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Deliverable D 2.6

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

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Report contributors		
Name	*Beneficiary Short Name*	*Details of contribution*
Marco Borinato	STS	Inclusion of summary, background and objectives in project template

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1. Executive Summary

The Scope of the D2.6 is to define a first 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.

In a second step, D2.7 and D1.4 will be issued at a later stage and respectively summarise in more detail, considering the Use Cases and the final KPIs report, the lessons learnt and identifying the way forward towards a TRL8/9 implementation of Intelligent Asset Management Systems (IAMS) within the organisations involved, trying to draw general conclusions from the experience of the Use Cases, demonstrators, and the different outcomes.

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	SIEMMENS
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 D2.6 “Definition of Use Cases, including Innovation, Business Assessment, KPIs definition and roadmap (first 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, 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 will be updated during the project, with the issue of a new Deliverable (D2.7 at M24) and will be used to present the different technical objectives targeted by the WPs, the current position and the foreseen impact on the railway industry. Each UC will define 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 ER – 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

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 Computerized 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 *optimizing 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 provided to the operator is generally poor and scarce (except for new systems that provide a dedicated diagnostic channel) and are often elaborated independently, instead merge 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 **suggests 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, tunnel entrances, level crossings) along the line. Specifically on this last point, it is envisioned **to use the current 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), 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 supports 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 5.1.1.1, currently the SCCM (Multistation Command and Control System) that is physically located at the central station, performs the functions of optimizing 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, ...) 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 manage 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 an "IN. RETE2000", 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 barriers 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

Wayside Signalling Equipment Monitoring System

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 continuous collection of 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, entrances to the tunnels, 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 setting appropriate threshold on each of the risk factors affecting the track and hence 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 satellite and to develop efficient procedure 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. Another example is related to people transiting or laying down occupying the level crossing passage. 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. 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 signal the availability of the passage. The hardware will allow stand alone and simultaneous detection, allowing Lidar and Radar to be used individually or simultaneously.

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 intervention 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 minimize the impacts due to maintenance interventions, increasing the quality of the service and guarantee regular and seamless connections.
The following functionalities shall be implemented:

- Visualizing the current assets state, highlighting any anomalies, and possibly providing assets status prediction.
- Visualizing, 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 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 with 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.

5.1.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

The development of 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 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 aim 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:

- Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50 %, in specific Use Cases;
- At least 20% of the TMS decisions will take into account the IAMS prescriptions.

To contribute to those high-level KPIs, the following specific KPIs are proposed for this Use Case:

- Reduction of speed restrictions on trains due to deteriorating asset condition.
- Reduction of infrastructural data management time, useful for TMS connection.
- Providing alarms to TMS in case of obstacles on the level crossing area.
- Corrective maintenance prediction.
- Reduction of service disruption.
- Data processing time.

5.1.2.2. KPI 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 of 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 KPI 1

The number of speed restrictions due to deteriorating asset condition 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.

$$KPI\,1\ (\%\ \text{speed restrictions}) = \frac{LTVn}{LTVt} x\ 100\ \%$$

Where:

- *LTVn* is the number of total speed restrictions in Line (the particular section examined) due to deteriorating asset condition with new maintenance strategy.
- *LTVt* is the number of speed restrictions in Line (the particular section examined) due to deteriorating asset condition with current maintenance strategy.

5.1.2.3. KPI2. – REDUCTION OF ON INFRASTRUCTURAL DATA MANAGEMENT TIME, USEFUL FOR TMS CONNECTION

Short description

The main objective of this KPI 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, tunnels, 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 foe activation of emergency procedure, mitigation actions.

How to compute KPI2

For the calculation of KP2, it is possible to estimate the time (man/hour) necessary for the management and selection of the data collected along the infrastructure (bridges, tunnels, 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:

$$KP2\ (\%\ time\ savings) = \frac{Time_{traditional\_method} - Estimated\ time_{new\_method}}{Time_{traditional\_method}} \times 100$$

Where:

- *Traditional Method Time* is the time required to perform the conventional data management.
- *Estimated time new method* is the time required to manage data after the application of the new approach.

If KP2 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 KP2 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:

$$KP2\ (\%\ cost\ savings) = \frac{Cost_{\ traditional\_method} - Estimated\ Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$$

Where:

- *Traditional Method Cost* is the cost required to perform the conventional data collection.
- *Estimated new method Cost* is the cost required to manage data after the application of the new monitoring approach.

