular shapes and structural constraints. Their unique characteristics necessitate specific considerations and precautions for train operations. In this context, the inspection robot can play a crucial role by scanning the tunnel geometry to address clearance issues. By documenting the clearance profile, the robot enables the identification of obstacles, insufficient space or the need for track adjustments. It also explores opportunities to raise the track when additional space allows. Through regular scans, the inspection robot identifies areas where the track needs to be adjusted, ensuring adequate clearance for trains, contributing to enhanced safety and operational efficiency.

Low gauge of the track and rails spacing*:* in the context of the rehabilitation of unused railway tracks for the circulation of an innovative mobile (Flexy2), IM needs to know the geometric configuration of the track before the innovative vehicle can be put on the road. The circulated tracks will be the old ones that currently do not ensure traffic. The passage of measurement trains is therefore not possible in this state. Only walking tours are possible. The robot should be able to perform cross-sectional scans of the track at the level of the rail head (with an accuracy still being defined) as well as in two 600 cm2 areas outside the track in the immediate vicinity of the rail and

with an accuracy of +/- 0.5mm. The longitudinal resolution of the scans and the precision of their positioning with respect to the curvilinear abscissa of the track is also being defined.

Water presence in railway tunnels poses significant risks to safety and infrastructure. When water infiltrates the concrete, it becomes contaminated and electrically conductive, leading to potential structural weakening, compromised track safety, damaged electrical systems and accelerated corrosion. To effectively manage water infiltration, implementing drainage systems, waterproofing measures and conducting regular inspections are essential. Proactive measures are crucial in mitigating risks and ensuring the long-term stability and functionality of tunnel infrastructure for safe train operations. The inspection robot may play a vital role in locating water intrusion points by identifying thermal patterns, abnormal reflectivity and discoloration. Furthermore, the potential integration of additional sensing techniques such as Ground Penetrating Radar (GPR) and Short Wave Infrared (SWIR) cameras may be considered to enhance detection accuracy and provide valuable insights into the extent and location of water infiltration, facilitating timely remedial actions.

Except for the low gauge, all situations can be covered with a sensor node mounted on a mobile base that moves on rails. This node can be orientable in 2 degrees of freedom (pan and tilt). It will feature an RGB camera, an infrared camera and a rotating LiDAR whose beams are reoriented to a reduced region of interest by a reflector comprising trapezoidal mirrors. This equipment is a module that can live independently of the mobile base used for our demonstrator.

A network of laser sensor (telemeters, profilometers) will be used to measure the low gauge of the track and the rails spacing. This too will be a module that can live independently of the demonstrator's mobile base and the other sensor node. Similarly, the mobile base can host other equipment than the 2 complex sensors described above. For example, SNCF is currently pre-studying an extension for track vegetation control.

Localisation: these different sub-uses involve the localisation of the robot on the longitudinal axis of the track, especially in contexts where localisation by GNSS is not possible (tunnels). The robot will embark a localisation system covering the requirements of the most severe application.
Possible extension to the mechanical integrity of the track (already worked in IN2SMART2 and 3) and initial diagnosis in case of fire in a tunnel.

The targeted measurable objectives at TRL6 are as follows:

- To develop and deploy an on-rail multipurpose inspection robot that can locally navigate the railway infrastructure, collect data and information and analyse it to identify potential hazards or issues.
- To demonstrate the robot's ability to detect and assess potential risks, defects or damage to the railway infrastructure for selected demonstrator use cases.
- To show that the robot's analysis can be used by the IM or RU to plan and prioritise maintenance and repair activities, resulting in significant cost savings and increased reliability of the railway system.

Although working at TRL6 instead of TRL8/9 can introduce uncertainty in scalability and integration with existing railway infrastructure, the use case targets measurable objectives at TRL6, limiting the scope to developing and demonstrating the technology at this stage of development. Therefore, the use case does not extend beyond TRL6.

9.14.1.4. Influence of the proposed innovation on the IM/RU problem

The proposed innovation of using an on-rail multipurpose inspection robot can have a significant impact on the IM/RU problem. By enabling quicker and more efficient inspections, a scaled solution based on the robot can increase inspection availability. If achieved, the IM or RU would be able to identify potential hazards or issues quickly, allowing for prioritisation of maintenance and repair activities. This, in turn, would reduce downtime, improve safety for passengers and freight transport, and lead to significant cost savings. Additionally, the IM or RU would reduce reliance on manual inspection processes or the availability of large track geometry cars, resulting in a more efficient and effective maintenance strategy for railway infrastructure. Ultimately, the proposed innovation has the potential to bring about a paradigm shift in the railway inspection process and the way that IMs and RUs manage and maintain their railway infrastructure.

9.14.2. UC18.1: Demonstrator's KPI

9.14.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VII	Infrastructure Operation: Reduction of service failures (25% reduction)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform sterenuous tasks, such as safely moving heavy loads...	Little/indirect

Table 134: UC18.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
18.1-1	Cost per measured kilometre	32 €/km
18.1-2	Confusion	10%

Table 135: UC18.1 PIs

We want to demonstrate that our robot is in line with SEO9. To make this demonstration, we propose to use the cost of an operation per kilometre of track controlled. However, cost cannot be the only indicator. If the robot can be operated at a lower cost but does not produce quality results that maintenance can rely on, it will not be useful. We propose to base an indicator on 2 of the classes of a confusion matrix.

9.14.2.2. PI18.1-1 – Cost per measured kilometre

Short description

The cost will be established with a very simple cost model clearly showing the calculation assumptions.

How to compute PI18.1-1

We will not cite specific values from any of the national IM here. We can however evoke reasonable orders of magnitude if we refer to the experience of the latter:

- heavy measurement equipment has a rather low synthetic efficiency rate (ratio of the number of hours actually used to the total number of hours in a year) which we estimate at 5%;
- the average cost of a heavy measurement device is estimated to 5M€;
- the measurement train is operated by a crew of 3 trained operators;
- service life of heavy equipment: 25 years;
- the maintenance cost over the entire lifetime is twice the purchasing cost.
- the energy comes from a diesel generator consuming on average 25 l/h for a cost of 1€/l
- LCC over the service life: 28 M€ (decommissioning not evaluated);
- operating speed: 80 km/h.

These different data lead to a cost of control by a heavy vehicle of 32€/km.
The objective is therefore to demonstrate that MPIR can operate at a cost per kilometre of less than 28€/km (using the same basic cost model).

$$PI_{18.1-1}C_{WF} = \frac{C_{WF} + C_{PURCH} + C_{MAINT} + C_{NRJ}}{Number\ inspected\ track\ length}$$

Where:

- $C_{WF} = Number\ workforce\ \times\ 8\ \times\ 200 \times\ Number\ work\ session\ per\ day\ \times\ 100$
- $C_{NRJ} = NRJ\ Cost\ for\ 1\ hour\ of\ operation\ \times 8 \times 200 \times\ Number\ work\ session\ per\ day$
- $Number\ insp.track\ length = operational\ rate\ \times\ 8760\ \times\ service\ life\ \times\ average\ insp.speed$

9.14.2.3. PI18.1-2 – Confusion

Short description

We choose to base our approach on the false positive and false negative rate for the detection of obstacles in the area of interest of the low gauge (rectangle of 30cm side outside the rail and on its full height) and/or the presence of water and/or the presence of arming elements of the catenary. We will compare them with the level of reliability normally accepted for a trained operator.

How to compute PI18.1-2

Real defects are listed. Defects are deliberately simulated (to ensure a representative statistical basis without raising the experimentation time with incompatible levels of project progress). The number of false positives is the number of reported defects that do not coincide with any simulated or real defect. The number of false negatives is the number of simulated or real defects that are not detected by the robot.

$$PI_{18.1-2A} = \frac{Number\ of\ false\ positive\ detections}{Number\ of\ real\ defects}$$

$$PI_{18.1-2B} = \frac{Number\ of\ false\ negative\ detections}{Number\ of\ real\ defects}$$

9.15. UC18.2: Automated installation of ERTMS balises and axle counters

The use case consists of integrating current technology and combining it for rail related purposes. It aims to demonstrate how the current state of technology benefits from its application and how future robots could enhance that.

This use case spans Task 18.4 “Use cases related tasks” and subtask 18.4.2 “Object installation robot”.

9.15.1. Overall aim of the use case

9.15.1.1. Problem to be solved

The overall problem is that the transition from current situation to ERTMS is a very long process. The workforce to install the infrastructure is not sufficient to ensure that ERTMS will be operational by 2050 in The Netherlands. Furthermore, the current signalling systems have reached their limitations. Therefore, the ambition is to accelerate the roll out of ERTMS and hopefully have it completed by 2040. Additional research and testing are also being conducted to explore the inspection and intervention of other railway assets, such as rail fastening systems. This is being done with a view to future developments beyond this project, to verify whether high TRL's could also be reached in these cases.

9.15.1.2. Industry current position/baseline

The baseline is the current number of qualified workers that are able to install the ERTMS infrastructure. The number of qualified workers is more likely to decrease than to increase. To accelerate the implementation of ERTMS in The Netherlands, the capacity must increase. The balise use case demonstrates that the application of robots is considered useful and serves as a showcase for potentially many activities during maintenance and other interventions in the rail sector, addressing shortages among other challenges. Complementary research is needed to explore the potential of robots designed for specialized tasks, such as tightening and inspecting rail fasteners. Initial exploration and testing of specific cases could accelerate future developments, helping to address the growing shortage of skilled labour and improving both the installation and maintenance processes of railway infrastructure.

9.15.1.3. Subproblem addressed by the use case and measurables

Track work is typically heavy work, both physically and mentally. The work is commonly carried out at night when the amount of traffic is low. The equipment used by trackworkers is heavy and powerful. The work method requires trackworkers to bend over or work on their knees.

Robots can work any time, are powerful, and able to manoeuvre/position themselves. Therefore, robots can do heavy repetitive work for the installation. The use case is about to mount the ERTMS balise and axle counter on the track. Operators will be relieved from lifting any heavy equipment or handling powerful tools.

In this context, parallel research into complementary robotic technologies, such as the torque tester robot, aims to reduce the physical strain.

9.15.1.4. Influence of the proposed innovation on the IM/RU problem

If the use of the robot is a success, the infrastructure manager expects that more robots will be developed for the construction and maintenance of the infrastructure. The infrastructure manger

hopes that the availability of robots will be sufficient to ensure that the track network can be renewed and maintained at stable/lower construction and maintenance prices.

9.15.2. UC18.2: Demonstrator's KPI

9.15.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	Little/indirect
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform sterenuous tasks, such as safely moving heavy loads...	High/direct

Table 136: UC18.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
18.2-1	Use of robotised tools	25%
18.2-2	Tender offer	NA
18.2-3	Heavy repetitive work	NA

Table 137: UC18.2 PIs

The list of chosen PIs has considered the potential robot contribution for Strukton. First of all, the mere use of the robot is the most important factor. Second, it is the effect on tenders and the associated economic value. Third, the expected benefit on health and safety by letting the robot execute heavy repetitive work that otherwise would be done by humans.

9.15.2.2. PI18.2-1 – Use of robotised tools

Short description

Management idea or vision to use modern technology and introduce robots in the sector. The development is based on viable use cases justified on their entrepreneurial feeling.

The idea is to use robotised tools to solve the following problems:

- Lack of staff.
- Improve health conditions.
- Quality of end-results in terms of recorded output and quality insurance.

Problems above have been identified by government, universities and financial institutions.

How to compute PI18.2-1

This PI is more in terms of statement of the stakeholders qualifying the end results. Criteria or ideas to be included are:

- Are robots autonomous: do they use robotised principles?
- Do they perform the task they are supposed to?
- Is the development a contribution for future developments?

9.15.2.3. PI18.2-2 – Tender offer

Short description.

The use of robots will affect the tender offer when tenders are proposed for the installation of axle counters and balises.

How to compute PI18.2-2

$$PI_{18.2-2}\ \text{tender offer development} = 1 - \frac{\text{tender offer price with robot}}{\text{tender offer price conventional}}$$

9.15.2.4. PI18.2-3 – Heavy repetitive work

Short description

Heavy repetitive work has an effect on health and safety. Every shift performed by the robot saves up a shift that would have otherwise been done by humans. When the robot is deployed for projects, it would be valuable to know how many shifts have been performed by humans and by the robot.

How to compute PI18.3-3

$$PI_{18.2-3}\ \text{shifts by robot development} = 1 - \frac{\text{shifts performed by robot}}{\text{shifts performed by humans}}$$

9.16. UC18.3: Disinfection of trains and small stations

A mobile robot devoted to the disinfection in Railway's environments (inside the rolling stock and inside stations) is an unmanned robotic system for intervention. It will be remotely supervised or fully autonomous with appropriate sanitation technologies aimed at sanitizing environments in an effective manner. This is how it is part of the DO7.

This use case spans Task 18.4 "Use cases related tasks" and subtask 18.4.3 "Disinfection robot in railway environment".

9.16.1. Overall aim of the use case

9.16.1.1. Problem to be solved

The overall Problem to be solved by the Infrastructure Manager (IM) and the Railway Undertaking (RU) using a disinfection robot is to ensure a safe, well-automated and monitored way to apply sanitation processes within railways environments - such as trains or stations –. Sanitation processes seek to better face potential needs from the global community (from basic hygiene to pandemic crises). The sanitation processes need to be carried out at regular intervals, (most likely during operation hours in the case of stations) and in a cost- and resource-efficient manner.

9.16.1.2. Industry current position/baseline

In France, the disinfection due to the Covid-19 during 2020 represented a 20% increase of the cost for the passenger area of the rolling stock.
The emergency of the SARS COV-2 pandemic has highlighted the need of instruments and procedures for disinfection of environments for both the IM and the RU for reducing the spread of similar respiratory infections. Many solutions have been put forward by IM and RU to react immediately to the evolving crisis, and many of them have been forced by contingency without rational time to evaluate pros and cons from the economic or engineering point of view. From this perspective, a more systematic approach with well-designed robotics solutions that can better address routine or critical disinfection problems could minimize process costs.

9.16.1.3. Subproblem addressed by the use case and measurables

In order to be able to disinfect a train or a station, the robot must be able to handle the following sub-problems:

1. **Move without issues inside the target environment:** The robot must be able to do a full sweep in the train or in the small station without the intervention of a human (except, potentially, moving the robot inside and outside the train). Since the use case is targeting at TRL6, it would be accepted that it might need a human intervention one time out of five.

2. **Undertake an effective disinfection technique that would not harm the environment:** Depending on the chosen technology (chemical compound and/or UVC light), the efficiency and non-aggressiveness will be elaborated by h experts' opinion in lab and field tests (the best possible effort allowed by TRL6 approach). The compatibility of the disinfectant must be ensured with the robot's sensors. It will be tested in the field.

3. **Ensure the absence of human beings in the area (the train or the small station):** We will refer to the best standards of people detection. Since the use case is targeting at TRL6, we'll investigate how the adoption of cross-methods can achieve high levels of detection.

If we are able to ensure that there is no human being present then we can also solve the following issue: Experience shows, when the train goes back to the garage or similar piece of infrastructure, people sometimes stay on it. This may imply safety problems for the passengers if decide to return via the tracks. It is unclear how such situations could affect the operation of autonomous robot systems within parked trains.

9.16.1.4. Influence of the proposed innovation on the IM/RU problem

A mobile disinfection robot can be useful for professional and safe sanitation of large environments, where the process must be complete in tight time constraints, such as stations and trains. Moreover, a sanitation robot can be suitable for smaller stations (without permanent staff) where the sanitation time is not a strict requirement but sending human sanitation teams is not practical for cost and travel time reasons.

- The advantages of using a mobile platform over a static solution are as follows: **Simplicity** in reaching every point of the space to be sanitised.
- **Low disinfection time** in the working environment.

The advantages of having an autonomous robot vs no robot are:

- The workforce is not required to look after it (except maybe for the access to the train) so the operator can do other tasks or pilot several robots.
- As the robot operates in a closed system without human presence, reduced risk exposure (since the chemicals are only handled to "fill" the robot), or negligible risk if we use UVCs.

This work can prepare for future work on cleaning.

9.16.2. UC18.3: Demonstrator's KPI

9.16.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	High/direct
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform strenuous tasks, such as safely moving heavy loads...	Little/indirect

Table 138: UC18.3 KPIs on a FP level from the Grant Agreement

A potential list of PIs which can be easily related to a disinfection robot within Railway's environments are the following:

PI	Description	Target
18.3-1	Disinfection Time (DT)	20 min
18.3-2	Disinfection Cost (DC)	10%

Table 139: UC18.3 PIs

All these measurable PIs are able to contribute to achieve the following aspects:

- Increased accuracy of inspections with respect to conventional interventions.
- Reproducibility of inspection with respect to conventional interventions.
- Cost reduction of the interventions.

9.16.2.2. PI18.3-1 – Disinfection time (DT)

Short description

If the robot is too slow or too many robots are needed it will not provide the expected service, or too many robots will be needed (which will greatly increase the LCC).

The disinfection time used by the robot (or multiple robots) should be around 20-25 min per train: The robot would disinfect 10 trains in 4h approx. (in some contexts this value corresponds to the maximum number of trains that are available for off-peak disinfection, which is what saturates the robot's capacity).
This disinfection time is calculated considering a robot speed of 0,4 m/s and a train length of 400m.

$$\frac{400m}{\left(0{,}4\ \frac{m}{s}\right)} \div 60s \approx 20\ min$$

Disinfection time can also depend on the shape factor of the environment where the robot will operate, concerning the technology being used.

How to compute PI18.3-1

The time to disinfect the selected trains will be measured in several field tests. The disinfection time will be the average value. There is not a unique relation to be used for calculating the disinfection time, since it will depend on the implemented technology for sanitising.

1. **In case of using a chemical compound**, the PI can be calculated:

$$PI_{18.3-1}\ DT = \frac{\text{Volume of the disinfection area}}{\text{Disinfection device flow rate}}$$

   Where:

   - Volume of the disinfection area is the total volume (station or train's interior area) to be treated, expressed in cubic meters (m^3).
   - Disinfection device flow rate is the amount of volume disinfected by the device per minute, expressed in cubic meters per minute (m^3/min). Hence, the disinfection device flow rate represents the speed at which the device can deliver the disinfectant.

2. **In the case of ultraviolet disinfection (UVR)**, there is no specific formula to calculate disinfection time, due to the fact that the exposure time required depends on various factors, such as the intensity of UVR emitted by the device and the specific sensitivity of the microorganism being targeted. From this perspective, the industry and UVR disinfection experts often establish specific guidelines or recommended exposure tables for certain microorganisms. These guidelines are based on scientific and experimental studies that determine the required exposure time to achieve effective disinfection. Therefore, to calculate the disinfection time using UVR, it is necessary to refer to such specific guidelines for the UVR device being used and the target microorganism. Typically, these guidelines specify the recommended exposure time based on the UVR intensity and the microorganism's sensitivity.

Alternatively, using an experimental approach, the PI can be calculated by considering the elapsed time for the whole process and then considering that time as effective after a demonstration that surfaces and volumes are sanitised (e.g.: by chemical analysis).

9.16.2.3. PI18.3-2 – Disinfection Cost (DC)

Short description

This is what will allow us to confront the SEO9. It should be related to the expected number of productive hours for the system over its lifetime. The disinfection cost represents the cost of carrying out a disinfection operation.

How to compute PI18.3-2

A disinfection cost of 60€/train is assumed (in line with what was observed during the 2020 pandemic). According to the SEO9, which aims for a 10% reduction, we therefore aim for an operation cost of 54€/train.

The disinfection cost will be calculated by dividing the LCC of the technical system (one or multiple robots) needed to ensure the disinfection time indicated above, by the number of trains cleaned over the same period of time (N_{TRAINS}).

$$PI_{18.3-2}DC = \frac{\text{LCC of the technical system}}{\text{N}_{\text{TRAINS}}}$$

The LCC will be determined at a later stage.

9.17. UC18.4: Train underbody inspection

ARGO (**A**utonomous inspection of **R**ollin**G** st**O**ck) will help maintenance staff to inspect the train underbody. Basically, it is a complementary device to the inspection gateway. An inspection robot can be more flexible to changes in traffic flow than a gate. In addition, the gate provides limited views of certain organs, for instance in the case of the underbody of the train. In the medium term, the arms that will be used to bring the cameras and other sensory organs to these difficult-to-access elements could also be used to carry out interventions (technical cleaning, etc).

This use case spans Task 18.4 “Use cases related tasks” and subtask 18.4.4 “Train underbody inspection robot (ARGO)”.

9.17.1. Overall aim of the use case

9.17.1.1. Problem to be solved

The overall Problem to be solved by using a train underbody inspection robot such as ARGO is to ensure a greater level of safety for passengers and personnel, while at the same time pursuing a parallel reduction in maintenance and material costs by means of 4.0 technologies compared to ordinary maintenance processes.

9.17.1.2. Industry current position/baseline

Today, the current practices for inspection of railcars and locomotives within RU are preventive and almost entirely manual processes. Precisely, trained personnel perform a visual and planned inspection of the rolling stock, usually while standing over an inspection pit, or from the wayside as it runs slowly past a trackside inspector. However, manual inspections are labour-intensive processes which generate complications as the systems become more complex. Although they reduce the unavailability of rolling stock when the failure has a certain regularity of occurrence, it is not desirable to apply scheduled maintenance techniques when a failure is hardly foreseeable. Furthermore, manual inspections have multiple risks and drawbacks, such as subjectivity in measuring and reporting of data, risks related to workers’ safety, possible oversights and failures

related to human error, and costs and time for both the process and staff training. All these factors limit the effectiveness and efficiency of the current inspection process.
Therefore, routine maintenance processes represent a critical and fundamental aspect to ensure safety and efficiency in rail transport. Compared to scheduled maintenance processes, 4.0 technologies thanks to the use of distributed modular sensors and robotic technologies allow the introduction of the “on condition” maintenance paradigm, able to prevent the occurrence of failures by monitoring predictive parameters and preventive intervention on "condition".
In this perspective, the design of a modular robotic underbody inspection system such as ARGO allows the operator to perform multiple maintenance tasks by remotely viewing the underbody of the trains using the position and orientation of an "on board" vision system: hence the idea of ARGO.

9.17.1.3. Subproblem addressed by the use case and measurables

The focal points of all activities around ARGO can be divided in HW & SW aspects. HW aspects to be pursued within a TRL 6 are mainly related to overcoming mechanical limitations with respect to environment in which it will operate.
On the other hand, SW aspects are the most confronted to achieve the goal of the project in getting a device which can make a real difference between classical TRL8/9 processes and novel ongoing innovation processes. Precisely, SW points mostly involve machine learning techniques in developing AI algorithms to increase the ARGO’s attitude towards the training.
Within a TRL6 level, the targeted measurable objectives which could be considered for training the robot are summarized in the following maintenance tasks (they are just included as examples):

- Binary recognition of crucial components (present or absent);
- Calculation of critical measurements for safety, such as:
    - thickness of pads;
    - thickness of brake disk;
    - state of relevant surfaces from the mechanical point of view.
- Recognition of possible leaks of crucial components.

ARGO is a modular, battery-powered, flat robotic vehicle provided with a particular traction system based on wheelsets that allow it to run inside the track, under a train, without colliding with the train. ARGO is provided with cameras – both fixed and moving – to perform visual inspection, capturing pictures of the train underbody. It can be remotely controlled by an operator or can execute an image collection routine automatically, collecting all the pictures from the desired spots. The pictures collected have associated train and location metadata and can be analysed through different computer vision algorithms; for example, neural networks algorithms can be used for object or fault detection and segmentation.

9.17.1.4. Influence of the proposed innovation on the IM/RU problem

RU implementing a novel modular robotic solution such as ARGO in the field of rolling stock maintenance area, can get many advantages. A modular robotic system – which is able to perform, integrate, and replace some functions currently carried out by operators - represents an intrinsic

advantage in terms of safety and personnel costs, then optimisation of the maintenance process. From the data processing perspective, an automated system, by exploiting the concepts of artificial intelligence and digital data acquisition, easily integrates with IoT (Internet of Things) which is starting to influence the public transportation.

This is reflected on the evolution of rolling stock maintenance plans from preventive to predictive. Predictive maintenance represents the killer application to compete within a globalised and under pressure marketplace, contributing to reach benefits related to operative results and methodologies, such as:

- Optimization of the maintenance periods.
- Minimization of the operators' risk when accessing the train underbody.
- Enhancement of the inspection procedure by structured and tracked data acquisition.
- Make the inspection procedure possible in actual train stations rather than in dedicated maintenance plants only.

9.17.2. UC18.4: Demonstrator's KPI

9.17.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
II	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)	High/direct
III	Rolling Stock Operation: Reduction of service failures (25% reduction)	Little/indirect
IV	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	High/direct
XIII	Reproducibility of inspections with respect to conventional interventions (25%)	High/direct
XIV	Cost reductions of the interventions (by at least 10%)	High/direct
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform sterenuous tasks, such as safely moving heavy loads...	Little/indirect

Table 140: UC18.4 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
18.4-1	Maintenance Costs (MC)	60%
18.4-2	Maintenance Time (MT)	50%
18.4-3	Defects Index (DI)	NA

Table 141: UC18.4 PIs

These measurable PIs can contribute to achieve the following aspects according to the table below:

A. Increased accuracy of inspections with respect to conventional interventions.
B. Reproducibility of inspection with respect to conventional interventions.
C. Cost reduction of the interventions.

In a preliminary prototyping phase, it may be possible to consider only a specific group of rolling stock under observation.

PI	Description	**A**	**B**	**C**
PI18.4-1	**M**aintenance **C**osts (**MC**)			X
PI18.4-2	**M**aintenance **T**ime (**MT**)			X
PI18.4-3	**D**efects **I**ndex (**DI**)	X	X	

Table 142: Contribution of UC18.4 PIs

9.17.2.2. PI18.4-1 – Maintenance Costs (MC)

Short description

This PI can be a representative synthetic index aimed at considering an estimation of maintenance cost that can be saved thanks to implementing the ARGO's tasks within possible upgraded maintenance processes.

Possible examples of cost reductions can be represented by:

- a greater duration of spare parts thanks to the robotic inspections coupled with AI results.
- a minor amount of personnel for specific inspection tasks due to the use of the ARGO robot.

How to compute PI18.4-1

This PI can be calculated by the following division:

$$PI_{18.4-1}MC = \frac{C_{\overline{ARGO}}}{C_{ARGO}} \qquad [< 1]$$

Where:

- $C_{\overline{ARGO}}$ is the cost of maintenance without the ARGO robot.
- C_{ARGO} is the cost of maintenance with the ARGO robot.

The expected result should be less than 1.

9.17.2.3. PI18.4-2 – Maintenance Time (MT)

Short description.
This PI can be a representative synthetic index aimed at considering an estimation of maintenance time that can be saved thanks to the implementation of the ARGO's tasks within upgraded maintenance processes. On the other hand, it could be read as an index that accounts for more availability of rolling stock.

How to compute PI18.4-2
This PI can be calculated as the reduction in the time interval between two maintenance interventions thanks to the use of the ARGO robot as follows:

$$MT = \frac{T_{\overline{ARGO}}}{T_{ARGO}} \qquad [< 1]$$

Where:

- $T_{\overline{ARGO}}$ is the whole duration time during maintenance process without the ARGO robot.
- T_{ARGO} is the whole duration time during maintenance process with the ARGO robot.

The expected result shall be less than 1.

9.17.2.4. PI18.4-3 – Defects Index (DI)

Short description
This PI can be a representative synthetic index aimed at considering an estimation of defects that can be recognized thanks to the implementation of the ARGO's tasks in upgraded maintenance processes.

How to compute PI18.4-3
This PI can be calculated by different perspectives:

$$DI = \frac{D_{ARGO}}{D_{\overline{ARGO}}} \qquad [> 1]$$

Where:

- D_{ARGO} is the number of defects found with the ARGO robot.
- $D_{\overline{ARGO}}$ is the number of defects found without the ARGO robot.

9.18. UC18.5: Automated fixed crossing repair

This first call, subtask 18.4.5 “Preparatory work for future (complex) developments” will give birth to components that will be useful for intervention robots. However, for the development of a crossing repair robot, preparatory work is necessary. The focus of this use case is on the approach of an automated repair welding process for fixed crossings and for the necessary tools. The overall goal of the first call is the development of a functional welding platform as stationary solution together with the project partners for demonstration of the crossing repair in laboratory (TRL 4).

This use case spans Task 18.4 “Use cases related tasks” and subtask 18.4.5 “Preparatory work for future (complex) developments”.

9.18.1. Overall aim of the use case

9.18.1.1. Problem to be solved

Concerning the repair of a fixed crossing, build-up repair welding is an indispensable and proven method to extend the in-service lifetime of fixed manganese steel crossings. However, build-up repair welding of fixed crossings is a fully manual process so far. Taking into account all the activities and aggregated times employed in the process (the track closure time, the manual repair welding process itself, the necessary preparatory and finishing work, such as grinding, crack testing or temperature control), the repair of fixed manganese steel crossings is, overall, a time-consuming and costly process.

9.18.1.2. Industry current position / baseline

Crossing repair by build-up welding is a time and cost consuming but essential process for the infrastructure management to extend the lifetime of the crossing in track and to lower the LCC. The goal of automating this process offers the possibility of cost reduction, procedure acceleration and quality improvement, among others.

9.18.1.3. Subproblem addressed by the use case and measurables

Build-up repair welding of manganese steel crossings is a challenging process requiring expertise, especially concerning weld paths and temperature control. The development of a functional, non-mobile welding platform for an automated fixed crossing repair will therefore focus on the ability to perform a geometry scan and welding path generation on the one hand, and to monitor intermediate layer temperatures on the other hand. The scanning and repair welding will be done

fully autonomously by the robot. These features will be demonstrated in laboratory (TRL 4) and this will lay the foundation for an automated repair welding process in track.

It should be noted that voestalpine Railway Systems is also involved in ER WP17 “Additive Manufacturing” with the development of an AM repair welding process for S&C components (especially fixed crossings). The focus in WP17 is clearly on the process side with the goals of selecting optimal filler metals and process parameters and optimizing the filler metals if necessary. Whereas WP18 “Robotics” - subtask 18.4.5 “Preparatory work for future (complex) developments” focuses on the methodology development for the automation of the repair welding process for fixed crossings, as stated above. Nevertheless, synergies between WP17 and WP18, for example regarding suitable filler metals, will be used, should they arise during the course of the project.

9.18.1.4. Influence of the proposed innovation on the IM/RU problem

The automation of the build-up repair welding process of fixed crossings using a stationary solution will result in a speeded-up process and cost reduction of the entire operation, as well as in a quality improvement and reproducibility of results in total. Subtask 18.4.5 “Preparatory work for future (complex) developments” focuses on the development of a functional robotics platform for an automated fixed crossing repair by build-up welding for demonstration in laboratory (TRL 4), which will be the first step in achieving the overall future goal of automated repair welding in track.

9.18.2. UC18.5: Demonstrator’s KPI

9.18.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
VI	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use case)	High/direct
VIII	Number of assets managed and monitored by Digital Twin (Increase by 25 %)	Little/indirect
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform strenuous tasks, such as safely moving heavy loads...	Little/indirect

Table 143: UC18.5 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PIs are proposed for this use case:

PI	Description	Target
18.5-1	Accuracy of inspections	25%
18.5-2	Reproducibility of inspections	25%
18.5-3	Cost reduction	10%

Table 144: UC18.5 PIs

9.18.2.2. PI18.5-1 – Increased accuracy of inspections of 25%

Short description

The automated fixed crossing repair done by a stationary robotised welding platform will allow performing the geometry scanning and repair welding fully autonomously, increasing the accuracy of the automated repair process compared to the manual process.

How to compute PI18.5-1

Comparison of the resulting geometry **of the automated repair welded fixed crossing -done by the robot on the developed welding platform**-, to the geometry of a manual repair welded fixed crossing in reference to the design geometry by the required time for subsequent finishing works as follows:

$$PI_{18.5-1}\ Time_finishing\ = \frac{T_{automated}}{T_{manual}} \leq 0{,}75$$

Where:

- $T_{automated}$: Time needed for geometry finishing work after automated repair build-up welding process.
- T_{manual}: Time needed for geometry finishing work after manual repair build-up welding process.

9.18.2.3. PI18.5-2 – Reproducibility of inspections of 25%

Short description

The stationary welding platform for an automated fixed crossing repair will allow doing the scanning and repair welding fully autonomously by the robot and will therefore enhance the reproducibility of the repair welding.

How to compute PI18.5-2

Comparison of the resulting geometry of several repair welded fixed crossings done by the robot on the developed welding platform in reference to the design geometry as follows:

$$PI_{18.5-2}\ Geometry_average\ = \frac{GA_{automated}}{GA_{manual}} \leq 0{,}75$$

Where:

- $GA_{automated}$: Average geometry deviation of serval automated repair-welded crossings to design geometry.
- GA_{manual}: Average geometry deviation of manual repair build-up welding process to design geometry.

9.18.2.4. PI18.5-3– Cost reduction by at least 10%

Short description

The development of a functional, non-mobile welding platform for an automated fixed crossing repair will allow to perform the scanning, repair welding and monitoring of the intermediate layer temperatures fully autonomously by the robot and will end up in time saving and therefore cost saving.

How to compute PI18.5-3

Comparison of the costs of current manual repair build-up welding process to the costs of the automated repair welding process as follows:

$$PI_{18.5-3}\ Costs = \frac{C_{automated}}{C_{manual}} \leq 0{,}9$$

Where:

- $C_{automated}$: Total costs of automated repair build-up welding process.
- C_{manual}: Total costs of manual repair build-up welding process.

9.19. UC19.1: Upper-body exoskeleton for worker's support in railway industry

This use case will focus on developing a novel exoskeleton that will be able to support the operator upper body during the execution of the most physically demanding maintenance tasks of the railway infrastructure. Exoskeletons can support the operator in the execution of manual tasks in the railway industry with significant improvement of working conditions, and safety, cost reduction, improved quality and higher accuracy of service.

This use case spans Task 19.4 “Technology Validation and Demonstration” and subtask 19.4.2 “Validation of Exoskeleton systems”.

9.19.1. Overall aim of the use case

9.19.1.1. Problem to be solved

Rail system maintenance activities often involve the use or handling of heavy objects or repeated activities that can lead to excessive operator fatigue.
Musculoskeletal disorders in the work environment (WMSD) are the leading cause of sick leave in work accidents and occupational diseases. Overexertion, the leading cause of WMSD, is directly linked to the physical workload. More specifically, in railway maintenance operations, WMSD is related to the following activities:

- Building railway overhead lines & constructions creates heavy physical load on human body (shoulders & elbows in particular).
- At great heights in rail platforms "above your head" and "in front of your body".
- Most important maintenance tasks for the lower and upper part of the railway infrastructure such as cutting and grinding of rail tracks, ballast tamping, bolt screwing/unscrewing and catenary maintenance.

It is a serious problem that generates a high social, health, business and economic cost in general:

a) Personal and family: the affected worker loses personal autonomy for their activities of daily living, must undergo various clinical processes and, in certain cases, also affects their future employability.

b) Socio-sanitary: The rehabilitation of musculoskeletal disorders represents a significant burden for health systems, and a significant cost for public health systems and labour mutual companies.

c) Business: companies bear an economic cost that is generally higher than what is reflected, due to the large number of hidden costs that are unknown, also called indirect or uninsured costs (first aid, lost time, interference in production, conflicts labour, loss of image and market, sanctions, legal proceedings, etc.).

Possible solutions can be found around specific machines & special tools to reduce physical load.

9.19.1.2. Industry current position/baseline

IMs have already tested several exoskeletons available on the market. However, none of the existing solutions satisfies the requirements of the railway maintenance sector, as they are conceived for other “cleaner” industrial environments such as manufacturing or logistic repetitive operations. More specifically, the disadvantages found in current systems can be summarized as follows:

- When working at height, on railway-platform, fall harness and leash are required.
- Practical tests have shown that it is hard to wear exoskeleton together with fall protection (fall harness and leash).

- The total weight of both personal and protective equipment cannot become so heavy as to create physical problems.
- Great “hook danger” on top of shoulder of exoskeleton. It is dangerous because the activities may imply walking on moving trains and under catenary-components.
- Too much resistance/friction when accomplishing downward movement with current exoskeleton. This takes extra energy in some cases (e.g., when picking up tools or components on floor of basket).
- No investigation has been done about what would happen if someone fell (wearing a leash) with fall harness and exoskeleton.
- Building in into materials that do not conduct electricity.

9.19.1.3. Subproblem addressed by the use case and measurables

Technology will be developed to improve human safety and skills in workplace by using Exoskeleton systems. A novel exoskeleton with a passive structure, designed to be mean and lean, and compatible with other protective tools will be developed. Besides, the exoskeleton will have the option to be scaled with active modules (compact devices with integrated actuators, energy source and electronics) that will easily snap in the passive structure to assist workers in managing heavy loads. The passive and active parts of the exoskeleton will result in the first hybrid exoskeleton in the market. To that end, new kinematics for improved mobility, new transmission reduction systems (more compact and lightweight), and novel snap-in solutions (to connect the active actuators and electronics with the passive system) will be researched among many other technological solutions. These innovations will allow developing a new type of hybrid exoskeletons, closer to the real assistance needed in industrial applications.

More specifically, the targeted objectives are listed below:

- To develop an exoskeleton to work with arm positioning at shoulder-height, e.g. when specialized operators weld some elements on the ceilings of the rolling stock, the fatigue resistance of the operator is extremely solicited.
- To develop an exoskeleton for handling heavy materials (> 2 kg). Very often operators have to transport for a few meters, heavy material to be assembled on the rolling stocks.
- To develop an ergonomic exoskeleton, compatible with other protective outfit common in railway maintenance.
- To develop a passive exoskeleton for upper limbs to be adapted to maintenance operations. It will include novel and unique capabilities to extend the exoskeleton with active modules/actuators, delivering the first hybrid exoskeleton for industrial applications in the market.

There is still uncertainty as whether the exoskeleton may reach TRL8/9 with regard to certain items such as the analysis of the impact of the exoskeleton in case the worker may fall and the materials used and the impact of active systems (batteries, actuators) on the working environment.

9.19.1.4. Influence of the proposed innovation on the IM/RU problem

WMSDs are a real problem that seriously affects railway maintenance workers. The development and use of the technology considered in this use case would allow reducing their incidence and improving safety.

9.19.2. UC19.1: Demonstrator's KPI

9.19.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
XIV	Cost reductions of the interventions (by at least 10%)	Little/indirect
XV	Societal impact: Support to rail workers - Exoskeletons are used to perform strenuous tasks, such as safely moving heavy loads...	High/direct

Table 145: UC19.1 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
19.1-1	Societal Impact	10%

Table 146: UC19.1 PIs

9.19.2.2. PI19.1-1 – Societal impact. improvement of user satisfaction by at least 10%

Short description

The use of exoskeleton technology will reduce the physical effort carried out by the workers in over-shoulder operations compared to the current manual operations. The use of an exoskeleton will improve ergonomics and overall workers' safety, thus reducing the incidence of Work-related Musculoskeletal Disorders (WMSD) on IM's employees, contracted consultants and contractors while at work at IM's premises and trackside. Both parameters, improved task performance due to fatigue reduction and reduction of workers' sick leaves and injuries, have a direct influence on the cost of the intervention and a high societal impact (reduction of injuries, reduction of public health system costs, personal autonomy for daily living, etc.).

How to compute PI19.1-1

We will carry out real maintenance task with and without the exoskeleton. A minimum of 2 workers in 4 different working scenarios will participate in the validation phase (8 workers in total). A subjective evaluation by the workers that will test and validate the exoskeleton will be carried out in order to evaluate their satisfaction when using the exoskeleton, mainly regarding physical effort reduction, safety, ergonomics and usability. Questionnaires will be developed, and Liker-type scales will be used for quantitative measures. Only one scenario will be considered for initial demonstration, while all scenarios will be deployed by the end of the project. PIs will also be measured in these two phases.

$$PI_{19.1-1} = \frac{Value_{new-method} - Value_{traditional-method}}{Value_{traditional-method}} \times 100$$

Where:

- $Value_{traditional-method}$ represents the answer of the operator to the questionnaire (rate scale) without the exoskeleton.
- $Value_{new-method}$ represents the answer of the operator to the questionnaire (rate scale) with the exoskeleton.

If PI19.1-1 is positive: Indicates that the new method is more satisfactory for the operator than the traditional method. Therefore, we can deduce that workers are willing to use the exoskeletons and thus we will get the targeted societal impacts, and indirectly the associated cost reductions.

If PI19.1-1 is negative: Indicates that the traditional method is more satisfactory for the operator than the new method, and the expected positive impacts are not perceived.

9.20. UC19.2: Augmented Reality tools to help and guide railway workers in maintenance operations

This Use Case will focus on developing Augmented Reality technology to provide railway maintenance workers with assistance during the assembly / maintenance procedures, with the aim of reducing time and cost of these operations.

This use case spans Task 19.4 “Use cases related tasks” and subtask 19.4.2 “Validation of AR tools”.

9.20.1. Overall aim of the use case

9.20.1.1. Problem to be solved

The railway infrastructure, as a complex system, integrates several assets with different technologies. The infrastructure must follow the continuous and growing technological upgrading without losing its safety and robustness.

To achieve these goals the maintenance has a primary importance, and the operators have to

combine the past experience with the needs of the innovative technologies.
Currently, many technical operations performed by the maintenance team are primarily driven by experience gained in the field, and sometimes there are not procedures in place for easy failure detection.
In this scenario, an augmented reality technology should be developed to support the maintenance teams in the following areas:

- To provide, when requested by the operator, electrical and mechanical schematics.
- To guide troubleshooting by indicating a list of checks.
- To provide a list of checks required before declaring the fault resolved and the asset re-commissioned.
- To provide remote assistance in real-time by an expert.

9.20.1.2. Industry current position/baseline

As already mentioned in the previous paragraph (9.20.1.1), today the maintenance teams are primarily driven by experience.
Operators have paper and electronic manuals to support their activities, deemed to be less efficient and effective than the technology to be developed as part of this use case.
This technology should offer advantages in terms of clarity of information and time of intervention without reducing the effectiveness and ultimate safety of the intervention.

9.20.1.3. Subproblem addressed by the use case and measurables

The use case addresses the need of technology to assist workers on complex and remote maintenance operations to reduce processes cost and time and improve safety. More specifically, the following objectives are targeted:

- **Process acceleration**: Augmented Reality can support in making processes in the field more uniform and then more efficient. By projecting clear instructions for employees, processes can be accelerated.
- **Error Reduction:** By projecting clear instructions for employees, errors are reduced during processes. In addition, an expert can be called in via the Remote Assistant function if an employee cannot figure it out himself.
- **Improve Security:** Due to the aforementioned instructions, and dial-in from experts, the chance of accidents is significantly reduced. In addition to these functions, warnings and real live data can also be projected. For example, the pressure in a pipe or the voltage on a cable can be shown in real time (not measured by the glasses themselves).
- **Train employees:** Through this technology, new employees can be trained faster, safer, more enthusiastically, more flexible and cheaper. For example, employees are more likely to get excited about interactive and structured training.
- **Attract new employees:** As mentioned earlier, the experience of using this technology has an enthusing effect. With this in mind, it can serve as a powerful tool to attract new

personnel for the rail industry. This can be done through demonstrations at trade fairs and workshops at schools.

There is still uncertainty as whether augmented reality tools may reach TRL8/9 with regard to certain items such dependence of good internet connectivity, battery life, compatibility with common glasses, etc…

9.20.1.4. Influence of the proposed innovation on the IM/RU problem

Remote maintenance operations, unskilled workforce and the difficulty to attract young people to work on maintenance operations are serious problems that IMs are currently suffering. The incorporation of technology, such as Augmented Reality, can be of great assistance tacking these issues. On one hand, it makes training of new unskilled workforce more attractive, reduces the cost of expert and senior workers assistance and attracts a new generation of young people to the sector. On the other hand, safety can also be improved by reducing the workforce errors by the use of the proposed technology.

9.20.2. UC19.2: Demonstrator's KPI

9.20.2.1. List of KPIs and related justification for the choice

The objectives that this use case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #7: Robotics & Interventions and the related KPIs. Specifically, the FP3-IAM4RAIL Grant Agreement connects the DO7 with the following Key Performance Indicators:

KPI (GA)	Description	Impact
XII	Increased accuracy of inspections with respect to conventional interventions (25%)	Little/indirect
XIV	Cost reductions of the interventions (by at least 10%)	High/direct

Table 147: UC19.2 KPIs on a FP level from the Grant Agreement

To contribute to those high-level KPIs, the following PI is proposed for this use case:

PI	Description	Target
19.2-1	Cost reduction of the interventions	10%

Table 148: UC19.2 PIs

9.20.2.2. PI19.2-1 – Cost reduction of the interventions by at least 10%

Short description

The use of the proposed Augmented Reality technology will reduce the time to complete a complex maintenance task. Thus, the cost of the maintenance operation is also reduced. The use of the proposed Augmented Reality technology will also reduce the number of errors in these operations as the system can make a quality check of the process. Ideally, the errors should approach to cero. This, in turn, also derives in a cost reduction and improved safety of the operation. The combination of these parameters will achieve the target PI19.2-1 goal.

How to compute PI19.2-1

We will carry out real maintenance operations with and without the proposed Augmented Reality technology. A minimum of 2 workers in 3 different working scenarios will participate in the validation phase (6 workers in total). Only one scenario will be considered for initial demonstration, while all scenarios will be deployed by the end of the project. PIs will also be measured in these two phases. We will measure the time needed to accomplish the tasks and the number of assistance requests (mainly in the case without the technology) to an expert worker. We will compare both time and cost (taking into account also the hour/cost of the expert worker) to carry out the operations with and without the proposed Augmented Reality system.

For computing P9.2-1A, it's possible to estimate time (hour/ man referred to the activity) to perform the activity and post-processing data and compare it with traditional methods to establish the time saving ratio that could be achieved with the application of this technological system. Errors will be taken into account by the additional time and cost required to amend the task.