If KP2 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 KP2 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. KPI 3. PROVIDING ALARMS TO TMS, VIA IXL, 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) that will take the subsequent decision regarding the specific logic implemented from the IM.

How to compute KPI 3

The obstacle detector will be tested on a trial site, in a representative environment and in different scenarios, with different type 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 KPI is trivial. In fact, when comparing the level crossing clarence assessment by visual inspection with its automated counterpart operated by the obstacle detector, it is clear how adoption of the obstacle detector results in a reduction of time communicating the line status to the TMS (more than 50% as per KPI). Equally, there would be a reduction of human intervention as visual inspection will be less demanded (more than 10% as per KPI).

5.1.2.5. KPI 4. CORRECTIVE MAINTENANCE PREDICTION

Short description

This KPI 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 KPI can be extended also to other fault modes if coherently described.

How to compute KPI 4

The evaluation of the KPI 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.

$$KPI4 = \frac{Sensitivity + Specificity}{2}$$

Where:

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

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

5.1.2.6. KPI 5. Reduction of service disruption

Short description

This KPI 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 KPIs is dependent on the availability of maintenance intervention planned and implemented to be used as a reference.

How to compute KPI 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

$$KPI5 \; [\%] = \left(\sum_{t=1}^{W} \frac{(\# \; corrective\_before_t - \; \# \; corrective\_after_t)}{\# \; corrective\_before_t} \right) * \frac{100}{W}$$

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, and 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. KPI 6. DATA PROCESSING TIME

Short description

Time required for 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 visualization on the HMI.

How to compute KPI 6

Several input data coming from the different assets monitored is processed, analysed and visualized 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.

$$KPI6 \; = \; time \; of \; single \; datapoint \; processing < 10 \; s$$

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

5.2.1. Overall aim of the Use Case

5.2.1.1. PROBLEM TO BE SOLVED

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 on the railway infrastructure are destined to the maintenance of assets.
These assets, highly linked to signalling, are located and controlled from the ADIF command centers, 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 centers 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 center 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.
For this reason, it is necessary to obtain innovative technological solutions that allow the application of a predictive maintenance strategy in diversion devices and detect structural damage in early stages and at level crossings. The implementation of predictive maintenance would lead to advantages such as:

- Planning better maintenance;
- Reduce downtime;
- Reduce and adjust maintenance costs;
- Lifetime extension;
- Make better use of work intervals.

The implementation of this predictive maintenance in the assets is expected from this project and 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

At ADIF, as previously mentioned, we assume that asset reviews are not carried out predictively, anticipating the possibility of asset failure, but rather via preventive maintenance (periodic inspections), as well as maintenance corrective, if the asset has already failed.
Achieving predictive maintenance is very important because it would accomplish, first, a significant cost reduction, since only what is necessary would be replaced, not as it’s currently being done, which is done periodically or when the part has failed. In the case of acting on the

railway asset once it has failed, it has the disadvantage of affecting rail traffic, so it is necessary to work in this direction in order to achieve economical and effective maintenance.
In addition, circulation control centers receive no information about the asset except whether it is working or not, which increases work time intervals and response time.

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 the 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 broken barrier is the most common failure of this type of equipment due to the environmental conditions in which they work (vibrations, adverse weather conditions, vandalism, ...). In addition, it provokes the trains to stop, causing serious delays in train operations.
As indicated in 5.2.1.1, we assume that reviewing level crossing barriers is not carried out predictively to anticipate the possibility of asset failures, but rather as a 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 operations to adapt them to different scenarios.

Unmanned System Data Acquisition - Switches monitoring system

To design and implement an unmanned and non-supervised data acquisition system. Leveraging on S2R TD2.10 Smart Wayside Objects Controller, data acquisition will be developed with new, more accurate and cost-effective inspection systems based on sensors, IoT and exogenous gathering that will enable the development of unmanned and no supervised asset diagnostic and self-diagnostics for condition monitoring of wayside solutions.
More specifically in the scenario of the switches, as sensitive elements with high impact in the operation, safety and investments, to early detect and predict defects and damages in the elements of the switch (structural, obstacles, etc) that prevent the element from its normal operation, increasing its availability as well as to optimise the maintenance and lifetime.
The most common failures in high-speed lines are: the break of the lock bars of the point machines of the points due to the vibrations and its own movements; and the slack in the "locks" to closure.
The relevant information for TMS is the availability of the switches due to the high impact in the train operation. As a counterpart for the analysis of the condition, it will be analysed if additional parameters provided by the TMS would be relevant.
Link with other WPs:

- WP8: the Unmanned Data Acquisition System contributes to the holistic asset management developed in the WP8 scope.