To evaluate this PI we can use the following formula.

$$PI_{19.2-1A}\ (\%\ time\ savings) = \frac{Time_{traditional_method} - Time_{new_method}}{Time_{traditional_method}} \times 100$$

Where:

- $Time_{traditional_method}$ is the time required to perform an inspection by the traditional method.
- $Time_{new_method}$ is the time required to perform an inspection by the new method.

If PI9.2-1A is positive: Indicates that the time for the new method is less than the time required for the traditional method. In this case, a positive value indicates a time saving or a reduction in the time required to complete the task, however, if PI9.2-1A is negative: Indicates that the time for the new method is greater than the time required for the traditional method. In this case, a negative value indicates that the new method would require more time compared to the traditional method.

The cost of personnel (h/m. referred to activity on singular bridge span) is indicated below:

$$PI_{19.2-1B}\ (\%\ cost\ savings)\ = \frac{Cost\ _{traditional_method} - Cost_{new_method}}{Cost_{traditional_method}} \times 100$$

Where:

- $Cost\ _{traditional_method}$ is the cost required to perform an inspection by the traditional method.
- $Cost_{new_method}$ is the cost required to perform an inspection by the new method.

If PI9.2-2B is positive: Indicates that the estimated cost for the new method is less than the cost required for the traditional method. In this case, a positive value indicates a time saving or a reduction in the cost required to complete the task, however, if PI9.2-1B is negative: Indicates that the estimated cost for the new method is greater than the cost required for the traditional method. In this case, a negative value indicates that the new method would require more cost compared to the traditional method.

10. Conclusions

The goal of this document is to provide a detailed description of the different Use Cases (UCs) defined by each WP of FP3-IAM4RAIL.

The objective is twofold:

Internally (within the FP3-IAM4RAIL consortium) it will serve as the cornerstone for the implementation of the different technical objectives. Each UC will define and monitor a series of relevant technical problems, providing the context and necessary developments needed to solve them, also in terms of different KPIs that will be validated at the end of the project.

Externally (with respect to the other FPs and other relevant parties) the document can be used to present the different technical objectives targeted by FP3-IAM4RAIL WPs, the current position and the foreseen impact on the railway industry. The definition of UCs and their context in the railway industry will be also useful to allow the definition of links with different ER – FPs that will be investigated during the course of the project and will serve as a base for the definition of future research activities within the Europe's Rail Programme.

The UCs are grouped by Cluster (there are 5 different technical Clusters from B to F). There is one chapter devoted to each Cluster UCs starting in Chapter 5 and ending in Chapter 9.

Each Chapter begins with a table listing the different Use Cases, to allow an easy search to the readers, then a series of sub-chapters follow with the definition of each Use Case. All Use Cases follow the same structure, a description of the problems addressed, the current baseline and the foreseen impact; then a list of KPIs is presented, targeting the technical problems described.

The project has also produced a catalogue that summarises the UCs. The catalogue presents in a more structured and concise way, the information related to the problems addressed, the milestones for the implementation and the target TRL.

The catalogue is attached to this deliverable as **Appendix A**

11. Appendices

APPENDIX A

Work package:	WP3 Task:	Sub-task:	UC detail	
WP3-4	3.1 3.2 4.1 4.2	All linked to the tasks on the left	UC ID:	3.1
			Int. Demo	
			Leading Partner	HITACHI RAIL-STS

UC Name:	**Wayside and Infrastructure IAMS for TMS optimisation**
Type:	Monitoring – IAMS – TMS
Problem Statement:	The management of a Railway line generally relies on several different wayside on-board and infrastructural systems, each dedicated to a specific functionality and integrated in different ways with one another, depending on the country and the type of line in question. These systems share vital operational data and information among themselves but rarely provide a dedicated channel for diagnostic purposes, especially legacy ones. However, even if a dedicated channel for diagnostic purposes is implemented, depending on the generation of the system, the level of granularity of the information can vary significantly. Most of these systems interact with signalling systems but are agnostic of each other and therefore do not provide direct correlation capabilities. This means that, in the event of a failure or disruption, the Infrastructure Manager must combine and analyse information directly from the systems involved, dispatching maintenance operator to the different locations and analysing the logs produced and correlating different data sources together in order to identify the cause of the problem.

Image / Diagram

Description:	In FP3-IAM4RAIL, a demo in Italy will be developed to address the problem.
How Does Solution Address Problem Statement:	The objective of the "Wayside and Infrastructure monitoring system for TMS optimisation" is to provide a remote and centralised interface with the existing railway systems (Signalling, TMS, Wayside Monitoring Systems, etc), automatically collecting reports, functional parameters, logs, alarms and other diagnostic data. Specifically, UC3.1 will develop a remote and non-intrusive data collection system to collect operational and diagnostic data from the IXL system, as well as dedicated interfaces with the TMS and ERP systems to acquire traffic and maintenance records. The collected data is then processed, cleaned and stored in a database to provide easy access to the maintainer, enable correlation of different sources and serve as a starting point for the development of data analytics procedures. The information that are derived from the collected data, that will range from statistics about some key operative indicators, prediction on assets status and of possible anomalies, will be exploited mainly to improve the maintenance activities to be performed and to optimise the scheduling of traffic. This will create therefor a link both with the Decision Support System and with the Traffic Management System.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CDM	FP1/TT	Conceptual Data Model specification and data sample coming from the current use case
TMS	FP1 & FP3-WP2	Definition (in collaboration with WP2 and FP1) of requirements for data exchange protocols and format to implement the TMS-IAMS channel
Track data	WP12-13	Track data from diagnostic train -> Task13.1.2
Hazardous areas	WP12-13	List of critical areas as identified from satellites, drones and ground data fusion -> Task13.1.3, Task13.1.4

Demonstration Method:	Location:	Facilities:	Date:
Preliminary analytics design, completed with general architecture and validation process.	Italy – Quadrivio Turro, Torino-Padova National Line	Regional	M18
Implementation of automatic data collection from the different wayside and infrastructure systems involved, with subsequent storage of data collected in the IAMS platform.	Italy – Quadrivio Turro, Torino-Padova National Line	Regional	M24
Evaluation of first results coming from the analytics on assets' status prediction and collection of feedback for improvement.	Italy – Quadrivio Turro, Torino-Padova National Line	Regional	M30
Implementation of a complete IMAS platform with user interface and implementation of defined functionalities. Validation of the results will be carried out by collecting the feedback and report from active users coming from the industry.	Italy – Quadrivio Turro, Torino-Padova National Line	Regional	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		
Anticipated FP3-IAM4RAIL TRL for Fixed Radar					X			

Work package:	WP3 Task:	Sub-task:	UC detail	
WP3-4	3.1 3.2 4.1 4.2	All linked to the tasks on the left	UC ID:	3.2
			Int. Demo	
			Leading Partner	HITACHI RAIL-STS

UC Name:	**Wayside monitoring in conventional and high-speed lines for TMS optimisation**
Type:	Monitoring – IAMS – TMS
Problem Statement:	Currently, in the general interest railway network in Spain, there are more than 15,000 switches and crossings, as well as thousands of level crossings with barriers. These assets are sensitive components in the railway infrastructure given their importance in traffic safety. More than 50% of the total investments in the railway infrastructure is destined for the maintenance of assets. These assets, highly linked to signalling, are located and controlled from ADIF command centres, where they determine the itineraries that the train must follow. Currently, these assets (switches and crossings and level crossings) send an alarm to the control centres signalling a "check" or "no check", which indicates whether it works correctly or, on the contrary, a defect has been found in its operation. If it does not work, the command centre gives the order for the trains to stop running. However, no other information is given to indicate what the exact problem is, nor is information collected on the status of the asset. The current maintenance of the switches and crossings devices is carried out by means of visual inspections and geometry, as well as ultrasound to detect internal defects, on a periodic basis. At level crossings, mobile elements and their correct operation and set-up are verified.

Image / Diagram

Description:	In FP3-IAM4RAIL, a demo in Spain will be developed to address the problem.
How Does Solution Address Problem Statement:	The objective of the "Wayside monitoring in conventional and high-speed lines for TMS optimisation" system is to develop monitoring solutions and sensors to enable the remote monitoring of point machines and level crossing barriers along the line and to collect diagnostic information needed for the development of anomaly detection models. The different monitoring solutions are then interfaced with a common IAMS application for the centralisation of alarms and HMIs that can support the operator in the management of the line. The information that are derived from the collected data, that will range from statistics about some key operative indicators, prediction on assets status and of possible anomalies, will be exploited mainly to improve the maintenance activities to be performed and to optimise the scheduling of traffic. This will create therefor a link both with the Decision Support System and with the Traffic Management System.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CDM	FP1/TT	Conceptual Data Model specification and data sample coming from the current use case
TMS	FP1 & FP3-WP2	Definition (in collaboration with WP2 and FP1) of requirements for data exchange protocols and format to implement the TMS-IAMS channel

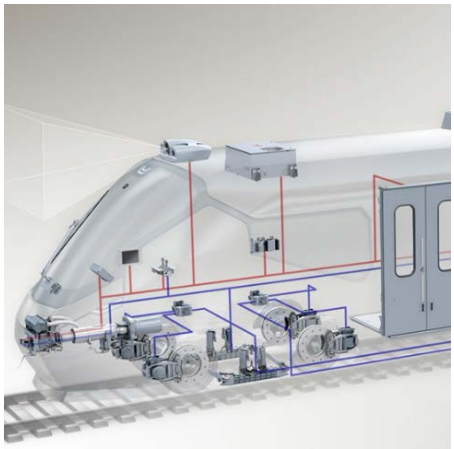
Demonstration Method:	Location:	Facilities:	Date:
Preliminary analytics design, completed with general architecture and validation process.	Madrid-Seville line Madrid-Valencia Line Asturias region	Regional and High-speed	M18
Implementation of automatic data collection from the different wayside and infrastructure systems involved, with subsequent storage of data collected in the IAMS platform.	Madrid-Seville line Madrid-Valencia Line Asturias region	Regional and High-speed	M24
Evaluation of first results coming from the analytics on assets' status prediction and collection of feedback for improvement	Madrid-Seville line Madrid-Valencia Line Asturias region	Regional and High-speed	M30
Implementation of a complete IAMS platform with user interface and implementation of defined functionalities. Validation of the results will be carried out by collecting the feedback and report from active users coming from the industry	Madrid-Seville line Madrid-Valencia Line Asturias region	Regional and High-speed	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.1 6.2 6.3	6.3.1	UC ID:	5.1
			Int. Demo	
			Leading Partner	ALSTOM TRANSPORT SA (ATSA)

UC Name:	**Bogie Monitoring System (on-board)**
Type:	Monitoring & Analytics
Problem Statement:	A current practise in the railway industry is to perform the maintenance of the bogie components based on fixed intervals that can be time and/or mileage dependent. This approach, called preventive maintenance, is not economically optimised because the components are exchanged/replaced before the end of their lifetime. As an additional risk, the component failure may happen between two pre-defined maintenance slots. The goal is to deliver information about the health status of the bogie components in order to enable condition-based maintenance (CBM) to reduce maintenance cost and to achieve high availability. Based on existing experiences, the idea of this use case is to develop a new generation of bogie monitoring systems with the associated assessment routines. The targets can be described as follows: - Extension of the monitoring range by applying also other types of sensors other than accelerometers (e.g., on-board acoustics) - Identify potentials for combining different sensor signals (sensor fusion) - Realisation of more economical monitoring technologies

Image / Diagram



Description:	Therefore, the UC aims to measure, acquire, collect, pre-process, transmit and store data in networks and ecosystems from onboard digital and analogue variables together with the system alarms and other non-vehicle-based data sources. The tasks can be described as follows: - Identify monitoring strategies by simulation that define physical parameters suitable to detect wear/defects on the main bogie components. - Identify the most promising monitoring technologies during roller rig tests focussing mainly on the drive system (motor and gearbox) by equipping a bogie with pre-defined damages/failures or worn components. - Test the most feasible monitoring technologies identified during the roller tig tests under real service conditions in the field.
How Does Solution Address Problem Statement:	The application of condition monitoring to railway vehicles provides a possibility to get information on the health condition of different train components under real operating conditions. Such information can facilitate the implementation of CBM for railway vehicles. Compared to preventive maintenance (PM), it is believed that CBM will bring not only higher reliability but also more cost-efficient maintenance to the rail sector. Using the available time series data, it is possible to predict the future health condition of components by applying advanced analytics, e.g., regression analysis. In such a way, maintenance activities can be planned based on a more precise estimation. This type of maintenance is called predictive maintenance (PdM) which can be considered as an extension of CBM.

System Integration:

"Label":	Interfacing sub-task:	Interface:
Data	FP3: Task 9.4.3	Re-Use of WP6 on track Demo in The Netherlands to also generate data for Track Monitoring -> 6.2
Current sensor	FP3: Task 6.4.3	Monitor the motor current to check if a defect on bearing change (increase) the motor current -> 5.1, 6.2 & 6.3
CBM	FP3: Sub-Task 7.4.2	Validation of on-board technologies with comparison with wayside based technologies. Results of roller rig test used for development of algorithms -> Task 5.1
Bogie Wayside Monitoring (BWM)	FP3: Sub-Task 7.3.2	Validation test of railway checkpoint in The Netherlands climate type sections with Demo (defects applied) of WP6 -> Task 6.2

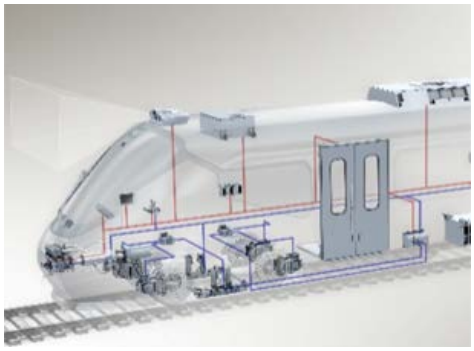
Demonstration Method:	Location:	Facilities:	Date:
Bench Test for bearing monitoring	Ornans, France	2 MW test bench	Until M24
Bench Test for oil sensor	To be decided if internally or externally	Test bench	Until M24
Test on track	The Netherlands	Lines TBD	Until M42

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.3 6.2 6.3	6.3.2	UC ID:	5.2
			Int. Demo	Demonstrator#2
			Leading Partner	KNORR-BREMSE SYSTEME FÜR SCHIENENFAHRZEUGE GMBH (KB)

UC Name:	**Health Monitoring & Analytics of HVAC & Brake systems (ES)**
Type:	Monitoring & Analytics
Problem Statement:	Railway operators in Europe face constant pressure to control operating costs while maintaining high levels of reliability and efficiency. Maintenance costs and increasing expectations present many challenges. The primary goal for any railway operator is to maintain their fleets well, requiring regular inspections and repairs. To address these challenges, railway operators must shift from the old maintenance paradigm, based solely on preventive and corrective maintenance strategies, to a new one that integrates new strategies such as condition-based maintenance. To pave the way for this shift, a set of maintenance algorithms should be developed to enable the transition to the new paradigm.

Image / Diagram



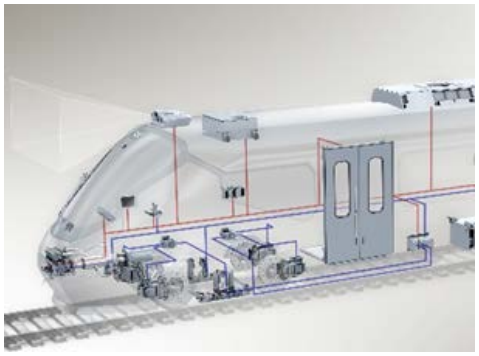
Description:	For the vehicles in subsystems in scope the goal is to implement the entire value chain (see below) in order to implement data retrieval and analysis for various systems.
How Does Solution Address Problem Statement:	The use case shall serve the RU specifically in the reduction of maintenance costs but also in the reduction of in-service failures. Scope includes a specific on-board system with different drivers for optimisation. Examples are: ▪ HVAC: filter lifetime, compressor lifetime, refrigerant level and status ▪ Brakes (Air Supply): compressor lifetime and status. The entire value chain of: Data Generation & Processing on the vehicle, Transfer Data off-board to a cloud, Analyse data and derive actionable information, Feed the results in a workflow to generate a measurable outcome will be the technical solution. This will provide the operator and maintainer with valuable information about the systems monitored, which in turn allows for more precise and efficient maintenance activities.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Sensor Data	WP6 Task 6.2	Input for demonstrator activities
FDS	FP1 W31	Possible use case for federated data spaces

Demonstration Method:	Location:	Facilities:	Date:
Data monitoring, using on-board data acquisition, data transfer and data processing in the cloud	Spain	Renfe/Talgo Fleet S106	Until M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:					X	X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.4 6.2 6.3	6.3.3	UC ID:	5.3
			Int. Demo	
			Leading Partner	KNORR-BREMSE SYSTEME FÜR SCHIENENFAHRZEUGE GMBH (KB)

UC Name:	**Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)**	Image / Diagram
Type:	Monitoring & Analytics	
Problem Statement:	Railway operators in Europe face constant pressure to control operating costs while maintaining high levels of reliability and efficiency. Maintenance costs and increasing expectations present many challenges. The primary goal for any railway operator is to maintain their fleets well, requiring regular inspections and repairs. To address these challenges, railway operators must shift from the old maintenance paradigm based solely on preventive and corrective maintenance strategies to a new one that integrates new strategies such as condition-based maintenance. To pave the way for this shift, a set of maintenance algorithms should be developed to enable the transition to the new paradigm.	

Description:	For the vehicles and subsystems in scope, the goal is to implement the entire value chain (see below) in order to implement data retrieval and analysis for various systems.
How Does Solution Address Problem Statement:	The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures*. Scope includes a specific on-board system with different drivers for optimisation. Examples are: ▪ HVAC: filter lifetime, compressor lifetime, refrigerant level and status ▪ Sanitary Systems: freshwater level, wastewater level, wear and tear of vacuum sanitary system ▪ Magnetic track brake: monitoring of brake shoe welding The entire value chain of: Data Generation & Processing on the vehicle, Transfer Data off-board to a cloud, Analyse data and derive actionable information, Feed the results in a workflow to generate measurable outcome will be the technical solution. This will provide the operator and maintainer with valuable information about the systems monitored, which in turn allows for more precise and efficient maintenance activities.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Sensor Data	WP6 Task 6.2	Input for demonstrator activities
FDS	FP1 WP31	Possible use case for federated data spaces

Demonstration Method:	Location:	Facilities:	Date:
Data monitoring, using on-board data acquisition, data transfer and data processing in the cloud	The Netherlands	NS / CAF SNG Fleet	Until M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:					X	X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.3 6.3	6.3.2	UC ID:	5.4
			Int. Demo	
			Leading Partner	FAIVELEY TRANSPORT SAS (FT)

		Image / Diagram
UC Name:	**Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes, Traction & Auxiliary systems (ES)**	
Type:	Monitoring	
Problem Statement:	Railway operators in Europe face constant pressure to control operating costs while maintaining high levels of reliability and efficiency. Maintenance costs and increasing expectations present many challenges. The primary goal for any railway operator is to maintain their fleets well, requiring regular inspections and repairs. To address these challenges, railway operators must shift from the old maintenance paradigm based solely on preventive and corrective maintenance strategies to a new one that integrates new strategies such as condition-based maintenance. To pave the way for this shift, a set of maintenance algorithms should be developed to enable the transition to the new paradigm.	

Description:	These tasks aim to retrieve data from the HVAC, Doors and Brake systems of CAF database from a Spanish fleet, in order to enable further analysis and algorithm development.
How Does Solution Address Problem Statement:	Based on the data gathered from these systems and the maintenance workshops, algorithms for condition-based maintenance will be developed. This will pave the way to shift in the maintenance paradigm applied to this fleets.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Telemetry and maintenance workshop data	WP6	Input for algorithm development activities in subtask 6.3.2

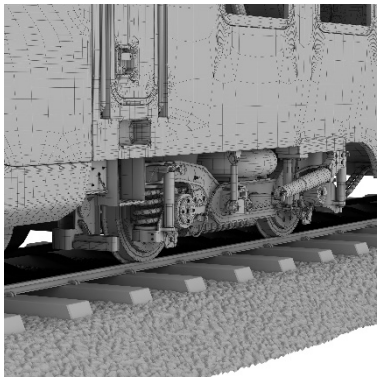
Demonstration Method:	Location:	Facilities:	Date:
Implementation of automatic data collection from HVAC, doors and Brake systems from CAF database fleets	Spain	CAF database fleet	Until M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:	X							
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.4 6.3	6.3.3	UC ID:	5.5
			Int. Demo	
			Leading Partner	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)

UC Name:	**Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)**
Type:	Monitoring & Analytics
Problem Statement:	Railway operators in Europe face constant pressure to control operating costs while maintaining high levels of reliability and efficiency. Maintenance costs and increasing expectations present many challenges. The primary goal for any railway operator is to maintain their fleets well, requiring regular inspections and repairs. To address these challenges, railway operators must shift from the old maintenance paradigm based solely on preventive and corrective maintenance strategies to a new one that integrates new strategies such as condition-based maintenance. To pave the way for this shift, a set of maintenance algorithms should be developed to enable the transition to the new paradigm.

Image / Diagram



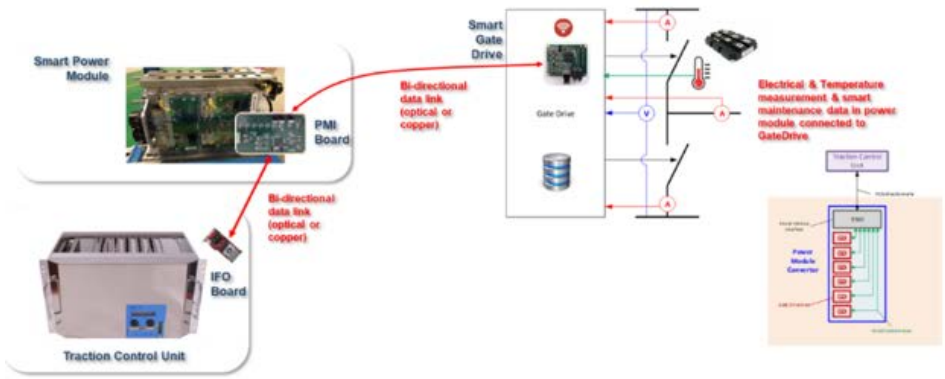
Description:	For the vehicles in subsystems in scope, the goal is to implement the entire value chain (see below) in order to implement data retrieval and analysis for various systems.
How Does Solution Address Problem Statement:	The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures*. Scope includes a specific on-board system with different drivers for optimisation. Examples are: ▪ HVAC: filter lifetime, compressor lifetime, refrigerant level and status ▪ Brakes: wear of friction material, compressor lifetime and status ▪ Doors: health status of the doors ▪ Traction & auxiliary system: create health indicators to detect anomalies in the early stage in these systems. ▪ Batteries: health status of battery The entire value chain of: Data Generation & Processing on the vehicle, Transfer Data off-board to a cloud, Analyse data and derive actionable information, Feed the results in a workflow to generate measurable outcome will be the technical solution. This will provide the operator and maintainer with valuable information about the systems monitored, which in turn allows for more precise and efficient maintenance activities.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Sensor Data	WP6 Task 6.2	Input for demonstrator activities

Demonstration Method:	Location:	Facilities:	Date:
Data monitoring, using on-board data acquisition, data transfer and data processing in the cloud	The Netherlands	NS / CAF SNG Fleet	Until M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.4	6.4.3	UC ID:	6.1
			Int. Demo	
			Leading Partner	ALSTOM TRANSPORT SA (ATSA)

UC Name:	**Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link**
Type:	Hardware
Problem Statement:	The current situation is that if we need, for example, to compare a semiconductor junction temperature measurement with a theoretical embedded model for health monitoring, it's not possible to physically connect each semiconductor temperature sensor to the traction control unit (TCU). Indeed, a TCU can drive more than 30 semiconductors. Needing to connect each of them with insulation protection, would lead to an excessive wiring system inside the traction cubicle. Moreover, this kind of solution would highly increase the unit price of a traction case (more than 10%) because it leads to multiplied numbers of TCU to install inside the traction cubicle to be able to read all measurements. Tomorrow's powertrains must make use of predictive maintenance data to reduce possession costs by optimising the number of maintenance operations on customer side and minimise equipment redundancies during design on the manufacturer side, which could lead to reduce acquisition cost for the customer. As for the traction side, the most significant maintenance operations are focused on power converter semiconductors, traction components circuit breaker, contactors, cooling systems and bearings. Our target is to be able to calculate on board and health indicator of cooling system (clogging level of cooling system heat exchangers) and bearings using traction case sensors and send this information to the customer for its train maintenance plan. All these functions need additional data which each requires its own wiring. This entails a very expensive product to allow this high level of data acquisition. To allow data driven operation for smart maintenance purpose with cheaper costs, we need to rebuild the traction control hardware architecture in a better way.
Image / Diagram	

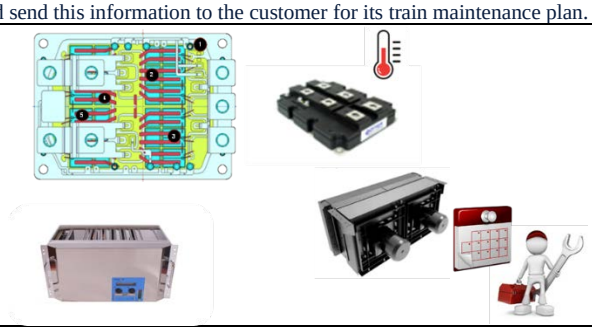
Description:	The use case target is to evaluate the capability of the proposal. Whether our new architecture is able to drive semiconductors for traction purpose at the same time they are being monitored for traction component health management, is subject to the investigation. For semiconductors, the state of the art of predictive maintenance requires the use of a measurement and/or an estimation of the semiconductor's internal temperature (e g., junction temperature). This information will be provided by the semiconductor manufacturers in the next years. The first call consists of using an estimator for semiconductor junction temperature throughout an embedded algorithm using available traction signal. This work would be the basis for the next step planned in the 2nd CALL.
How Does Solution Address Problem Statement:	Thanks to this innovation proposed within the FP3-IAM4Rail project, the rolling stock owner would be able to reduce its maintenance costs by only execute maintenance operations when necessary (instead of doing it arbitrarily at a fixed moment). Besides it will also allow the RU to anticipate failures in operation: the direct consequence is a more reliable service seen from the end-customer. This will help the RU to build its train fleet maintenance plan according to the traction purposes.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
HWTMEAS	FP4 WP6 (task 6.2)	Hardware for testing real-time semiconductor health monitoring

Demonstration Method:	Location:	Facilities:	Date:
Bench Test	ALSTOM Semeac (FR)	Power test bench with inverter & traction motor	M26
Test on track	The Netherlands	Lines TBD	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.2 6.2 6.3	6.3.1 6.3.5	UC ID:	6.2
			Int. Demo	
			Leading Partner	ALSTOM TRANSPORT SA (ATSA)

UC Name:	**Traction component health monitoring & predictive Maintenance**
Type:	Monitoring & Analytics
Problem Statement:	The current situation is that the rolling stock owner must follow train manufacturer recommendations in terms of maintenance path. As an example, for the traction case cooling system, the train manufacturer could advise to clean the heat exchanger every 6 months, even if the RU observes that concretely even after 6 month of commercial operation the heat exchanger is clean. This implies that there are much more maintenance operations executed in comparison with what it is really needed. Tomorrow's powertrains must make use of predictive maintenance data to reduce ownership costs by optimising the number of maintenance operations on the customer's side and minimise equipment redundancies during design on the part of the manufacturer, which could lead to reduce acquisition costs for the customer. From the traction side, the most significant maintenance operations are focused on power converter semiconductors, traction components circuit breaker, contactors, cooling systems and bearings. Our target is to be able to calculate on board and health indicator of cooling system (clogging level of cooling system heat exchangers) and bearings using traction case sensors and send this information to the customer for its train maintenance plan.
Image / Diagram	

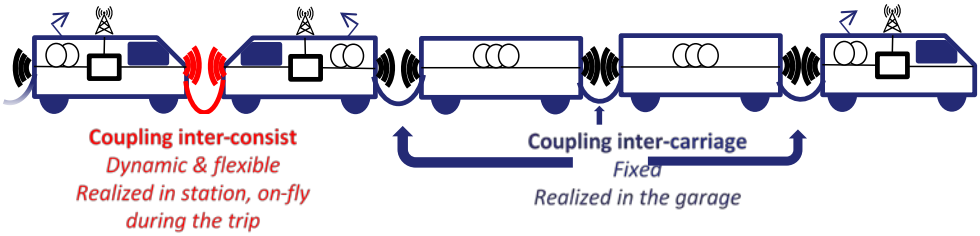
Description:	For semiconductors, the state of the art of predictive maintenance requires the use of a measurement and/or an estimation of the semiconductor's internal temperature (i.e., junction temperature). This information will be provided by semiconductor manufacturers in the next years. The first call consists of using an estimator for semiconductor junction temperature throughout an embedded algorithm using available traction signal. This work would be the basis for the next step planned in the 2nd CALL.
How Does Solution Address Problem Statement:	Thanks to this innovation proposed within the FP3-IAM4Rail project, the rolling stock owner would be able to reduce its maintenance costs by only executing maintenance operations when necessary (instead of doing it arbitrarily at a fixed moment). Besides it will also allow the RU to anticipate failures in operations: the direct consequence is a more reliable service seen from the end-customer. This will help the RU to build its train fleet maintenance plan according to traction purposes.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
PMLSS	From task 5.2 to task 6.2 & subtask 6.3.1 FA4 – task 6.2	Integration of the tested algorithm in the embedded traction software.

Demonstration Method:	Location:	Facilities:	Date:
Bench Tests	ALSTOM Semeac (FR) ALSTOM Ornans (FR)	Power test benches	Started in M4 Planned in M13
Train Tests	The Netherlands	ICNG Train (NS) Test track area	Start in M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.4	6.4.1	UC ID:	6.3
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

UC Name:	**Set up of an adaptative wireless telecom network between train elements**
Type:	Wireless Backbone
Problem Statement:	The TCMS (Train Control and Monitoring System) deployed on board trains is currently very simple and its efficiency can be greatly improved. It is based on networks multifunction (vehicle bus-MVB and Wire Train Bus-WTB). Due to the increase of information volumes and the limitation capacities of the links, it will be replaced by Ethernet based networks (Ethernet consist network-ECN and Ethernet Train Backbone - ETB). However, despite the performance increase and cost reduction, some important weaknesses remain, e.g. maintenance issues at the level between inter coach and inter unit due to the efforts applied on the cables/connectors at these places. To counteract these limitations, wireless connection links are investigated within the framework of this project. Moreover, the "one common bus" concept is under study in different European projects (Shift2Rail, ERJU...), to convey different types of traffic (with different criticality and requirements in terms of bandwidth, latency, etc.). In conclusion, the wireless communication shall therefore take care of the quality of the service required by each of the traffic flows.
Image / Diagram	

Description:	For Wireless Backbone, the project will focus on the technical and scientific objectives related to the design and evaluation of a safe, secure and resilient solution for train-to-train wireless communications (inter train/consist and inter-carriage). The technologies will be studied in a laboratory and with simulations, namely: ITS-G5, UWB (Ultra-Wide Band), LTE (Long Term Evolution) and 5GNR (5Generation New Radio).
How Does Solution Address Problem Statement:	Thanks to this innovation proposed within the FP3-IAM4Rail project, the rolling stock would be able to reduce its operation & maintenance costs by providing a flexible solution and operating some operations "on the fly".

System Integration:		
"Label":	Interfacing sub-task:	Interface:
WLTB	WP6	Set up of adaptative wireless telecom network between train elements -> Task 6.4.1

Demonstration Method:	Locations:	Facilities:	Date:
TRL4 demonstrator, using SDR boards, open and flexible, compatible with railways constraints	France	Railway test center	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:	X							
Anticipated FP3-IAM4RAIL TRL:				X				

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.3	6.3.5	UC ID:	6.4
			Int. Demo	
			Leading Partner	PRORAIL BV (PRORAIL)

UC Name:	Adhesion estimation for management
Type:	Simulation, estimation, measurements
Problem Statement:	Properly estimating the value of the coefficient of friction (COF) it is critically important for traction and braking and the minimisation of wear, deformation and rolling contact fatigue of rail and wheel. The increasing importance of rail transport in a CO2 neutral society demands an increase in railway capacity, requiring faster, heavier and more frequent trains with short distances between trains. In this case, real-time measurement of COF from operational trains is needed to guarantee a safe operation. The railway infrastructure is an open system where the COF at the wheel-rail interface changes with humidity, contamination/lubrication, roughness and stress in the contact area, among other factors.

Image / Diagram

Description:	The use case adhesion estimation for management aims to design methods to estimate/measure the COF in real time under real operation conditions to determine at a certain time window, e.g., safe braking distance and, if necessary, the (strategy for) control of COF by friction modification (using sanding, lubrication, etc.). This will contribute (among other things) to increasing service availability and optimal capacity. In the use case, we focus on the modelling of the traction drive system, using electro-mechanical physical approaches and data-based methods to estimate COF.
How Does Solution Address Problem Statement:	In the FP3-IAM4Rail project, the basis of a new train-borne COF measurement method will be envisaged by incorporating in the motor control an estimator of the adhesion level from the relation between the motor current and its corresponding rotor speed. We also require the estimation of the creepage of the wheel-rail rolling contact. Then, by controlling the traction/braking force through the electricity input to/output from the traction motor and estimating the operational location of the wheel-rail contact in the creepage-creep force curves, the COF could be estimated. The method will be first demonstrated in a simulation environment using parameters available in the literature. Then, an electromechanical system is built by including the complex dynamics involving both the electrical and the mechanical subsystems. In the framework of FP3-IAM4Rail, the target is to develop the method on trains in collaboration with rolling stock manufacturers. This will make it possible, in the future, to deploy the method as part of a holistic asset management system, with an on-line (time-varying) accurate estimation of the COF over the whole railway network. IN2TRACK3 development is TRL4 by the end of the project. The inclusion of rolling stock data has not been considered so far and it is major research in FP3-IAM4Rail to close the gap between experimental work and on-board application. The developments for this use case in FP3-IAM4Rail are simulation-based.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
COF	WP6	To be defined

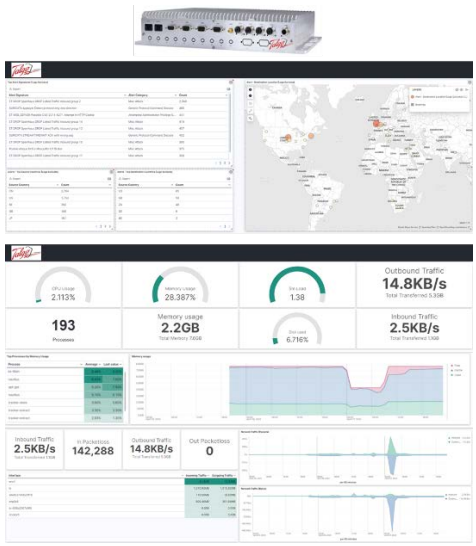
Demonstration Method:	Locations:	Facilities:	Date:
Simulation / Lab tests / Use of real-life train measurement data	TUDelft laboratory and the Dutch railways (NS), The Netherlands	V-Track test rig Measurement campaigns with train data from rolling stock manufacturers	Until M46

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X	X				
Anticipated FP3-IAM4RAIL TRL:				X	X			

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.4	6.4.2	UC ID:	6.5
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	**Wayside Signalling Equipment Monitoring System**
Type:	Monitoring & Analytics
Problem Statement:	Nowadays, technology is a key element in railway transport, and its use has become increasingly common to improve efficiency, safety and passenger experience. However, this increase in IT systems and their interconnection also introduces new cybersecurity risks that have not been considered and managed to date. For example, modern trains are often equipped with entertainment systems, security systems, speed control systems and other electronic components that are connected to a communications network. If one of these components is hacked, it can have a significant impact on the entire railway system, which can cause impacts such as service disruptions, panic among passengers or even accidents. It is also important to consider that railway systems can be attractive targets for targeted cyber-attacks, due to their direct relationship with countries' strategic services and infrastructures, as well as the large amount of sensitive data they can handle. The current problem is centred on a railway industry with limited or absent technical cybersecurity controls and monitoring measures.

Image / Diagram



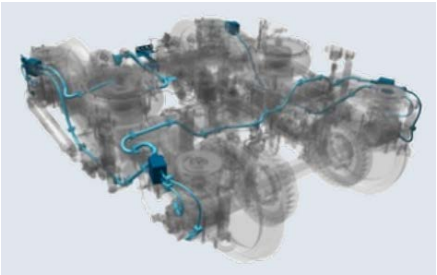
Description:	The use case focuses on defining and creating initial mechanisms to introduce the first elements of monitoring, with the objectives of defining and implementing technical controls and alert mechanisms against cyber-attacks on the train itself, both through internal systems and from train to ground communications.
How Does Solution Address Problem Statement:	Addressing the problem will focus on developing a cybersecurity system to manage the main threats according to the ENISA Threat Landscape (ETL) report in 2022, as well as adapting to compliance with cybersecurity guidelines, regulations and standards, the development of which is gaining importance worldwide. This system would introduce and improve cyber security capabilities in onboard systems and train networks, focusing on reducing the risks derived from threats that affect them.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Cybersecurity	Sub-task 6.4.2	FP3 – WP6 – Task 6.4

Demonstration Method:	Location:	Facilities:	Date:
Implementation of a cybersecurity MVP into a train as a real POC (Proof of Concept), collecting cybersecurity events and alerts. Cyberattacks will be simulated using a test battery previously defined by cybersecurity experts.	Talgo Train (details to be compiled), Spain	Madrid – Spain Talgo factory	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.2		UC ID:	6.6
			Int. Demo	
			Leading Partner	SMO Siemens Mobility

		Image / Diagram
UC Name:	**On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany**	
Type:	Bogie diagnostics	
Problem Statement:	Currently, maintenance is based on fixed intervals. These fixed regimes may not represent the best maintenance strategy regarding the train availability, plannability of maintenance actions and economic issues. An on-board bogie diagnostic solution may be an enabler for a condition-based maintenance process.	

Description:	The SMO on-board bogie diagnostic solution is applied to at least one train operating in Germany. Not only the results of the BD solution shall be assessed but also how these results can support the maintenance process.
How Does Solution Address Problem Statement:	The following work packages shall be addressed: 1. Installation of the BD (bogie diagnostic) solution (HW and SW) on at least one train operating in Germany. 2. Monitoring of the performance of the BD solution. 3. Elaborate requirements on the on-board BD solution together with the train operator and the train maintainer. This direct collaboration and feedback loop shall reveal the concrete needs of the train maintainer and operator resp. regarding the application of an on-board BD solution. 4. Develop new maintenance strategies and processes based on the BD solution embedded in the classical maintenance process. 5. Integration of the results of the BD solution into the digital platforms used during the maintenance process.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CBM	WP7 – subtask 7.4.2	TBD

Demonstration Method:	Location:	Facilities:	Date:
Application of bogie diagnostic solution to train(s) operation in Germany	Germany	On train of fleet Rheintal Los 1 operating in Baden Württemberg	Approx. M22 to M25

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.3	6.3.3	UC ID:	6.7
			Int. Demo	
			Leading Partner	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)

UC Name:	Digital twin for energy
Type:	Monitoring
Problem Statement:	A big part of the operational cost of rolling stock assets is due to the energy consumption. Moreover, there is a big concern regarding Europe energy dependence with other countries and the carbon footprint due to climate change.

Image / Diagram

Description:	In this use case a digital twin to model the energy consumption of a particular train of NS fleets (Atlantic climate type) will be developed. This digital twin will make use of theoretical models, designed data and real data gathered from the operation of the train. In addition to this, the digital twin will be used to find the optimal way to operate the train regarding energy consumption subject to particular operational constraints (time constraints, circulation requirements, etc.). Then, the results will be validated against the real data gathered.
How Does Solution Address Problem Statement:	The output of the model will help operators to identify measures they can be implemented to minimise energy consumption by comparing drivers' performance, units' performance and identifying the optimal speed profile.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Data in the Cloud	WP5->T5.3	Inputs for Rules, and AI models to be developed in task 6.3.3 must be disposed and delivered to Cloud systems through activities included in task 5.2. Data from the different systems of the train in relation to energy consumption must be available and shared from the unit to the ground

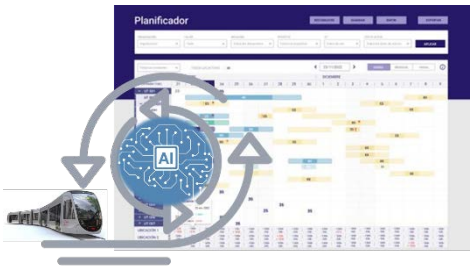
Demonstration Method:	Location:	Facilities:	Date:
Presentation of an Energy Digital Twin and related Dashboards containing data and instructions once the mentioned techniques are applied to the data collected from the train. The Digital Twin will focus con NS Fleets.	The Netherlands	NS / CAF SNG Fleet	Until M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	6.3	6.3.4	UC ID:	6.8
			Int. Demo	
			Leading Partner	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)

UC Name:	Smart maintenance scheduling tool
Type:	Monitoring, maintenance and asset management
Problem Statement:	Under a preventive maintenance strategy, it was relatively easy to forecast and schedule in a sensible way the different maintenance tasks required, while complying with operational requirements. However, the information coming from the different algorithms and the data gathered from the fleet, are dynamic in nature and the amount is vast, which makes it difficult to schedule and organise the required maintenance tasks along with the operational requirements. In this sense, an intelligent system capable of managing this information is required to help operators to make sense of all this data and to decide which actions should be taken. This will lead to a scenario where operators will be able to exploit all the advantages and improvements of a condition-based maintenance program.

Image / Diagram



Description:	In this use case a dynamic scheduler will be implemented. This dynamic scheduler will propose a sequence of required maintenance tasks based on information coming from ML models, the maintenance plan in place, required corrective actions, operational requirements as well as maintenance workshop constraints optimising multi-criteria objectives regarding cost and train availability.
How Does Solution Address Problem Statement:	The system will integrate the outputs of different sources into the maintenance process in place in the workshop by providing a tool that helps maintenance schedulers to decide which maintenance tasks shall be performed based on all this data.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Data in the cloud	WP5->Task 5.3	Inputs for analytical tasks, aimed to build the theoretical model, to be developed in task 6.3.3 must be disposed and delivered to Cloud systems through activities included in task 5.3. Data from the different systems of the train in relation to energy consumption must be available and shared from the unit to the ground

Demonstration Method:	Location:	Facilities:	Date:
A planning proposal generated through SMS will be presented. The idea is to follow the guidelines proposed by it, and measure the main maintenance KPIs, comparing the values under SMS and outside of it, under traditional planning.	Spain	Euskotren/CAF fleet	Until M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP7 Task:	Sub-task:	UC detail	
WP7	7.2, 7.3		UC ID:	7.1
			Int. Demo	
			Leading Partner	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)

		Image / Diagram
UC Name:	**Bogie Monitoring System (Wayside – acoustic, 2D images, video, laser and RFID)**	
Type:	Development, monitoring, data collecting and data analysis.	
Problem Statement:	Train maintenance inspections on bogies are critical to avoid service disruptions due to failing trains and the need to reduce the maintenance costs. Currently, train maintenance inspections are performed manually and periodically. Rolling stock owners/maintenance managers are very interested in solutions that can help to increase fleet availability and reliability. Condition-Based Maintenance (CBM) is believed to be an attractive lever for gaining maintenance efficiency. Bogie components, such as axle bearings, motors, gearboxes and others, are often classified as business-case-positive in the implementation of CBM. To implement CBM, a condition monitoring solution is often required. One possible approach is wayside monitoring. By collecting visual and acoustic data of bogies, which can be analysed to define patterns, bogie monitoring can be done automatically and more frequently. This will be done using some different technologies: acoustic, 2D images, video, laser and RFID, which allow to know the bogies' status. This information can support the increase of security, reliability and the reduction of the maintenance costs.	

Description:	Development of different technologies installed on wayside to monitor the bogies. Determine and record relevant data required for bogies monitoring. Analyse these data to determine the bogies status.
How Does Solution Address Problem Statement:	By collecting visual and acoustic data of bogies, which can be analysed to define patterns, bogie monitoring can be done automatically and more frequently. This will be done using some different technologies: acoustic, 2D-3D images, video and laser that allow to know the bogies' status. This information can support the increase of security, reliability and the reduction of maintenance costs.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Bogie Wayside Monitoring (BWM) - IVG	Sub-Task 7.3.1	Validation test of railway checkpoint on Spanish sections -> Task 7.2
BWM-IVG	Sub-Task 7.3.2	Validation test of railway checkpoint in The Netherlands climate type sections -> Task 7.2

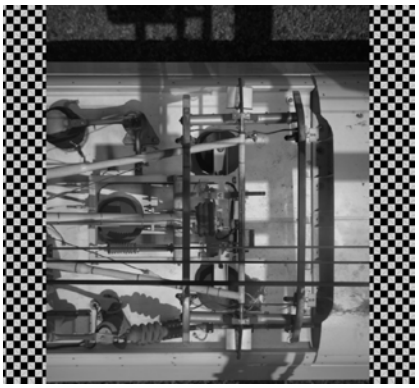
Demonstration Method:	Location:	Facilities:	Date:
Validate results using test data from bogies with known component condition	- Beasain, Humanes and La Sagra (Spain). - Hekenddorp, Swifterbant Hoofddorp (The Netherlands)	Railway Checkpoint	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP7 Task:	Sub-task:	UC detail	
WP7	7.2, 7.3		UC ID:	7.2
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	**Pantograph Monitoring System (Wayside – video and 2D-3D images)**
Type:	Development, monitoring, data collecting and data analysis.
Problem Statement:	Train maintenance inspections are critical to avoid service disruptions due to train failures and the need to reduce maintenance costs. Currently, train maintenance inspections are done manually and periodically. The pantograph is a key element that can cause disruptions in the circulation of trains. For this reason, it is a key piece to take into consideration.