Asset Status Forecasting System

The use of sensitization using SWOC capabilities and integration through the EULYNX (SDI-P), allows a standard integration of the new measures in the platform. To integrate and process the new information for self-diagnostics, providing it over for the data analysis in collaboration for T4.1 and enabling TMS exchange and holistic asset decisions.

Using AI technologies, the information acquired from the sensors and stored in the AIM will be processed to detect erroneous operating patterns and make predictions of possible problems. This will allow to plan maintenance and changes in the operation that reduce the impact of the problem before it occurs.

Decision Support System for Optimised Maintenance Scheduling

With the data provided by the sensor networks stored in the AIM and with the information provided by the TMS, the AI system will perform an analysis and will be processing to infer the state of the elements and will be able to extract relevant information that can provide additional information of the status to the maintenance team.

Integration of Analytics with TMS

With the data provided by the TMS and the sensor networks stored in the AIM, the AI system will perform an analysis and will be processing to infer the state of the elements and will be able to extract relevant information that can help the maintenance work and provide additional information of the status 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 alone the Spanish railway network.

Such innovative system allows a 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 to optimise the operation (TMS).

Unmanned System Data Acquisition

The Unmanned System has a direct influence in the more than 15,000 switches of the railway network in Spain, as well as sensitive components in the operation and destination of high investments for maintenance.

Such as innovative system allows a predictive maintenance and the detection of damages in early stages, providing new and additional information for the optimization of the operation (TMS), the optimization 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 aim 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:

- Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50 %, in specific Use Cases;
- At least 20% of the TMS decisions will take into account the IAMS prescriptions.

We have decided that we are going to leave the KPIs that we include and that are included in the Grant Agreement and that, since they are the minimum necessary, we would prefer not to commit to more KPIs for now, given the very early phase of the project in which we are. As we move forward, we are open to include more KPIs.

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 Cluster C 21 Use Cases are listed in Table 2.

UC ID	Title	Relevant WP/DO
5.1	Bogie Monitoring System (on-board)	WP5/DO2
5.2	Health Monitoring & Analytics of HVAC & Brakes systems (ES)	WP5/DO2
5.3	Health Monitoring & Analytics and ML algorithms development of HVAC, Sanitary Systems & Brakes, Traction & auxiliary system (NL)	WP5/DO2
5.4	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries & Brakes (ES)	WP5/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-3D images, video and laser)	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 3D images)	WP7/DO2
7.4	Railway checkpoint use case (ES)	WP7/DO2
7.5	Railway checkpoint use case (NL)	WP7/DO2
7.6	Data path diagram use case	WP7/DO2
7.7	Data Analytics for Railway Checkpoints use case	WP7/DO2
7.8	Optimization of rolling stock maintenance use case	WP7/DO2
7.9	CBM algorithms for freight	WP7/DO2

Table 2: Cluster C Uses Cases

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

6.1.1. Overall aim of the Use Case

6.1.1.1. PROBLEM TO BE SOLVED

Deliver information about health status of the bogie components in order to enable condition based maintenance, 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 applying also other types of sensors than accelerometers (e.g.: on-board acoustics);
- Identifying potentials for combining different sensor signals (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 for the bogie components based on time and/or mileage fixed intervals. The current practise is not economically optimised because the components are exchanged/replaced before the end of their lifetime. There is a risk that the component failure may happen between 2 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 analogic variables together with system alarms and other non-vehicle-based data sources.

- Identify monitoring strategies by simulation defining physical parameters suitable to detect wear/defects on main bogie components;
- Identify most promising monitoring technologies during roller rig tests focussing mainly on the drive (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.

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 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 (PM) which can be considered as an extension of CBM.

6.1.2. UC5.1: demonstrator's KPI

6.1.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The following KPIs are reported in the GA:

- **KPI II:** (AM & Rolling Stock) - Asset Management of Rolling Stock Operation, including specific solutions for freight): reduction of maintenance costs up to 10% in specific use case;
- **KPI III:** (AM & Rolling Stock): 25% reduction of in-service failures;
- **KPI IV:** (AM & Rolling Stock): increasing rolling stock availability respective reducing workshop downtime targeting 10% in specific Use Cases.

6.1.2.2. LIST OF OWN KPIs

The following KPIs will be calculated for the UC5.1:

- **KPI 1:** Number of components / assets that could be monitored with each sensor;
- **KPI 2:** Accuracy (of detecting faulty components);
- **KPI 3:** Reduction of in-service failures.