Image / Diagram



Description:	Development of different technologies installed on wayside to monitor the pantograph. Determine and record the relevant data required for the pantograph monitoring. Analyse this data to assess the pantograph status.
How Does Solution Address Problem Statement:	By collecting visual data of the pantograph, which can be analysed to define patterns, pantograph monitoring can be done automatically and more frequently. This will be done using different technologies: video and 2D-3D images that allow to know the pantograph status. This information can support the increase of security, reliability and the reduction of maintenance costs.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP5-WP29	Railway checkpoint use cases and requirements

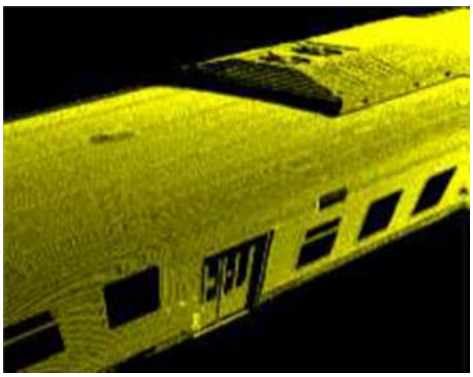
Demonstration Method:	Location:	Facilities:	Date:
By testing in track with trains (wayside and onboard equipment)	- Humanes and La Sagra (Spain) - Hekendorp and Hoofdorp (The Netherlands)	To be tested mainly in workshops and we would like to get data from the pantograph in commercial services	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X	X				
Anticipated FP3-IAM4RAIL TRL:					X	X		

Work package:	WP7 Task:	Sub-task:	UC detail	
WP7	7.2, 7.3		UC ID:	7.3
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	**General physical anomaly detection Monitoring System (Wayside – video and 2D-3D images)**
Type:	Development, monitoring, data collecting and data analysis.
Problem Statement:	Train maintenance inspections for the detection of general physical anomalies (e.g., rolling stock exceeded gauges) are critical to avoid service disruptions or infrastructure damage. Currently, train maintenance inspections are done manually and periodically.

Image / Diagram



Description:	Development of different technologies installed on wayside to monitor physical anomalies. Determine and record relevant data required for general physical anomalies monitoring. Analyse these data to determine, for example, rolling stock exceeded gauges.
How Does Solution Address Problem Statement:	Due to the criticality of these assets and thanks to the systems under development we are going to be able to monitor the health of the general status of the rolling stock with no need for stopping the train (resulting in more availability and over maintenance reduction).

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP5-WP29	Railway checkpoint use cases and requirements

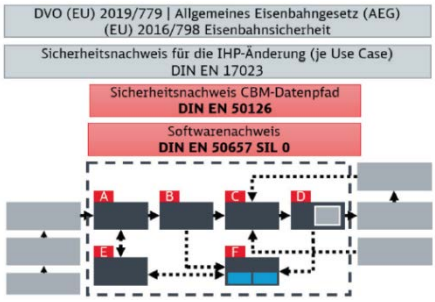
Demonstration Method:	Location:	Facilities:	Date:
By testing in track with trains (wayside equipment)	- Beasain and La Sagra (Spain)	To be tested mainly in workshops and we would like to get data from the wayside equipment in commercial service	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:				X	X			

Work package:	WP7 Task:	Sub-task:	UC detail	
WP7	7.4	7.4.1	UC ID:	7.4
			Int. Demo	
			Leading Partner	DEUTSCHE BAHN AG (DB)

UC Name:	**Data path diagram use case**
Type:	Method development / Standardization
Problem Statement:	Due to the new type of maintenance strategy CBM, ECM2 functions face challenges in adapting their maintenance regimes. There is no generic standard for the creation of a safety certification within the CBM maintenance process. Basis: development of a CBM End to End System (S2R)

Image / Diagram



Description:	Development of a generic, applicable safety certification for CBM data path
How Does Solution Address Problem Statement:	Applicability of the data path to different CBM use cases and another RUs

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CBM	To be updated	To be updated

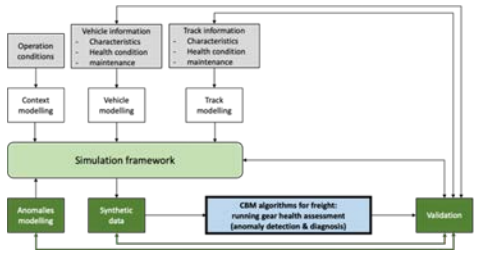
Demonstration Method:	Location:	Facilities:	Date:
Transfer of the generic security certificate to another company DB Netz	DB, DB Netz, Germany	To be compiled	Report, M25

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:				X				

Work package:	WP7 Task:	Sub-task:	UC detail	
WP7	7.4	7.4.2	UC ID:	7.5
			Int. Demo	
			Leading Partner	ASOCIACION CENTRO TECNOLOGICO CEIT (CEIT)

UC Name:	CBM algorithms for freight
Type:	Anomaly detection
Problem Statement:	The railway freight transport sector today has aa lot of potential to be the leader in clean transport (low CO2 emissions) but also has a great need to automate and digitise operational and functional processes for more efficient transport that can compete with other means of transport. Improving maintenance, knowing in real time and in advance the state of health of some components of the rolling stock is one of the challenges of the railway freight transport sector.

Image / Diagram



Description:	Development of algorithms for the assessment of the health status of the bogie (and its components) of freight trains to enable CBM methodologies. No real data is foreseen for this activity. Rather, the algorithms will use synthetic data representing different operating conditions. This synthetic data will be equivalent to the operational data that could be gathered by real on-board sensors.
How Does Solution Address Problem Statement:	The algorithms will allow the assessment of the health status of the bogie (and its components) of freight trains in an automatic way.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Anomaly detection for CBM (freight)	FP3-W7-7.4.2	Anomaly detection and diagnosis algorithms will be delivered for freight applications (e.g., CBM of freight wagon bogies)

Demonstration Method:	Location:	Facilities:	Date:
Different anomalies will be generated by simulation. By running the algorithms, the detection and diagnosis of these anomalies will be benchmarked according to the KPIs	Spain France	N/A	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP8 Task:	Sub-task:	UC detail	
WP8	8.2		UC ID:	8.1
			Int. Demo	
			Leading Partner	NORWEGIAN RAILWAY DIRECTORATE (NRD)

UC Name:	**Long term asset management and LCC**
Type:	Analysis
Problem Statement:	The remaining service life of existing railway bridges must be determined to ensure safe and reliable operation of the bridges and allow efficient distribution of limited funds for maintenance and renewal of the railway infrastructure. Numerical models are essential in railway asset management due to the vast number of components in each individual bridge and the number of bridges in the railway network that need service life assessment. Models are used to represent loading and the damage mechanism and to predict the response in the structure. A lot of work has been performed on the modelling uncertainty of the first two aspects, but modelling uncertainty related to structural modelling has largely been neglected in the literature despite its large influence on lifetime estimates. Uncertainty quantification theory and methodology are widely available and applicable to the present problem in the service life estimation of railway bridges.

Image / Diagram

Description:	The remaining service life of bridges plays an important role in making critical safety decisions regarding operations and maintenance. Today, these decisions are based on conservative estimates of safety factors and scheduled maintenance guidelines. These result in an estimate of life and maintenance intervals that are insensitive to the actual condition of the bridge, thereby increasing safety risk as well as maintenance costs. By instrumenting the bridge with appropriate sensors, the sensory information can be utilised to correct the model-based estimates recursively to improve the accuracy. Besides, by utilising novel data-driven techniques, sensory information, in combination with several other data sources, can be investigated to develop computationally efficient techniques to assess the remaining service life rapidly. These developments, the high-accuracy models with reduced uncertainty, and data-driven techniques will provide the operation and maintenance personnel with an accurate assessment of the health of the infrastructure and assist in reliable data-driven decision making.
How Does Solution Address Problem Statement:	The objective of the Use Case is to improve the remaining service life estimation of civil structures and to safely extend the asset life, thereby reducing renewal costs. This is achieved by the development of new techniques, methods, and algorithms based on new cross-border data sources from existing multiple sensors (i.e., multi-sourced), which will fill the gaps where data capture does not currently exist and supplement existing data (i.e., big-data). This combined and richer data will be used to analyse remaining service life estimations on a deterministic basis and to enhance the historical analysis.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Not reported	Not reported	Not reported

Demonstration Method:	Location:	Facilities:	Date:
Correlation measurement, modeling and simulations	-Norway – Lundamo bridge	Bridge structure	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP8 Task:	Sub-task:	UC detail	
WP8	8.1 8.3 8.4		UC ID:	8.2
			Int. Demo	
			Leading Partner	TRAFIKVERKET - TRV (TRV)

UC Name:	Holistic long-term asset management
Type:	Data analysis
Problem Statement:	Railway asset management can be conducted in different planning perspectives, e.g., operational (now to 2 years), tactical (2 - 5 years) and strategic (5 - 20 years). Infrastructure managers are, in many cases, lacking adequate decision support for tactical and strategic asset management planning. Maintenance programmes and maintenance concepts are available for operational asset management. They are, however, often static (almost unchangeable) and difficult to coordinate with other planning perspectives. Another challenge facing IM managers is planning and executing operations simultaneously with multiple AM plans. The main objective of railway AM is to provide the required dependability from the assets while at the same time consuming a minimum of resources. An increased integration between AM planning perspectives and traffic operations is required to facilitate required dependability with optimized utilization of resources.

Image / Diagram

Description:	The objective of this Use Case is to provide decision support for a more holistic long-term asset management. Contribution to AM comes from three types of decision support (D1-D3), developed for the purpose of increasing asset dependability and reducing resource consumption.
How Does Solution Address Problem Statement:	**D1 Management of dynamic maintenance programs and resource effective execution** Optimizing the utilization of resources requires decision support tools that, today, lack holistic analysis of information (correlation of multiple CBM sources and correlation of maintenance activities with asset conditions). The decision process is supported by the integration of holistic CBM and analytics to provide: IAMS Holistic condition monitoring and decision support for management of dynamic maintenance programs and resource effective execution based on a holistic view with different assets involved (i.e., geographical correlation, time correlation), assets providing diagnostic (or context) about other assets, exodata (weather) and predictions. This also includes analytics rendering and visualization of spatial-temporal data. Algorithms for translating various localization coding to and from a pivot representation, with measurement uncertainty. Algorithms for matching positions to an infrastructure and reconstructing a trajectory on the network (or the network itself). Matching algorithms between routes, routes and areas, and tools for visualisation / HMI. **D2 Maintenance optimization in a dynamic maintenance program** On the iron ore line, there is a need for improvement in the maintenance concept in terms of better coordination between traffic operation, reinvestment activities, and maintenance planning. Maintenance programmes need to become more flexible to facilitate a more rational maintenance concept. Track and S&Cs are linear assets; they age differently, are installed on different occasions, and experience varying loads, which causes them to degrade differently throughout the network. The fixed maintenance plans and schedules often don't consider this variation of degradation across the network. Hence, there is a need for a more dynamic maintenance programme. The objective is to develop a system that describes RAMS parameters for the track as functions of assets' status, components, and traffic, hence serving as decision support for maintenance optimization in a dynamic maintenance program. **D3 Dynamic maintenance programs in train plan** Most of the asset maintenance measures significantly reduce the capacity of a railway line, which is why these measures in railway operations must be planned for the long term and across borders. To achieve this goal, there is a great need to improve communication between all actors involved. Maintenance activities must be considered in the timetable as part of the network capacity planning process. Therefore, the definitions of maintenance activities are to be captured in a digital format with high accuracy. This concerns all planning phases, from strategic/ long-term and tactical planning and capacity management to real-time support of the TMS. The objective is to set up and demonstrate a system (DMPS) for maintenance planning on a cross-border line, allowing the registration and planning of the maintenance activities based on a microscopic infrastructure data model for all process phases. The planned maintenance activities are to be transferred to the network capacity planning system for consideration as Temporary Capacity Restrictions (TCR) with respect to required train regulations to address the impact of these activities.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CDM	FA1 Motional WP29	API Interface for extracting the data from the existing database sources from Trafikverket through CDM mechanism
CDM	FA3 IAM4RAIL WP9	Import of requests for failure reduction

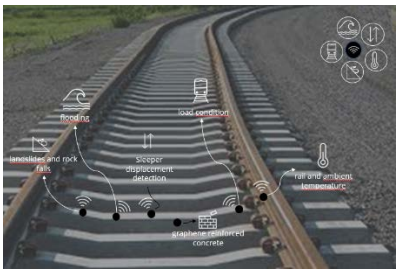
Demonstration Method:	Location:	Facilities:	Date:
Through a cloud-based tool or a standalone application	Workshops	Virtual meeting	M37

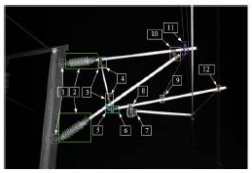
	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X	X				
Anticipated FP3-IAM4RAIL TRL:					X	X		

Work package:	WP9 Task:	Sub-task:	UC detail	
WP9	9.1	9.1.1 9.1.2 9.1.3	UC ID:	9.1
			Int. Demo	
			Leading Partner	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)

UC Name:	**Sensing railway superstructure system components**
Type:	Sensing and interface solutions
Problem Statement:	This Use Case aims to pave the way towards smart/intelligent assets at the component level by focusing on sensing requirements. Three innovations are considered in this use case for three components: sleepers, ballast and the contact line system. Part of the research is to capture the essential characteristic of each component, yet integrating innovation at component levels into asset management solutions faces some common challenges. For instance, the data fusion with information about the asset from different measurement devices and sources. The different types of interfaces, for instance, between different components and interfaces with different systems involved start from the data acquisition system to the higher level of feature analysis with the extraction of key valuable information for maintenance plans.

Image / Diagram





Description:	Part of the research is to capture the essential characteristic of each component, yet integrating innovation at component levels into asset management solutions faces some common challenges. For instance, the data fusion with information about the asset from different measurement devices and sources. The different types of interfaces, for instance, between different components and interfaces with different systems involved start from the data acquisition system to the higher level of feature analysis with the extraction of key information useful for maintenance plans. In the future, this will allow additional information from these assets to trigger a better-tailored maintenance scheme and allow data updates between the physical system and virtual twins of each component.
How Does Solution Address Problem Statement:	Intelligent sleeper: A new concept of an intelligent sleeper, using reinforced graphene as an additive in concrete, is assessed. The sleeper includes harvesting energy capacities with multi-sensor data recording and processing (temperature, flood detections, loading conditions or vibrations) and effective tools for automatically assessing its conditions and decision-making. Onboard LIDARs for Ballast: LIDAR sensing will be studied to estimate ballast profiles and volume to allow decision support using visual conformity evaluation. Cloud point data from LIDAR is to be integrated into existing track maintenance tools. Interface BIM and Design model for the contact line: research on the interface between BIM models and design applications for contact lines is conducted. The information flowing between them is analysed to develop and demonstrate a standardised interface.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
-	-	No interface reported

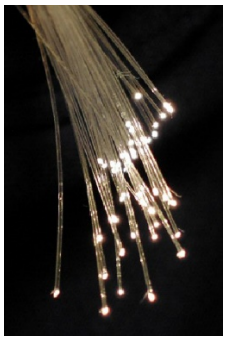
Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	Spain – Madrid	- IMA and CEDEX laboratory	M36
Report of the approaches and validation results	France	-SNCF facilities	M36
Report of the approaches and validation results	Virtual - Germany	- SMO facilities	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X	X		
Anticipated FP3-IAM4RAIL TRL:							X	X

Work package:	WP9 Task:	Sub-task:	UC detail	
WP9	9.2	9.2.1 9.2.2 9.2.3	UC ID:	9.2
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

UC Name:	**Railway infrastructure monitoring using optic fibre**
Type:	Sensing and interfaces solutions
Problem Statement:	The inspection and monitoring of asset status and operational performance information are crucial for controlling the operation and maintenance activities in the railway industry. Regarding train operation, the detection and monitoring of train positions are essential for a train management system. For maintenance purposes, accurate measurement of the asset state is vital to enable optimal maintenance planning and avoid safety-related failures that could reduce capacity.

Image / Diagram



Description:	In this Use case, the aspects of interest for monitoring and detection include the infrastructure and degradation of the vehicle fleet and fault states, security threats, and unauthorized individuals along the track. On the infrastructure side, measuring track properties such as embankment movements, rock fallouts, and overall vibration levels along the track can be of interest. Regarding vehicles, it is important to measure maintenance aspects related to the interaction between the vehicle and the track to prevent damage to the track system, such as wheel flats and unstable bogies. Currently, sensors and detectors are predominantly located at specific geographical points. However, larger areas can be covered more efficiently by utilizing a distributed technology like Distributed Acoustic Sensing (DAS).
How Does Solution Address Problem Statement:	This Use Case demonstrates the application of distributed sensing based on fibre optics for monitoring railway superstructure components and events. New methodologies will be developed by tailoring state-of-the-art technologies and solutions for distributed sensing to the specific applications and their railway environments, such as train identification and intrusion detection. The core of this Use Case is railway infrastructure monitoring, focusing on understanding vibrations in the infrastructure. First, optical fibre data is analysed and focused on monitoring the superstructure. Then, train identification and intrusion detection using DAS/DTS in existing optical fibre installations are developed. Finally, dark fibre solutions are developed for vibrations, damaged wheels, rock fallouts, and the integrity of trains and embankments.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
DAS	-	No interface reported

Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	France	SCNF Facilities	M36
Report of the approaches and validation results	Sweden – Iron Ore Line	TRV Facilities	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X		X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP9 Task:	Sub-task:	UC detail	
WP9	9.3	9.3.1 9.3.2 9.3.3	UC ID:	9.3
			Int. Demo	
			Leading Partner	MER MEC ENGINEERING S.R.L. (MME)

UC Name:	**Track Geometry and S&C condition monitoring**
Type:	Analytics
Problem Statement:	Despite the accuracy and reliability of the mobile/mechanised track geometry measuring systems, there are still cases in which interpretation and data translation is required to improve data to the right quality level for running predictive analytics. Equivalently, mobile and wayside inspection systems for turnout conditions introduce the necessity to combine and translate different information to actionable insights, supporting IMs on taking the right decisions for turnout maintenance and planning activities.

Image / Diagram

Description:	The first problem to address is evaluating effective solutions for monitoring tracks and S&Cs. A key challenge is to reduce the person-hours in track for manual work to detect and assess defects (such as squats, wheel burns, etc.). Further, visual inspections strongly depend on the lighting conditions, which can be overcome by using infrared technology. Therefore, one of the scopes of this use case is to provide the base for the standardisation of turnout health and maintenance indexes (THI and TMI) that weights and combines the different turnout components characteristics, failure modes and operational characteristics, which nowadays remain unlinked or with limited interdependencies. Concurrently for the plain track, by using modern and advanced analytics, the use case aims to improve the quality of the data to understand how the current plain track condition can evolve in the future. This objective will be achieved by considering two levels of analysis. On the one hand, the identification and prediction of the single-track geometry defects using the concept of the defect fingerprint and, on the other hand, the prediction of the track geometry indexes at longer sections of tracks targeting the generation of medium and long-term maintenance plans using advanced analytics.
How Does Solution Address Problem Statement:	The objective is to increase the accuracy of the track geometry prediction at the defect and section level with the automatic identification of resurfacing works using advanced analytics and define a turnout health and maintenance index to allow a consistent and objective method of prioritising turnout maintenance. Also, to improve the detection of rail head surface defects, track and S&Cs quality by using low-cost smartphones and using validation data from onboard sensing solutions (such as video images and acceleration)

System Integration:		
"Label":	Interfacing sub-task:	Interface:
S&C	-	No interface reported

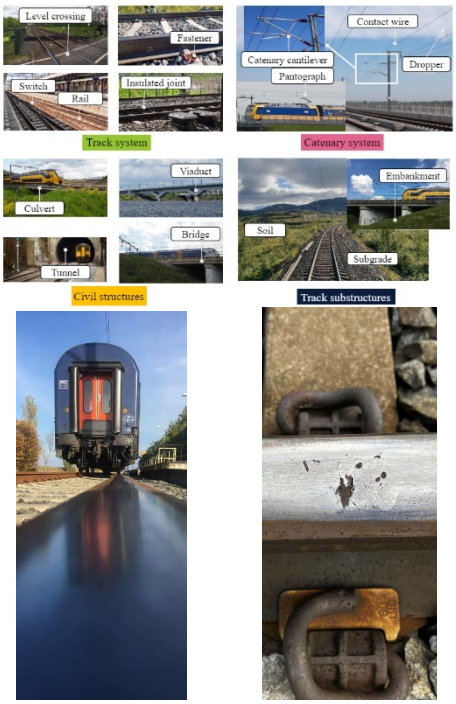
Demonstration Method:	Location:	Facilities:	Date:
Report on the approaches and validation results of innovation for track geometry and S&C condition	- Spain	Database from IM in Spain	M36
Report on the approaches and validation results of innovation for track geometry and S&C condition	- Germany	Database from IM in Germany & trainlab of DB	M36
Report on the approaches and validation results of innovation for track geometry and S&C condition	- France	Database from IM in France & SNCF track monitoring trains	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP9 Task:	Sub-task:	UC detail	
WP9	9.4	9.4.1 9.4.2 9.4.3 9.4.4 9.4.5 9.4.6	UC ID:	9.4
			Int. Demo	
			Leading Partner	DEUTSCHE BAHN AG (DB)

UC Name:	**Prescriptive maintenance for railway infrastructure**
Type:	Sensing and interface solutions, Monitoring and Maintenance
Problem Statement:	The most common practice of infrastructure managers is reacting to inspection results, which leads to short-term and, thus, inefficient and expensive maintenance planning. Medium-term planning is often based on the experience of the infrastructure operator due to the lack of forecasting tools and the traditional planning approach. Root cause analysis in conjunction with LCC-based analysis is not a common practice. As a result, maintenance is not designed to address all the current challenges in railway systems, that is, not only to guarantee a level of availability but also to be sustainable, as individual faults tend to recur after a short time. Further, health condition monitoring and maintenance play an essential role in ensuring safety, availability, and service reliability and increasing the life span of the infrastructure. The early detection of defects throughout sensing technologies allows preventive maintenance activities to be conducted before failures occur, thus showing great potential for cost savings. The continuous monitoring of critical components has not only increased the level of safety but drastically increased the availability of the infrastructure, as early warning systems allow the inclusion of the repairs or replacement of these components during the routine maintenance slots.

Image / Diagram



Description:	In this Use Case, the focus is on prescriptive maintenance, which incorporates state-of-the-art techniques (for example, advanced analytics, AI, big data, etc.) to anticipate failures but, most importantly, to provide holistic/explainable solutions for delaying or deleting failures. In this way, the efficiency and sustainability of the railway system can be increased via maintenance design, and the knowledge about the root causes for track deterioration can be improved, as predictions of deterioration are necessary. Further, we develop integrated and robust approaches to monitor and maintain railway infrastructures continuously. In this Use Case, technologies with TRL levels between 4 and 7 are used. These technologies are developed by testing them under new conditions and investigating possible extended capabilities in combination with different data sources.
How Does Solution Address Problem Statement:	Characterization of anomalies and root cause analysis provide the information necessary to address the root cause before correcting the defects. This supports the shift from addressing symptoms to addressing root causes. In summary, this Use Case provides the fundamentals and essential building blocks for prescriptive maintenance. First, the focus is on defining data models, interfaces, regular collection, and data pre-processing from various sources, such as monitoring, inspections, and TMS. Then, in the use case, we improve and validate the sensing technologies necessary for the prescriptive maintenance of tracks and S&C. The measurement data to be obtained (either from existing sources or with additional measurement campaigns) in this Use Case includes Track geometry (periodical long-wavelength, ride comfort, and rail defects), video images, and axle box acceleration data. Eddy current-based sensor/Lindometer – for anomaly detection of, for instance, fastening systems, with an on-track demonstration to be conducted in Sweden and Germany. LDV and axle box acceleration measurements will be collected in the Netherlands to estimate the transfer function of the railway track that accounts for inputs (loading) and outputs (frequency responses). Axles rotational speed to evaluate if it is possible to retrieve vertical track defects throughout the train mechanical response to these defects (using already available train speed sensors).

System Integration:		
"Label":	Interfacing sub-task:	Interface:
-	-	No interface reported

Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	- Germany	DB Facilities	M36
Report of the approaches and validation results	- The Netherlands	PRORAIL-TUDelft facilities	M36
Report of the approaches and validation results	- Sweden	TRV facilities	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X	X	X		
Anticipated FP3-IAM4RAIL TRL:					X	X	X	

Work package:	WP10-11 Task:	Sub-task:	UC detail	
WP10 & 11	10.2 11.3 11.4	n.a.	**UC ID:**	11.1
			Int. Demo	
			Leading Partner	STRUKTON POWER BV (SR Power)

UC Name:	**Linking (new) monitoring technologies to asset management issues**
Type:	Monitoring
Problem Statement:	The problem at hand is to assess how new monitoring technologies can contribute to critical asset management issues in the rail industry by identifying patterns and linking them to specific issues. Integration and usage of these technologies may introduce challenges, making experimentation and data analysis essential to fully understand the insights they provide. Through data experiments and collaboration with data scientists, a comprehensive range of asset management issues can be uncovered and addressed, leveraging the capabilities of these technologies.

Image / Diagram

Description:	a) Experimenting with the data collected from the new monitoring technologies, such as microwaves or sound, to identify relevant patterns and insights related to asset management. b) Leveraging the expertise of data scientists to analyse the data and detect potential issues or challenges that may impact asset management processes. c) Developing a deeper understanding of the relationship between the data generated by the monitoring technologies and the asset management objectives. d) Identifying specific asset management issues that can be addressed through the integration of new monitoring technologies and proposing suitable solutions. e) Assessing the feasibility and effectiveness of integrating the new monitoring technologies into the asset management framework through pilot projects or demonstrations.
How Does Solution Address Problem Statement:	The solution addresses the problem statement by conducting individual tests on various sensors to collect data sets that can be used for initial assessments. This collaborative effort between data scientists and rail experts allows a comprehensive analysis of the data collected from these sensors. By combining the expertise of both groups, the solution enables a thorough evaluation of the sensors' performance and their potential contribution to addressing the identified asset management issues. This approach ensures that the data collected is effectively used and provides valuable insights for informed decision-making in the rail industry.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Monitoring	To be updated later	Data will be shared with the use case

Demonstration Method:	Location	Facilities:	Date:
On site and using Leonardo platform for train bound systems	- Spain – Rifa/Tarragona	Leonardo platform and tracks on locations	M37
On site and using Leonardo platform for train bound systems	- Spain – Toledo	Leonardo platform and tracks on locations	M37
On site and using Leonardo platform for train bound systems	- The Netherlands - Weesp	Leonardo platform and tracks on locations	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP10-11 Task:	Sub-task:	UC detail	
WP10 & 11	10.2 11.3 11.4	n.a.	UC ID:	11.2
			Int. Demo	
			Leading Partner	STRUKTON POWER BV (SR Power)

UC Name:	**Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis**
Type:	Monitoring tools, data gathering and data analytics
Problem Statement:	The problem at hand is the limited effectiveness of current fault detection and diagnosis methods in the rail industry due to reliance on data from individual onboard or wayside sensors. This results in inaccurate and delayed fault detection, leading to increased maintenance costs, operational disruptions, and safety risks. The use case addresses this problem by fusing data from onboard and wayside monitoring solutions to improve the accuracy of fault findings, identify new asset issues, and enhance maintenance decision-making in the rail infrastructure subsystem.

Image / Diagram

Description:	a) Developing monitoring systems that utilize multi-sensor and multi-vehicle modular architectures for data acquisition, which includes collecting data and matching asset, location, and time from the different sources. b) Implementing advanced algorithms and models for fault detection and diagnosis, leveraging the fused data from onboard and wayside sensors. c) Demonstrating the capability to assess the health condition of turnouts through anomaly detection and early prediction of failures. d) Developing decision support tools based on unsupervised, supervised, and reinforcement learning approaches to aid maintenance decision-making. e) Achieving higher TRL (Technology Readiness Level) for the developed fault detection and diagnosis solutions, indicating their readiness for real-world implementation
How Does Solution Address Problem Statement:	The solution addresses the problem by combining data from onboard and wayside monitoring sources and using modern data analysis techniques. The expectation is that the integration provides a comprehensive view of asset conditions, overcoming limitations of partial data and finding new insights. Proactive maintenance decision-making, optimized resource allocation, and enhanced safety are achieved by identifying both known and previously unrecognized asset issues. This will create new instances of how data can be used, ready for implementation and deployment. Advanced algorithms and machine learning enable accurate fault detection and diagnosis.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Monitoring	To be updated later	Data will be shared with a use case for federated data spaces

Demonstration Method:	Location	Facilities:	Date:
On screen through dashboard	- Spain – Rifa/Tarragona	Dashboards on location	M37
On screen through dashboard	- Spain – Toledo	Dashboards on location	M37
On screen through dashboard	- The Netherlands - Weesp	Dashboards on location	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP12-13 Task:	Sub-task:	UC detail	
WP12&13	12.3	12.3.1	UC ID:	12.1
			Int. Demo	
			Leading Partner	MER MEC ENGINEERING S.R.L. (MME)

UC Name:	**Multiscale monitoring of civil assets**
Type:	Monitoring
Problem Statement:	One of the latest targets of the FS Group consists of designing, developing and implementing a system of control and management for the entire life cycle of civil infrastructure assets (e.g. bridges), railway infrastructure and surrounding territories (vegetation, landslides, floods and other external factors affecting railway infrastructure). Today, maintenance activities are often managed separately and not integrated. To move toward a holistic approach to control and management of the railway infrastructure, information from various data sources (from different technologies) must be jointly exploited to provide support to the decision-making process of IM operators. Another objective that must be pursued is to minimize the response times during emergency phases.

Image / Diagram

Description:	In FP3-IAM4RAIL, a demo will be developed in Italy to address the problem.
How Does Solution Address Problem Statement:	Design and development of a bridge management platform, integrating image acquisition, processing, and classification services for the automatic detection of defects and estimation of the residual lifetime of civil infrastructures. The platform will become a new tool to support decisions pertaining to bridge maintenance. Design and development of a railway monitoring platform, integrating different data sources (satellite, drones, in-situ) to provide actionable insight into the condition of the whole railway network and its surroundings. The platform will represent a one-stop shop for information related to hydrogeological risks, vegetation growth and third-party interference and will support the decision-making process of IM operators involved in railway maintenance.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Track data	WP3-4	Track data from diagnostic train -> Task13.1.2
Hazardous areas	WP3-4	List of critical areas as identified from satellites, drones and ground data fusion -> Task13.1.3, Task13.1.4

Demonstration Method:	Location:	Facilities:	Date:
Showcase the functionalities of the web platform	- Italy -	Bridges, Stations, railways and surroundings	M37
Bridges inspection via drones and AI	- Italy - Melfi	Several Bridges across the Italian territory.	M37
Hydrological risk estimation via AI	- Italy – Milan – Novara & Tortona-Voghera	Railway & surroundings	M37
AI Assets classification & detection of anthropic activities via satellite	- Italy – Rome & Surroundings, Sesto San Giovanni	Station, Railway across the Italian territory	M37
Hydrological risk estimation via AI	- Italy – Milan – Novara & Tortona-Voghera	Railway & surroundings	M37
Detection of subsidence and land slide via satellite	- Spain – Villar De Silva - Italy – Cerignola	Railway & surroundings	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP12-13 Task:	Sub-task:	UC detail	
WP12&13	12.3	12.3.2	UC ID:	12.2
			Int. Demo	
			Leading Partner	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)

Technology Name:	**Bridges and earthworks assets management aided by geotechnics**
Type:	Monitoring
Problem Statement:	Bridge assets management. The study of premature deterioration of POT bearings in long bridges (close to 1000 meters) in areas with high thermal gradient, especially if they are designed in a curve. Therefore, according to the specifications provided by manufacturers, some of these assets are very close to reaching the end of their useful life. Earthworks assets management. The study of two specific slope movements with a long history of problems associated with instabilities. One of these is aggravated by the presence of a reservoir, causing damage to the tunnel lining and levelling defects on the track (Vilar de Silva) and the other slope is mainly composed of clayey soil that slides due to water saturation. This saturation causes a plastic behavior with no resistance to sliding (Briones).

Image / Diagram

Viaduct over Arroyo de las Huertas de Mateo

Slope of tunnel 40

Description:	In FP3-IAM4RAIL, a demo will be developed in Spain to address the problem.
How Does Solution Address Problem Statement:	Bridge assets management. A predictive maintenance tool will be developed to evaluate the progressive damage of the supports and identify the optimal moment of replacement of the POT bearings before their failure or blockage occurs. LVDT sensors, accelerometers, tiltmeters, and temperature sensors, among others, will be deployed to follow this pathology. Earthworks assets management. It is intended to deploy a network of low-cost sensors to gather real-time on-site data correlated with those provided by existing data (inclinometers, piezometers, crack meter and levelling data) in a digital platform to monitor the movements of the slope with the ability to manage alarms and trigger actions to assist maintenance.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Analysis	WP13	EO data collection, ground data processing, algorithms and platform for asset management -> Task 13.2

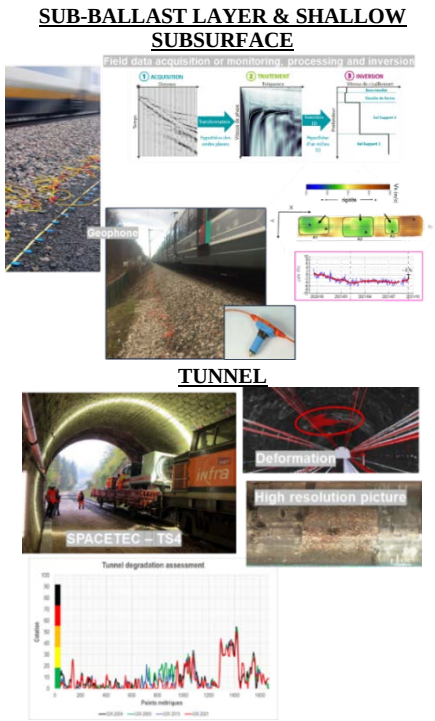
Demonstration Method:	Location:	Facilities:	Date:
Multiscale monitoring of civil assets system implementation & Bridges and earthworks asset management system implementation report	- Spain – Minglanilla (Cuenca)	- Viaduct over Arroyo de las Huertas de Mateo, located on line 040 HSL Madrid – Levante	M36
Multiscale monitoring of civil assets system implementation & Bridges and earthworks asset management system implementation report	- Spain – Briones (La Rioja)	Eartworks: Briones slope, CL 700 Castejón - Bilbao	M36
Multiscale monitoring of civil assets system implementation & Bridges and earthworks asset management system implementation report	- Spain – Villar De Silva (Ourense)	- Eartworks: Entrance slope to tunnel 40, CL 800 Palencia-La Coruña	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP12-13 Task:	Sub-task:	UC detail	
WP12&13	12.3	12.3.3	UC ID:	12.3
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

UC:	**Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels**
Type:	Processing / Investigation / Inspection / Monitoring
Problem Statement:	The Infrastructure Manager's first mission is to guarantee the safety of rail traffic, in particular by regularly checking the integrity of the platform, shallow subsurface and infrastructures (e.g, tunnel). Thus, the multi-scale diagnosis of the railway platform/structure concerns: (1) the platforms to evaluate and control the mechanical state of the subgrade. (2) the supporting soil to understand the phenomena of the appearance of disorders in the track generated by a deterioration of the underlying cavity. (3) the tunnels to control the integrity of the structure, identify the damages and monitor and check the convergence. Today, for the mechanical characterization of the sub-ballast layer and sub-soil and to diagnose the soil support for the risk of subsidence, we use classical geotechnical and geophysical methods, which are punctual, not accurate in some cases and not compatible with the constraints of the railway. Traditionally, convergence tapes and topography have been used to measure the convergence of tunnels. Still, these methods do not allow their automation, which is one of the main objectives of these actions. We aim this approach to reach predictive maintenance. Aims of project: Decrease maintenance operations, guarantee traffic safety, and obtain better constrained input data for optimizing work design, thus maintenance and regeneration cost.

Image / Diagram



Description:	Develop maintenance tools to characterize the behaviors of sub-ballast layers, the sinkhole hazards, the evolution of identified cavity below the earthwork, damages in tunnels with accuracy, the evolution of tunnels degradation, and the convergence of tunnels with high-definition. Specifically, what will be developed: Sub-structure characterisation 1. Collection of seismic surface wave measurement data from 2 or 3 test sites. 2. Proposal of a toolbox describing the methodology of processing approach, the results, and the correlation of results with track and the geotechnical information. Tunnel Monitoring 1. Start investigation with photogrammetry, lasergrammetry and infrared thermography on specific tunnels. 2. Apply AI to an internal database describing tunnel behaviour and predicting the evolution of tunnel structural health. Application on a specific tunnel. 3. A passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels. Sinkhole hazard monitoring 1. Instrumentation of a site with problems in sinkholes thanks to passive seismic surface wave. 2. To characterize the shear velocity for substructure and shallow subsurface needs. Analysis of results and study of the influence of hydrogeological context. To develop tools to assist in the dimensioning of geophysical missions and the data's interpretation
How Does Solution Address Problem Statement:	The project will allow the development of an approach for predictive maintenance for the platform and the infrastructures: - Know and predict the evolution of tunnel structural health - Adjusting the seismic surface wave method to the railway context

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Analysis	Task 13.3	Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels

Demonstration Method:	Location:	Facilities:	Date:
Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	- France – Hattencourt	- Site with a sinkhole hazard	M36
Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	- France – Migennes	- Site with problems's plateform (sub-ballast layer)	M36
Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	- France – Sarresburg	- Site in abandoned tunnels in France	M36
Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	- Spain – Madrid	IMA and CEDEX laboratories in Spain	M36

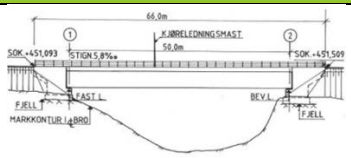
	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:				(X)			X	

(X): For the development of a passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels

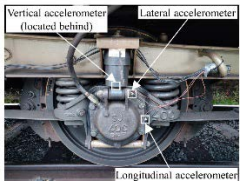
Work package:	WP12-13 Task:	Sub-task:	UC detail	
WP12&13	12.3 13.4 13.5	12.3.4 13.4.2 13.4.3 13.5.5	UC ID:	12.4
			Int. Demo	
			Leading Partner	PRORAIL BV (PRORAIL)

UC Name:	**Data analysis for condition monitoring**
Type:	Methods and technology for monitoring
Problem Statement:	Norway: Many bridges in Norway are near or over the designed life duration, and they are not instrumented, making it challenging to understand their current health condition fully. The local characteristics of the Norwegian bridges and infra manager operation create the need to implement state-of-the-art technologies for monitoring and assessment under local conditions. A bridge in the iron ore line is selected due to its accelerated load-induced degradation. Numerical modelling with multibody software is also considered. Tentative bridge: Søsterbekk bridge. The Netherlands: The Dutch railway is facing major challenges regarding the stability of embankments. To obtain continuous updates, as the network is highly occupied, the capabilities of onboard monitoring together with historical data are analysed to determine and study locations with excessive deformation. The goal is to determine the complementarity of the data to obtain better estimations of the embankment stability without increasing the need for track access. Tentative railway lines: Dordrecht – Lage Zwalage and Delft-Schiedam.

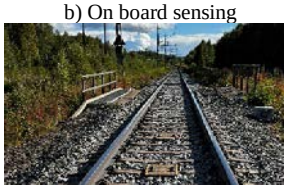
Image / Diagram



a) Bridge



b) On board sensing



c) Bridge and Embankment

Description:	Automated monitoring and inspection can give consistent data quality that is objective using a combination of permanent and mobile instrumentation (acceleration, strain, optical, laser, thermography, ultrasound, etc.), augmenting expert judgment and providing data that can be analysed subsequently. A combination of moving sensors, permanent sensors, and a low-cost and lightweight measurement vehicle (multi-purpose inspection robot) can efficiently collect necessary data for regular and ad-hoc operations. Also, methods and models for monitoring and structural assessment will be developed and used for potential structural upgrades for concrete bridges. In this use case, existing technologies with high TRL levels are used (ABA with TRL7, track geometry measurements already standard in the railway industry, and other well-known instrumentation setups). However, the research is focused on cases where insufficient or no studies have been conducted, for instance, to estimate their applicability to the local conditions for embankment stability in the Netherlands and for bridge monitoring in Norway.
How Does Solution Address Problem Statement:	The use case is to automatize existing manual activities for data collection and analysis, focusing on high-risk areas. In this project, these areas have been identified with bridges and embankments. The goal is to reduce costs by enabling condition-based maintenance through automated data collection, analysis, and decision support. The use-case will also enable increasing the quality of results, e.g. verification of performed work, especially by third parties. Further, methods developed from this use case could be used as a methodology for structural assessment on railway concrete bridges. Thus, we aim to improve bridge performance, reduce costs, and make it possible to improve designs for better and longer-lasting bridges by extending the service life of large concrete structures instead of demolishing and building new ones.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Analysis	FP3: Sub-task 8.2	Data models and instrumentation for structural health monitoring of bridges

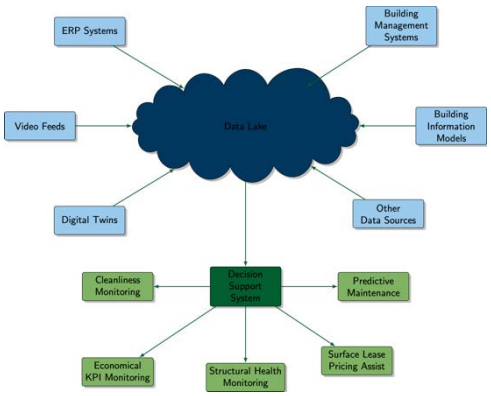
Demonstration Method:	Location:	Facilities:	Date:
Correlation measurement, modelling and simulations	- Norway - Søsterbekk bridges, Ofoten line	Bridge structure and transition zone	M36
Correlation measurements	- The Netherlands - Lage Zwalage Delft-Schiedam	CTO Train TUDelft – BBMS data base ProRail	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X	X				
Anticipated FP3-IAM4RAIL TRL:					X	X		

Work package:	WP3 Task:	Sub-task:	UC detail	
WP14-15	14.1	14.1.1 14.1.3	UC ID:	15.1
			Int. Demo	
			Leading Partner	POLSKIE KOLEJE PANSTWOWE SPOLKA AKCYJNA (PKP)

UC Name:	**Decision support systems for railway station asset management**
Type:	Decision support
Problem Statement:	Efficient management of a multifaceted asset which is a railway station requires taking decisions on multiple levels of organisation, all specified in individual organisation structure. The implementation of this use case will be provided as a modular and expandable instance of data-driven decision support using, among others, BIM and Digital Twin.

Image / Diagram



Description:	The proposed decision support system in station management will help to combine various data from different areas and concerning various processes (main and auxiliary) that take place at the station and which can be managed. Data from disparate sources will be included in the data lake structure, that will allow accessing information on multiple levels of decision making, offering support in such decisions like (but not limited to): predictive maintenance, cleanness maintenance, KPI tracking, structural health monitoring and real estate management. Modular structure of decision support will allow adaptation to different levels of organisational structure.
How Does Solution Address Problem Statement:	• Increase coverage of assets by predictive maintenance decision support • Increase coverage of accessibility assets by predictive maintenance decision support • Reduce costs of maintenance of railway stations • Reduce time needed to detect cleanliness events • Serve the Europe's Rail's Flagship Area 3 "Intelligent & Integrated asset management" objective: "Cost-effective asset management addressing short, mid and long-term interventions widely supported by digital (diagnosis) technologies and data analytics."

System Integration:		
"Label":	Interfacing sub-task:	Interface:
DSS	14.1.2	• Introduction of Digital Twin and BIM data into data lake • Providing information from DSS into digital twin

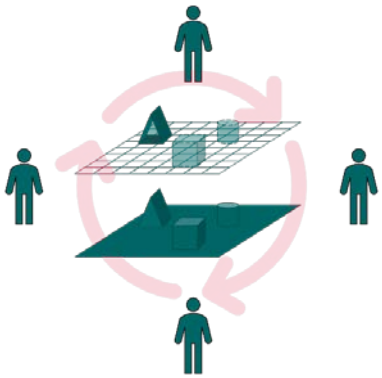
Demonstration Method:	Location:	Facilities:	Date:
Implementation of prototype	Poland – Łódź Kaliska Station, Łódź	Regional	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	Task:	Sub-task:	UC detail	
WP14-15	14.4 15.3	14.4.2 15.3.2	UC ID:	15.2
			Int. Demo	
			Leading Partner	FERROVIE DELLO STATO ITALIANE SPA (FS)

UC Name:	**Blockchain for certification management of railway infrastructure**
Type:	Digital Twin & Asset Certification
Problem Statement:	The use case proves the use of Digital Twin improving: • **Asset data collection, organisation and sharing for certificate management:** it is a time-consuming activity due to multiple sources of information, non-standard data formats and the lack of common data environment. Certificate storing relies on heterogeneous archive methods which bring great inconsistency and inefficiency in information management and lengthen the overall process duration.

Image / Diagram



Description:	This use case constitutes the core feature of an envisioned framework for the railway infrastructure certification that exploit the possibilities offered by blockchain and Digital Twin technologies. • Within the framework, this use case provides the technology and the methods to track the exchanges between actors involved in the life cycle of the infrastructure certificates and to access the related data.
How Does Solution Address Problem Statement:	• Use of blockchain for certification process tracing and certificate management; • Use of Digital Twin for data accessibility and sharing. It provides a conceptual data model to integrate asset data from a variety of sources and to relate heterogeneous asset models

System Integration:		
"Label":	Interfacing sub-task:	Interface:
CDM, CDE	FP1/TT	Conceptual Data Model specification and Digital Twin toolchain including Common Data environment -> Task 30.1, 14.4, 15.3
VCF	FP2 WP34-35	Virtual Certification Framework (benchmark) -> Task14.4

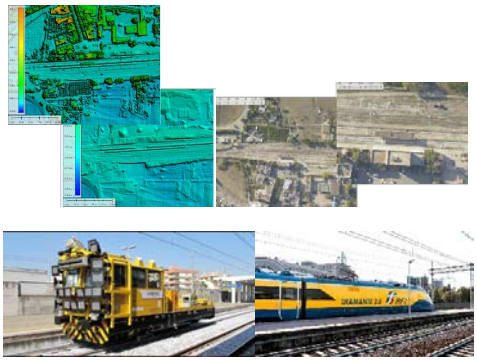
Demonstration Method:	Location:	Facilities:	Date:
Stage an instance of the Virtual Certification Framework for the issue of asset certification	Italy	FS facilities	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP14_15 Task:	Sub-task:	UC detail	
WP14-15	14.2 15.1	14.2.1 15.1.1 15.1.2 15.1.3	UC ID:	15.3
			Int. Demo	
			Leading Partner	MERMEC

UC Name:	**Track Condition data fusion in Point Clouds**
Type:	Digital Twin for Asset Management
Problem Statement:	The use case proves the use of Digital Twin improving different critical asset management processes: • **Unlinked database and data silos:** different data streams that result from asset mobile surveying and diagnostic services; limited data cross correlation between departments and data sharing • **No fusion between Point clouds and raw data condition:** multiple environments to access the data; no actual correlation of the data; limited root-cause analysis. • **Extracted features and digitalised assets detached from diagnostic information:** decision-making process for assets maintenance and renewals is based on missed or subjective information.

Image / Diagram



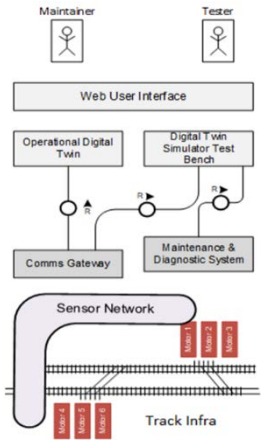
Description:	The implementation of this use case will support remote track inspection and verification of the condition of the infrastructure by providing a unique web-based environment that will bridge Point cloud insights with Track Diagnostic information, digitalised assets and railway corridor. Airborne, train borne and diagnostic systems will be used for the collection of the required data streams, which will be later fused based on GPS coordinates. The web-based platform will make use of a micro-frontend and micro-services architectural framework that allow standalone module development linked to each other.
How Does Solution Address Problem Statement:	• Verification of existing asset databases with the outputs of the digitalisation mapping services • Integration between surveying outputs such as orthophotos, digital terrain models and cartography maps with digitalised assets • Visual synchronisation of multi-disciplinary data streams • Enriching Point Clouds with track condition raw data measurements • Definition of the software architecture that supports the visual correlation of the different data streams • Common localisation between the different data streams

System Integration:		
"Label":	Interfacing sub-task:	Interface:
N/A	N/A	N/A

Demonstration Method:	Location:	Facilities:	Date:
Track Condition data fusion in Point Cloud – Web Platform	Monopoli (BA), Italy	MERMEC SpA, Headquarters, Monopoli (BA), Italy	M35

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	Task:	Sub-task:	UC detail	
WP14-15	14.4 15.3	14.4.3 15.3.2	**UC ID:**	15.4
			Int. Demo	
			Leading Partner	Hitachi Rail GTS Deutschland

UC Name:	**Digital Twin of Point Machine to enable Virtual Certification Framework**	**Image / Diagram**
Type:	Digital Twin & Asset Certification	
Problem Statement:	The use case proves the use of Digital Twin improving: • **Asset data collection, organisation and sharing for certificate management:** it is a time-consuming activity due to multiple sources of information, non-standard data formats and the lack of common data environment. Certificate storing relies on heterogeneous archive methods which bring great inconsistency and inefficiency in information management and lengthens the overall process duration.	

Description:	This use case constitutes the core feature of an envisioned framework for the railway infrastructure certification that exploits the possibilities offered by blockchain and Digital Twin technologies. Within the framework, this use case provides the technology and the methods to track the exchanges between actors involved in the life cycle of the infrastructure certificates and to access the related data.
How Does Solution Address Problem Statement:	• Use of Digital Twin for data accessibility and sharing. It provides a conceptual data model to integrate asset data from a variety of sources and to relate heterogeneous asset models

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
CDM, CDE	FP1/TT	Conceptual Data Model specification and Digital Twin toolchain including Common Data environment -> WP30.Task 30.1 and Task 30.4
VCF	FP2 WP34-35	Virtual Certification Framework (benchmark) -> Task14.4

Demonstration Method:	Location:	Facilities:	Date:
Stage an instance of the Virtual Certification Framework for the issue of asset certification	Germany	GTSD facilities	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:	X							
Anticipated FP3-IAM4RAIL TRL:				X				

Work package:	WP3 Task:	Sub-task:	UC detail	
WP14-15	15.4	14.2.3 15.1.3 15.4.3	**UC ID:**	15.5
			Int. Demo	
			Leading Partner	AZD PRAHA SRO (AZD)

UC Name:	**Demonstration of automatic track visual inspection by unmanned means (drones)**
Type:	Digital Twins/Automatic Surveillance
Problem Statement:	• Sensor-based detection of railway assets is not enough to plan maintenance actions • Traditional visual detection costly and onerous for normal operation • Drone inspections currently limited by low degree of integration, regulatory requirements (flying within line of visibility) and lack of data processing solutions

Image / Diagram

Description:	The objective of the use case is to develop an integrated solution for major technical challenges of drone surveillance of railway infrastructure, especially signalling assets: • Integration of mission planning and execution: a web-based controlling interface connected to an on-board computer for streamlined office-based waypoint definition and mission planning • Extension of regulatory approval for flying beyond line of visibility: safe and secure communication and additional safety measures for the drone • Extension of operational range by automatic recharging in intelligent mobile airports • Data processing and integration into a digital twin: a generalised data model for signalling assets and track, linking reference visual data, used by algorithms to detect failures and clearance envelope violations
How Does Solution Address Problem Statement:	• Remove obstacles to frequent and timely identification of asset defects and clearance envelope violations, • Significantly reduce OPEC, risks and environmental impact, • Offer new angles for visual and point-cloud data collection inaccessible by traditional means, • Integrate collected data into a model for the infrastructure manager (Digital Twin) • Serve the Europe's Rail's Flagship Area 3 "Intelligent & Integrated asset management" objective: "Cost-effective asset management addressing short, mid and long-term interventions widely supported by digital (diagnosis) technologies and data analytics."

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
UAV	FP3: Sub-task 15.4.2	• Detection of defects triggers start of the maintenance and re-certification • Collected data fed into a model of certifiable assets agreed by subtasks

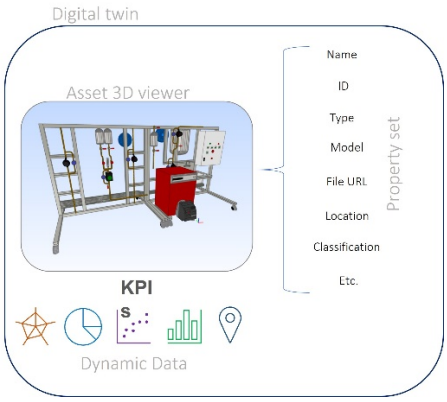
Demonstration Method:	Location	Facilities:	Date:
Visual and Point cloud data collection along AŽD test tracks in Czechia	• Most – Lovosice branch line, Czech • Dolní Bousov – Kopidlno branch line, Czech	Local	M34

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP3 Task:	Sub-task:	UC detail	
WP14-15	14.1	14.1.2	UC ID:	15.6
			Int. Demo	
			Leading Partner	HITACHI RAIL GTS France (GTSF)

UC Name:	**BIM model as support to communicate and populate the Station's Asset Management System**
Type:	Digital Twin
Problem Statement:	• Sorting, organising and capturing asset information to create a usable database for facility management is a long-term job that can generate capture errors without any added value for the station. A poor interoperability and the traditional asset management process can produce losses of time and money. • Common solution of Station Asset Management offers poor adaptability to various use cases encountered in transportation. • Most solutions do not include features dedicated to the increase of maintenance easiness, like the integration of 3D BIM models

Image / Diagram



Description:	The project proposes an approach to the benefits of using BIM, as well as the implementation of a methodology around BIM for operation, management, collaboration, information flow, building performance and data updates.
How Does Solution Address Problem Statement:	The objective of this use case is: -To have an up-to-date building data "As-built", to reduce maintenance costs, reduce intervention times and increase user's satisfaction. -Identify the process and information required in the BIM Model for asset management interventions. -Deploy a methodology for updating BIM information and reduce the cost and time to populate the Asset Management System called AIM -Identify the technology needed to develop a BIM-AIM working method and Digital Twin -Create a methodology for the exchange of information between the asset management system, the digital twin and the BIM Model. The expected results are: -Better knowledge of the site, and 3D & 2D visualisation of the building without displacement. -All the asset information needed for the maintenance and operation. -Unique identification of each element with a specific location in the building. -Identification of Zones to identify system assignments and schedule repairs. -Reduce unnecessary information and delete repeated information. -Reduce maintenance costs and increase equipment performance using an optimal solution -Reduce travel caused by lack of information. -Increase the performance of preventive maintenance. -Access to information and data in real time.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
BIM	14.1.1-14.1.2	BIM geometry and data exported to IFC4 standard

Demonstration Method:	Location:	Facilities:	Date:
Deployment of an asset management solution with Web client in a public cloud. Configured by BIM file	Velizy - France	GTSD	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.1	16.1.1	UC ID:	16.1
			Int. Demo	
			Leading Partner	VOESTALPINE (vaRS)

UC Name:	**Green turnout**
Type:	Statistical approach
Problem Statement:	Railway transportation is the most environmentally friendly form of transport but has high emission of CO2 during production and operation. Optimisation of design solutions, production and maintenance of the railway could significantly reduce the environmental impact in these areas as well as increase the availability in track. Key challenge targeted in this use case is to reduce the ballast destruction for turnouts by optimising the turnout deflection with a simulation model. Forthermore introduce optimised turnout components to reduce the CO2 emission of the turnout during its lifetime.

Image / Diagram

Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	Tailor analysis methods for specific turnouts of the customer and optimise the bedding situation by introducing and install several enhanced components and solutions to enlarge the durability and availability of turnouts.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Green TO	N/A	No integration with other systems

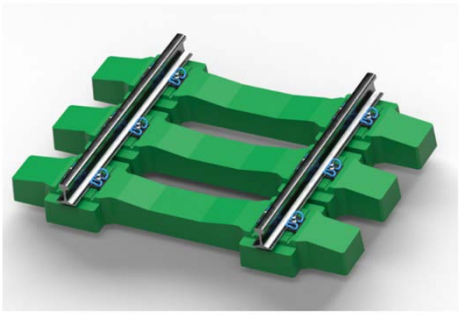
Demonstration Method:	Location:	Facilities:	Date:
Installation of green turnout demonstrator railway.	Austria	TBD	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.1	16.1.2	UC ID:	16.2
			Int. Demo	
			Leading Partner	VOESTALPINE (vaRS)

UC Name:	**Innovative Sleeper System**
Type:	Statistical approach
Problem Statement:	Railway transportation is the most environmentally friendly form of transportation but has high emission of CO2 during production and operation. Optimisation of design solutions, production and maintenance of the railway could significantly reduce the environmental impact in these areas as well as increase the availability in track. Key challenge in this use case is to develop an innovative sleeper system by developing optimised concrete mixtures, new shapes of sleepers and fastening system.

Image / Diagram



Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	Tailor analysis methods for specific tracks of the customer and optimise the bedding situation by introducing and install several enhanced components and solutions to enlarge the durability and availability of tracks.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Innovative Sleeper System	N/A	No integration with other systems

Demonstration Method:	Location:	Facilities:	Date:
Validate the innovative sleeper system	Austria	TBD	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:				X				

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.1	16.1.2	UC ID:	16.3
			Int. Demo	
			Leading Partner	VOESTALPINE (vaRS)

		Image / Diagram
UC Name:	**Maintenance Reducing Squat Resistant Rail**	
Type:	Statistical approach	
Problem Statement:	Railway transportation is the most environmentally friendly form of transportation but has high emission of CO2 during production and operation. Optimisation of design solutions, production and maintenance of the railway could significantly reduce the environmental impact in these areas as well as increase the availability in track. Key challenge of this use case is to optimise the resistance of rails against squats and reduce the need of maintenance, which cause huge problems in real tracks.	

Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	Tailor analysis methods for specific tracks of the customer and optimise solutions to enlarge the durability and availability of tracks. Develop test methods and models for understanding realistic behaviour in rail material.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Maintenance Reducing Squat Resistance Rails	N/A	No integration with other systems

Demonstration Method:	Location:	Facilities:	Date:
Installation of maintenance reduced squat resistance rails	Austria	TBD	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.2	16.2.1 16.2.2	UC ID:	16.4
			Int. Demo	
			Leading Partner	TRAFIKVERKET - TRV (TRV)

UC Name:	**Bridge dynamics**
Type:	Statistical approach
Problem Statement:	Some bridges in rail infrastructure are likely to have been built with overly-conservative values based on models which do not reflect the realistic dynamic behaviour of the bridge. This leads to limitations and costs in the railway system, for example when new high-speed lines are not allowed to run on existing bridges or new bridges are built overly robust.

Image / Diagram

Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	The project aims to develop train-track-bridge interaction models for realistic estimates of dynamic effects on bridges and to increase the understanding of the behaviour of bridges with ballasted tracks under dynamic loading. Collected track data as well as data from bridge monitoring will be used to verify and calibrate the models. Moreover, 3D DEM ballast modelling and simulations combined with full-scale laboratory bridge testing will be used to investigate the behaviour of ballasted tracks on bridges under varying amplitude and frequency.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Bridge dynamics	InBridge4EU (open call)	16.2.1: Train-track-bridge interaction models (WP3). 16.2.2 Laboratory testing and simulation of the dynamic behaviour of ballasted tracks (WP5).

Demonstration Method:	Location:	Facilities:	Date:
Train-track-bridge interaction models calibrated using bridge response data from dynamic monitoring and available data of recorded track irregularities.	Sweden	KTH	M36
Bridge model for dynamic analysis based on refined simulations compared to experimental data, both from a full-scale bridge tested in laboratory and previously tested in-situ bridges.	Sweden	KTH	M36
Monitoring system of a two isostatic span bridge, based on accelerometers with an integrated external temperature sensor. Additionally, it includes strain gauges placed on the rails to characterise the rolling stock.	Spain	INECO	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.2	16.2.3	UC ID:	16.5
			Int. Demo	
			Leading Partner	SNCF

UC Name:	**Platipus**
Type:	Statistical approach
Problem Statement:	The increasing vulnerability of engineering structures, like bridges, to weather-related scouring and submersion due to climate change poses significant safety risks to rail transport. Climate change has led to more frequent and severe weather events, such as heavy rainfalls resulting in flooding and erosion, which challenge the stability and integrity of these structures. Identifying and managing the risks associated with these hydraulic variations is crucial to ensure the safety and reliability of railway infrastructure.

Image / Diagram

Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	The PLATIPUS project aims to make engineering structures safer, such as bridges and retaining walls, whose foundations are located in a water environment. This initiative takes into account the growing challenges posed by climatic risks, such as flooding and erosion, which threaten the stability of these essential infrastructures. The proposed solution includes a digital platform that integrates advanced data processing, artificial intelligence and visualisation technologies for risk assessment and management. A key component is a machine learning model that predicts the risk of scour in aquatic foundations, enabling timely alerts and interventions. The solution facilitates coordination among stakeholders and supports decision-making by providing actionable insights and real-time updates on infrastructure conditions, thus mitigating the risk of failures.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Platipus	N/A	No integration with other systems

Demonstration Method:	Location:	Facilities:	Date:
Developed tools for maintenance of railway system considering climate change impact	France	SNCF	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.2	16.2.3 16.2.4	**UC ID:**	16.6
			Int. Demo	
			Leading Partner	SNCF

UC Name:	**Diagn'eau**
Type:	Statistical approach
Problem Statement:	With a view to ensuring a satisfactory level of service during flood events, the SNCF has developed guidelines to be used during the management of significant flood events: flood risk resilience plans built on predicted and historic water levels to help operational staff anticipate problem areas on the network. The tool has its limitations, such as the vulnerability of all railway assets not being integrated in the tool and knowledge of asset vulnerability is often limited to one water level due to lack of scaled data.

Image / Diagram

Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	Further develop tool to help build operational activity management, integrate the flood risk in projects and determine flood alerts thresholds.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Scour-Flood-Tool	N/A	No integration with other systems

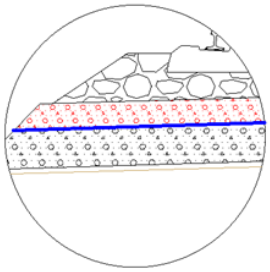
Demonstration Method:	Location:	Facilities:	Date:
Developed tools for maintenance of railway system considering climate change impact	France	SNCF	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP16 Task:	Sub-task:	UC detail	
WP16	16.2	16.2.4	UC ID:	16.7
			Int. Demo	
			Leading Partner	SNCF

UC Name:	**Geogrids**
Type:	Statistical approach
Problem Statement:	In order to decrease the cost and the environmental impact of the track bed renewal projects, the use of geogrids is proposed. The aim of the project is to find an optimised dimensioning for track bed, including geogrids, on conventional lines.

Image / Diagram



Description:	Approach in IAM4RAIL
How Does Solution Address Problem Statement:	The aim of the UC is to determine the type of geogrids that can be used in the French network and to find an optimised track bed dimensioning that guarantee life service, cost efficiency and low environmental impacts.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Geogrids	N/A	No integration with other systems

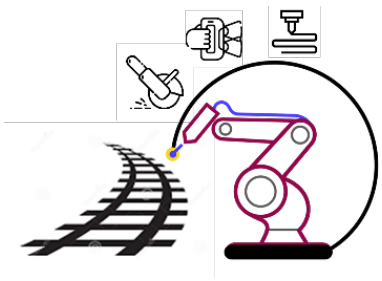
Demonstration Method:	Location:	Facilities:	Date:
Track bed dimensioning solution using geogrids	France	SNCF	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.1	UC ID:	17.1
			Int. Demo	
			Leading Partner	ASOCIACION CENTRO TECNOLOGICO CEIT (CEIT)

UC Name:	**In-situ AM repair machine for rails, switches or crossings**
Type:	Additive Manufacturing
Problem Statement:	Damaged track elements like rails or switch&crossings are currently repaired by manual electric welding. The repeatability and quality of the repair is compromised by human error.

Image / Diagram



Description:	A machine for in-situ repair of rails, switch or crossings using AM technology is being developed. The machine integrates several subsystems to remove material before the repair, add material using Laser-DED powder, remove material to reach final dimensions and measure final dimensions.
How Does Solution Address Problem Statement:	The repeatability and quality of the repairs will be improved through three lines of research: 1) Automation of manual repair operations: since human errors are inevitable, implementing automated repairs minimises errors increasing accuracy and consistency. This results in a much more efficient repair, which ultimately leads to an extension of the repaired component service life. 2) Repairs carried out by AM are expected to be of better quality than those carried out by welding. 3) The development of new repair materials specially designed for AM will contribute to improve the repair performance.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM		This demonstrator does not share information with other systems.

Demonstration Method:	Location:	Facilities:	Date:
A repair of a rail or switch&crossing element will be performed: A repair will be performed using the developed repair system which integrates at least the following operations: grinding, surface measuring and repair by additive manufacturing. For this purpose, a relevant environment consisting of a track box with at least slippers, damaged track element (rail or switch&crossing part) with the corresponding fasteners and ballast will be installed at CEIT facilities.	San Sebastián, Spain	CEIT	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.2	UC ID:	17.2
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	AM repair machine for wheels
Type:	Additive manufacturing
Problem Statement:	Wheels are one of the most important consumables of the train in terms of cost and weight. To recover the wheel and try to avoid side and risk operations like disassembly and assembly of the axle from the wheel, we want to study the use of AM method to "remanufacture" the wheel

Image / Diagram

Description:	At least two different AM technologies: cold spray and Laser-DED. On-bench testing of wheels repaired by AM resembling running conditions. The results of the test should allow identifying the best process and material combination for wheel repairing.
How Does Solution Address Problem Statement:	Fully characterisation of mechanical properties achieved using different technologies to assure the different steps in the development based on a safety approach. Intensive campaign in different levels to assess the process. Follow the requirements, as much as possible, from the wheel standard EN 13262.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM		This demonstrator does not share information with other systems.

Demonstration Method:	Location:	Facilities:	Date:
A repair of a wheel using two different AM methodologies, laser DED wire and laser DED powder Characterisation at different levels from test probe to representative test bench.	Spain	Test bench and laboratories: San Sebastian (CEIT) and Eibar (Tekniker)	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.2	UC ID:	17.3
			Int. Demo	
			Leading Partner	FUNDACION TEKNIKER (TEKNIKER)

UC Name:	In situ repair of track metallic assets
Type:	Repair and reinforcement by laser technology
Problem Statement:	Rails and switches are two of the most sensitive elements of the railway infrastructure, which suffer from different types of defects, such as wear, deformation, spalling, slipping, etc. These important components are usually recovered whenever possible on the track itself, in situ, following mainly economic and safety criteria. One of the most widespread methods is manual hardfacing operations using arc welding technology. This conventional welding technology, assisted by other tools such as grinders, allows the rail components to be recovered quickly. However, these methods are not a definitive solution, as they have several drawbacks. They tend to generate high thermal stress in the treated regions, deformations and generally low or medium durability recoveries. In addition, the associated equipment and the techniques used are very difficult to handle and require a great deal of experience, as well as risks to the health and safety of the workers who carry them out, which means that highly qualified operators are required.

Image / Diagram

Description:	Repaired and recovery of track metallic assets (rails, switches or crossings) based on laser-DED technology. The use case will be focused on two components: 1. Recovery and reinforcement of rails. Main requirements: o Local rolling surface defects such as crushed or worn ends, sliding marks, flaking and spalling, arc weld or aluminothermic weld defects, equal to or less than 1 mm deep. o Rail base materials: R260 and R350 HT steels. o Recovery temperature: between 350 ºC and 420 ºC. 2. Recovery and reinforcement of switches or crossings. Main requirements: o Defects on running surfaces: worn ends, tracks and cracks. o Materials: manganese steels. o Temperature: < 200 ºC to avoid quenching processes.
How Does Solution Address Problem Statement:	In addition to the advantages associated with laser technology, such as easy automation and high flexibility, recovery technologies based on DED laser processes stand out from conventional welding techniques due to the application of a very localised heat input, enabling greater precision and control of the process, as well as minimal thermal impact. As a result, the weld deposit has a higher quality finish, which means a considerable saving in terms of the amount of material to be removed during the subsequent machining and/or finishing stages. Mininum thermal stress on the substrate results in a smaller heat affected zone, reduced residual stresses and consequently lower distortions.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM		This demonstrator does not share information with other systems.

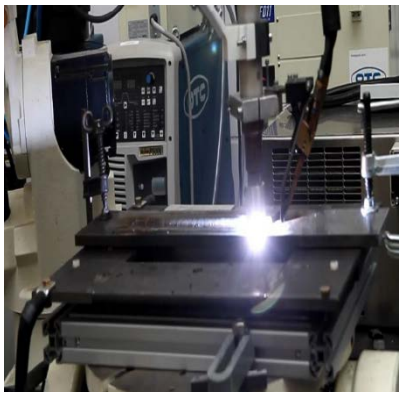
Demonstration Method:	Location	Facilities:	Date:
Recovery of rails and switches using DED laser techniques, on tracks where the consortium has tenders for recovery on the European rail network, within the foreseen period. It is expected that at least 1-2 interventions can be carried out, which will take place on different days and different sections of the network and at off-peak hours, usually at night. In these interventions, the results achieved in the study carried out in the previous tasks will be put into practice, applying the defined stages, conditions and strategies in each of them.	Spain	Adif	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.2	UC ID:	17.4
			Int. Demo	
			Leading Partner	VOESTALPINE RAILWAY SYSTEMS GMBH (vaRS)

UC Name:	**Stationary solution for AM repaired turnout crossings using WAAM technology**
Type:	Additive Manufacturing
Problem Statement:	The repair of a railway crossing by build-up welding is a time and cost consuming process, but essential for the infrastructure management to extend the lifetime of the crossing in track and lower the LCC. The goal of automating this process offers the possibility of cost reduction, procedure acceleration and quality improvement, among others. To extend the lifespan of a railway crossing more than by normal repair welding due to using a specific distribution of customised material concepts, will strongly influence the LCC.

Image / Diagram



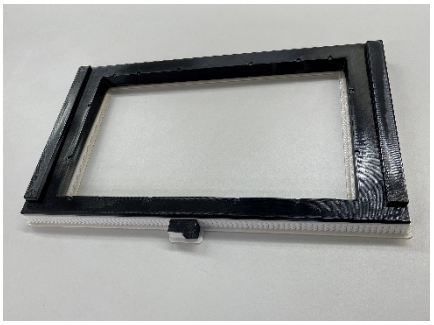
Description:	The focus of this use case is on an AM repaired turnout crossings using WAAM technology. The developed AM repair process features an ideal distribution of specific metal alloys according to the specific position in the complex internal structure of a crossing to meet local stress situations and individual material resistance requirements (wear, fatigue, plastic deformation).
How Does Solution Address Problem Statement:	The repair welding of railway crossings is a challenging process that requires a lot of expertise. The state-of-the-art process is characterised by a significant amount of manual work and a small number of the available filler metals for the repair welding of a railway crossing. The development of a functional WAAM repair welding process for crossings and the use of specific material concepts will allow to affect the LCC in a positive way. These features will be demonstrated in a laboratory (TRL 4) and this will lay the foundation for an AM repair process for railway crossings.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM	-	This demonstrator does not share information with other Systems

Demonstration Method:	Location:	Facilities:	Date:
Demonstration in the laboratory: The development of a functional WAAM repair welding process for crossings and the use of specific material concepts will be demonstrated in a laboratory.	Aachen, Germany	RWTH Aachen – ISF	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X					
Anticipated FP3-IAM4RAIL TRL:				X				

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.3	UC ID:	17.5
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

		Image / Diagram
UC Name:	**Additive Manufacturing of large & flame-retardant polymer spare parts**	
Type:	Additive Manufacturing	
Problem Statement:	RU maintains a large number of trains in operational conditions which requires thousands of spare parts references. This maintenance means a wide variety of components and small quantities needs compared to other industries. Suppliers often require large quantity orders which leads to high-cost physical storage. In some cases, spart parts are no longer produced by suppliers. Transforming the physical stock in a digital storage becomes a strategic objective for RU. The present use case focuses on polymer parts and deals with two crucial needs of polymer components: large dimensions and flame retardancy. Currently, very few flame-retardant polymer materials for 3D printing exist on the market and the dimensions of printed parts are limited by the capacities of printers. The capability of large printers needs to be demonstrated and compared to railway specification and standards.	

Description:	The demonstrator is a large interior flame-retardant polymer component: 1. The component follows the EN-45545-2 standard and reaches the R1-HL2 requirements. 2. The dimensions will be about 1m. 3. The component can be a driver's cab desktop, a command panel or buffet car component. 4. External fairings will be also considered as a backup option. This option aims to enlarge the variety of components, to ensure a proper component is found.
How Does Solution Address Problem Statement:	The use case proposes new flame-retardant materials which increases the use of additive manufacturing to make spare parts and accelerate the storage digitalisation. The cost of these new materials will meet the railways needs, < 100€/kg. The use case brings additive manufacturing for large parts. The use case increases the number of available processes and suppliers to make one component making the supply chain more resilient.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM		This demonstrator does not share information with other Systems

Demonstration Method:	Location:	Facilities:	Date:
To reach TRL 6, the material will be characterised and validated for R1-HL2 level and environment conditions. The process will be also characterised to ensure the feasibility of large components. Finally, the component will be tested on a bench.	Austria France Germany	ÖBB, DB and SNCF facilities	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP17 Task:	Sub-task:	UC detail	
WP17	17.5	17.5.4	UC ID:	17.6
			Int. Demo	
			Leading Partner	DEUTSCHE BAHN AG (DB)

UC Name:	**Digital Warehouse**
Type:	Additive Manufacturing
Problem Statement:	On-demand manufacturing methods like additive manufacturing have shown big potentials in the railway market and have been used since 2015. European Railway operator currently identifies parts for additive manufacturing bottom-up from suggestions of their employees and struggle to identify parts for additive manufacturing from their existing ERP systems. The vision to procure spare parts on-demand by printing is hampered by the labour-intensive bottom-up approach and missing technical data in the ERP system to use currently available solutions to identify parts for additive manufacturing. Methods and processes are needed to identify spare parts top down from the existing ERP systems of railway operators.

Image / Diagram

Description:	The concept of a Digital Warehouse for on-demand production of spare parts, especially their identification, will be evaluated and methods to cope with the challenges will be documented.
How Does Solution Address Problem Statement:	The concept of a digital warehouse with a focus on additive manufacturing will be specified and examples of an implementation at Railway operators will be shown.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AM		This demonstrator does not share information with other Systems

Demonstration Method:	Location:	Facilities:	Date:
Mock-Up of a digital tool, illustrating the standard functionality of the digital warehouse. Report about the concept of a digital warehouse, including in deepth analysis of a few AM use cases included in a digital warehouse.	Austria Germany France	ÖBB, DB and SNCF facilities	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.4	18.4.1	UC ID:	18.1
			Int. Demo	
			Leading Partner	NORWEGIAN RAILWAY DIRECTORATE (NRD)

UC Name:	**Light and Flexible on-track Inspection**
Type:	High-tech automated solutions for inspection and interventions
Problem Statement:	The overall problem to be solved by the Infrastructure Manager (IM) or the Railway Undertaking (RU) with an on-rail multipurpose inspection robot is to ensure the safe and efficient operation of the railway system. The inspection robot can be used to detect and assess potential risks, defects or damages to the railway infrastructure, such as the track, signals, infrastructure, bridges and tunnels. On some small or remote lines (due to the availability of the measurements systems or due to the difficulties to transport them at the right location) the traditional means of inspection (measuring trains, for example) cannot be mobilised or not in such a flexible way as required to carry out particular surveillances. IMs are looking for lighter and more flexible means of inspection which can cover multiple inspection tasks.

Image / Diagram

Description:	The inspection robot must be able to locally navigate the railway system, collect data and information, identify potential hazards or issues and adapt its behaviour. The IM or RU must then use this information to plan and prioritise maintenance and repair activities to ensure continued safe and reliable operation. The ultimate goal of the on-rail multipurpose inspection robot is to prevent accidents, reduce downtime and ensure the highest level of safety for passengers and freight transport. By using advanced technology to automate the inspection process, the IM or RU can improve the efficiency and accuracy of inspections, leading to significant cost savings and increased reliability of the railway system.
How Does Solution Address Problem Statement:	The proposed innovation of using an on-rail multipurpose inspection robot can have a significant impact on the IM/RU problem. By enabling quicker and more efficient inspections, a scaled solution based on the robot can increase the inspection availability. If achieved, the IM or RU would be able to identify potential hazards or issues quickly, allowing for prioritisation of maintenance and repair activities. This, in turn, would reduce downtime, improve safety for passengers and freight transport, and lead to significant cost savings. Additionally, the IM or RU would reduce reliance on manual inspection processes or the availability of large track geometry cars, resulting in a more efficient and effective maintenance strategy for railway infrastructure. Ultimately, the proposed innovation has the potential to bring about a paradigm shift in the railway inspection process and the way that IMs and RUs manage and maintain their railway infrastructure.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Robotics	To be defined	To be defined

Demonstration Method:	Location:	Facilities:	Date:
Field tests carried out by an inspection robot and report after in depth analysis". It is uncertain by the description whether the robot already exists or will be designed/adapted/improved for the occasion	Uncirculated French track section: Autun-Etang or similar	No additional facility required	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.4	18.4.2	UC ID:	18.2
			Int. Demo	
			Leading Partner	STRUKTON RAIL NEDERLAND BV (SRNL)

UC Name:	**Automated installation of ERTMS balises and axle counters**
Type:	High-tech automated solutions for inspection and interventions
Problem Statement:	The overall problem is that the transition to ERTMS is a very long process. The workforce to install the infrastructure is not sufficient to ensure that ERTMS will be operational by 2050 e.g., in The Netherlands. Furthermore, the current signalling system has reached its limitations. Therefore, the ambition is to accelerate the roll out of ERTMS and to be completed by 2040. In addition, the associated track work is typically hard both physically and mentally. The work is typically carried out at night when the amount of traffic is low. The equipment used by trackworkers is heavy and powerful. The work method requires track workers to bend over or work on their knees. The IM wants to find a solution to lower the impact on their workforces.

Image / Diagram

Description:	The objective of this use case is to integrate the current technologies and combine it for rail related purposes in order to ensure automated installation of ERTMS balises and axle counters. It will demonstrate how the current state of technology benefits from its application and how future robots could enhance that.
How Does Solution Address Problem Statement:	Robots can work any time to accelerate the deployment of ERTMS balises. By replicating the robots, the system can be even more efficient without engaging additional human workforces. In addition, robots are powerful and able to manoeuvre and position themselves. Therefore, robots can do heavy repetitive work for the installation. The use case aims to mount the ERTMS balise and axle counter on the track. Operators will be relieved from lifting any heavy equipment or handling powerful tools.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Robotics		This use case does not share information outside of this WP

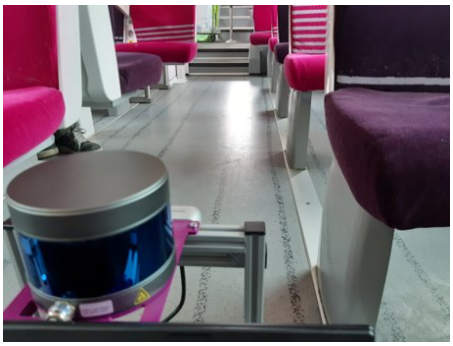
Demonstration Method:	Location:	Facilities:	Date:
Field test and report	In The Netherlands (located in one of the 8 sections where ERTMS installation will be deployed)	ERTMS compact eurobalise mounted on concrete sleepers common in Dutch network. Axle counter Thales mounted on 54E1 rail, most common rail profile in Dutch network. A connection to exchange design and build information of the assets installed with the robot and to navigate between the installed assets.	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X	X			
Anticipated FP3-IAM4RAIL TRL:							X	

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.4	18.4.3	UC ID:	18.3
			Int. Demo	
			Leading Partner	FERROVIE DELLO STATO ITALIANE SPA (FS)

UC Name:	**Disinfection of trains and small stations**
Type:	High-tech automated solutions for inspection and interventions
Problem Statement:	The overall problem to be solved by the Infrastructure Manager (IM) and the Railway Undertaking (RU) with a disinfection robot is to ensure a safe, well-automated and monitored way to apply sanitation processes within railways environments - such as trains or stations – in order to better face potential needs from the global community (from basic hygiene to pandemic crises). The sanitation processes need to be carried out on regular intervals, at stations possibly during operation hours, in a costs and resources effective way.

Image / Diagram



Description:

A mobile robot devoted to the disinfection in Railway's environments (inside the rolling stock and inside stations) is an unmanned robotic system for intervention. It will be remotely supervised or fully autonomous with appropriate sanitation technologies aimed at sanitising environments in an effective manner.
In order to be able to disinfect a train or a station, the robot must be able to handle the following sub-problems:

1. **Move without issues inside the target environment**: the idea is that the robot must be able to do a full sweep in the train or in the small station without the intervention of a human (except potentially to bring the robot inside and outside the train). Because the project is aiming at TRL6, it would be accepted that it might need a human intervention once out of five times.

2. **Embark an effective disinfection technique that would not damage the environment**: depending on the chosen technology (chemical compound and/or UVC light), the efficiency and non-aggressiveness will be worked out through experts' opinion in lab and field tests (the best possible effort allowed by our TRL6 approach). The compatibility of the disinfectant must be ensured with the robot's sensors. It will be tested in the field.

3. **Ensure the absence of human beings in the area (the train or the small station)**: we will refer to the best standards of people detection. Because the target is TRL6, we'll investigate how the adoption of cross-methods will achieve high levels of detection.

If we are able to ensure that there is no human being present, then we can also solve the following issue: experience shows, when the train goes back to the garage or other infrastructures, people sometimes stay on it, which also causes problems on arrival, particularly in terms of safety for the passenger if they decide to return via the tracks. It is unclear how such situations could affect the operation of autonomous robot systems within parked trains.

How Does Solution Address Problem Statement:

A mobile disinfection robot can be useful for professional and safe sanitation of a large environment, where the process must complete in tight time constraints, such as stations and trains. Moreover, a sanitation robot can be suitable for smaller stations (without permanent staff) where the sanitation time is not a strict requirement but sending human sanitation teams is not practical for cost and travel time reasons.
Advantages in using a mobile platform with respect to static solution are represented by:

- **Simplicity** in reaching every point of the space to be sanitised.
- **Low disinfection time** in a working environment.

The advantages of having an autonomous robot vs no robot are:

- No requirement of a workforce to look after it (except maybe for the access to the train) so the operator can do another task or pilot several robots.
- As the robot operates in a closed system without human presence, this reduces exposure to risks (since the chemicals are now only handled to "fill" the robot) or even eliminates it if we use UVCs.

This work can prepare for future work on cleaning.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Robotics		This use case does not share information outside of this WP

Demonstration Method:	Location:	Facilities:	Date:
Field tests and report	Near Paris, France OMC Osmannoro and Maintenance plants in Rome Poland	Z50 000 train in SNCF factory FSI facilities TBD where in Poland	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.4	18.4.4	UC ID:	18.4
			Int. Demo	
			Leading Partner	FERROVIE DELLO STATO ITALIANE SPA (FS)

		Image / Diagram
UC Name:	**Train Underbody Inspection**	
Type:	High-tech automated solutions for inspection and interventions	
Problem Statement:	The overall problem to be solved by the Railway Undertaking (RU) is to ensure a greater level of safety for the whole passengers and personnel, while pursuing a parallel reducing of maintenance and material costs thanks to 4.0 technologies with respect to ordinary maintenance processes. The inspection gateways are very powerful in their perspective, but they are not flexible enough to match all types of traffic flow. In addition, the gate provides limited views of certain organs, for instance in the case of the train underbody. The RU needs complementary inspection solutions.	

Description:	ARGO (**A**utonomous inspection of **R**ollin**G** st**O**ck) will help the maintenance crew to inspect the train underbody. An inspection robot can be more flexible to changes in traffic flow than a gate. In the medium term, the arms that will be used to bring the cameras and other sensory organs to these difficult-to-access elements could also be used to carry out interventions (technical cleaning, etc).
How Does Solution Address Problem Statement:	The focus points of the whole activities around ARGO can be divided in HW & SW aspects. HW aspects to be pursued within a TRL 6 are mostly related to overcome mechanical constraints with respect to environment where it is going to operate. On the other hand, SW aspects are the most facing for achieving the goal of the project in getting a device which can make a real difference between classical TRL8/9 processes and novel ongoing innovation processes. Precisely, SW points mostly involve machine learning techniques in developing AI algorithms to increase the ARGO's attitude towards the training. Within a TRL6 level, the targeted measurable objectives which could be considered for training the robot, are summarised in the following maintenance tasks (they are possible examples): • Binary recognition of crucial components (present or absent). • Calculation of critical measurements for safety, such as: o thickness of pads; o thickness of brake disks; o state of relevant surfaces from the mechanical point of view. • Recognition of possible leaks of crucial components.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Robotics		This use case does not share information outside of this WP

Demonstration Method:	Location:	Facilities:	Date:
Field test and report	OMC Osmannoro and Maintenance plants in Rome Germany Netherlands	FSI facilities DB facilities NS facilities	M37

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:					X			
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.4	18.4.5	UC ID:	18.5
			Int. Demo	
			Leading Partner	VOESTALPINE RAILWAY SYSTEMS GMBH (vaRS)

UC Name:	**Automated fixed crossing repair**
Type:	High-tech automated solutions for inspection and interventions
Problem Statement:	Concerning the repair of a fixed crossing, build-up repair welding is an indispensable and proven method in order to extend the in-service lifetime of fixed manganese steel crossings. However, build-up repair welding of fixed crossings is a fully manual process so far. Considering the track closure time, the manual repair welding process itself, and the necessary preparatory and finishing work, such as grinding, crack testing or temperature control, the repair of fixed manganese steel crossings is overall a time-consuming and costly process.

Image / Diagram

Description:	In FP3-IAM4RAIL, “preparatory work for future (complex) developments” will give birth to components that will be useful for intervention robots. However, for the development, and in particular a crossing repair robot, preparatory work is necessary. The focus of this use case is on the approach of an automated repair welding process for fixed crossings and for the therefore necessary tools. The overall goal is the development of a functional welding platform as stationary solution together with the project partners for demonstration of the crossing repair in the laboratory (TRL 4).
How Does Solution Address Problem Statement:	Build-up repair welding of manganese steel crossings is a challenging process requiring expertise, especially concerning weld paths and temperature control. The development of a functional, non-mobile welding platform for an automated fixed crossing repair will therefore focus on the ability to perform a geometry scan and welding path generation on the one hand, and to monitor intermediate layer temperatures on the other hand. The scanning and repair welding will be performed completely autonomously by the robot. These features will be demonstrated in the laboratory (TRL 4) and this will lay the foundation for an automated repair welding process in track.

System Integration:		
“Label”:	Interfacing sub-task:	Interface:
Robotics		This use case does not share information outside of this WP

Demonstration Method:	Location:	Facilities:	Date:
Demonstrator in laboratory	Joanneum Research (Niklasdorf, Austria)	Dedicated welding installations and associated monitoring equipment	M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:			X	X				

Work package:	WP19 Task:	Sub-task:	UC detail	
WP19	19.4	19.4.2	UC ID:	19.1
			Int. Demo	
			Leading Partner	STRUKTON RAIL NEDERLAND BV (SRNL)

UC Name:	**Upper-body exoskeleton for worker's support in railway industry**
Type:	Maintenance operations
Problem Statement:	Musculoskeletal disorders in the work environment (WMSD) are the leading cause of sick leave in work accidents and occupational diseases. Overexertion, the leading cause of WMSD, is directly linked to the physical workload. In railway maintenance operations, WMSD is related to: - Building railway overhead lines & constructions creates heavy physical load on human body (shoulders & elbows in particular); - At great heights in rail platforms "above your head" and "in front of your body". Possible solutions can be found around specific machines & special tools to reduce physical load.

Image / Diagram

Description:	The problem will be addressed by developing a novel exoskeleton that will be able to support the operator's upper body during the execution of the most important maintenance tasks for the upper part of the railway infrastructure, such as bolt screwing/unscrewing and catenary maintenance. A novel exoskeleton with a passive structure will be developed, designed to be robust and thin, and compatible with other protective tools.. Besides, the exoskeleton will have the option to be scaled with active modules (compact devices with integrated actuators, energy source and electronics) that will easily snap in the passive structure to assist workers in managing heavy loads. The passive and active parts of the exoskeleton will result in the first hybrid exoskeleton in the market. To that end, new kinematics for improved mobility, new transmission reduction systems (more compact and lightweight), and novel snap-in solutions will be researched among many other technological solutions. These innovations will allow developing a new type of hybrid exoskeletons, closer to the real assistance needed in industrial applications.
How Does Solution Address Problem Statement:	Exoskeletons can support the operator in the execution of manual tasks in the railway industry with significant improvement of working conditions and safety, cost reduction, improved quality and higher accuracy of service. An exoskeleton specifically developed for the support of workers support during on track operations, that can reduce the gravity load of tools, relieve the physical load of arms and shoulders and be compatible with other protective equipment, so overall reducing the risk of the occurrence of Work-related Musculoskeletal Disorders (WMSDs).

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Exoskeleton		

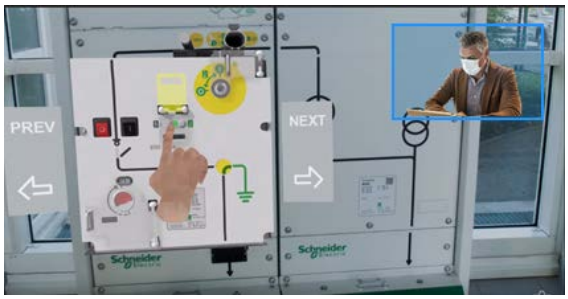
Demonstration Method:	Location	Facilities:	Date:
Validation of the new exoskeleton system in 4 testing scenarios and KPI measurement compared with current manual process.	The Netherlands (Strukton) Italy (Mermec) Italy (FSI) Poland (PKP)	Strukton working site Mermec working site Test Circuit of Bologna S. Donato Green Modular Station	M36, technology demonstrated in one site. M46, technology demonstrated in all sites.

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP19 Task:	Sub-task:	UC detail	
WP19	19.4	19.4.1	UC ID:	19.2
			Int. Demo	
			Leading Partner	RETE FERROVIARIA ITALIANA (RFI)

UC Name:	**Augmented Reality tools to help and guide railway workers in maintenance operations**
Type:	Maintenance operations
Problem Statement:	Currently, many technical operations performed by the maintenance team are primarily driven by experience gained in the field, and there are not always procedures that allow for easy detection of a failure. Technology should be developed to provide technical support such as: - Providing, when requested by the operator, electrical and mechanical schematics. - Guide troubleshooting by indicating a list of checks. - Providing a list of checks required before declaring the fault resolved and the asset re-commissioned. - Providing remote assistance in real-time by an expert.

Image / Diagram



Description:	Augmented Reality (AR) tools and technology will be developed to assist maintenance operators in remote and complex tasks. Author tools will be developed to easily provide content to the system, and both local and remote systems will be deployed open, modular and scalable.
How Does Solution Address Problem Statement:	The AR system will provide operators step by step guidance with the sequence and type of operations to be performed, and it will be able to assist them during the assembly/maintenance of each component of the system and make it operational in the shortest possible time. This will therefore allow to: - reduce the time and cost of preliminary training on assembly operations; - reduce maintenance times; - reduce the costs of travel of maintenance staff; - create truly usable digital manuals.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
AR		

Demonstration Method:	Location	Facilities:	Date:
Validation of the AR system and tools in 3 testing scenarios and KPI measurement compared with current manual process.	Netherlands (Strukton) Italy (Mermec) Italy (FSI)	Strukton working site Mermec working site Test Circuit of Bologna S. Donato	M36, technology demonstrated in one site. M46, technology demonstrated in all sites.

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		