6.1.2.3. KPI1 – NUMBER OF COMPONENTS THAT COULD MONITORED WITH EACH SENSOR

Short description

Nowadays, for the monitoring of bogie components normally at least 1 sensor per component is needed. This leads to a high number of sensors resulting in high costs. The intention of this work package is to find ways to reduce the number of sensors that means that 1 sensor can monitor different components at the same time.

How to compute KPI1

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

6.1.2.4. KPI2 – 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 KPI1

For binary classification, accuracy can be calculated using the following formula.
Accuracy = (TP + TN) / (TP + TN + FP + FN)
TP: True Positive
TN: True Negative
FP: False Positive
FN: False Negative

6.1.2.5. KPI3 – REDUCTION OF IN-SERVICE FAILURES

Short description

Without condition monitoring, there is a risk that in-service failures occur leading to the situation that the effected trains get stuck on the line. By applying condition monitoring, the number of failures can be reduced.

How to compute KPI3

$$KPI_3\ (in\ \%) = \frac{Number\ of\ failures_{current\ maintenacne\ strategy} - Number\ of\ failures_{new\ maintenance\ strategy}}{Number\ of\ failures_{current\ maintenacne\ strategy}} \times 100$$

Where:

- $Number\ of\ failures_{current\ maintenacne\ strategy}$ is the number of failures in service in the current maintenance strategy
- $Number\ of\ failures_{new\ maintenance\ strategy}$ is the number of failures in service in the new maintenance strategy

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

6.2.1. Overall aim of the Use Case

6.2.1.1. PROBLEM TO BE SOLVED

The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures,* using systems with different drivers for optimization and with specific scope in on-board system. Examples are:

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

6.2.1.2. INDUSTRY CURRENT POSITION / BASELINE

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

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

6.2.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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. However, the selected solution may not reach TRL9 maturity. A possible instance of deviation from TRL5/6 could involve prototyping the inclusion of extra sensors or utilizing "off-the-shelf" data acquisition and IoT/edge devices, which might later be integrated into dedicated new devices in a subsequent stage.

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 optimize 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

Correlating KPIs on FP level from Grant Agreement to which this use case contributes to, are the following:
- Reduction of maintenance costs up to 10%;
- 25% reduction of in-service failures.

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.

6.2.2.2. KPI1 – REDUCTION OF MAINTENANCE COST

Short description
This KPI 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 KPI1

The KPI is mainly computed by measuring the following factors:

- Reduction in Cost of working hours;
- Reduction of Cost of spare parts.

The calculations can be done as follows:

$$KP1.1\ (\%\ material\ savings)\ = \frac{Material\ cost\ _{current\_method} - Estimated\ Material\ Cost_{new\_method}}{Material\ Cost_{current\_method}} \times 100$$

Where:

- *Current Method material cost* is the cost associated with the current material needed.
- *Estimated new method material cost* is the cost associated with predicted material need with the new monitoring and data analysis.

$$KP1.2\ (\%\ time\ savings)\ = \frac{Time_{current\_method} - Estimated\ time_{new\_method}}{Time_{current\_method}} \times 100$$

Where:

- *Current Method Time* 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. KPI2 – 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 KPI concerns at 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 KPI2

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:

$$KP2.1\ (\%\ Reliability\ Improvement)\ = \frac{Reliability_{current\_method} - Estimated\ Reliability_{new\_method}}{Time_{current\_method}} \times 100$$

Where:

- *Current Method reliability* is the cost associated with current maintenance strategy.
- *Estimated new method reliability* is the reliability expected with the new monitoring and data analysis.

One way to estimate the reliability, is 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.
A more direct way of estimating 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.

6.3. UC 5.3: Health Monitoring & Analytics and ML algorithms development of HVAC, Sanitary Systems & Brakes, Traction & auxiliary system (NL)

6.3.1. Overall aim of the Use Case

6.3.1.1. PROBLEM TO BE SOLVED

The use case shall serve the RU specifically in the *reduction of maintenance costs* but also in the *reduction of in-service failures,* using systems with different drivers for optimization and with specific scope in on-board system. Examples are:

- HAVC: filter lifetime, compressor lifetime, refrigerant level and status;
- Brakes: wear of friction material, compressor lifetime and status;
- Sanitary Systems: freshwater level, waste water level, wear and tear of vacuum sanitary system;
- Traction & auxiliary system: detect failure in the early stage avoiding service interruptions. Also includes a DT (digital twin) for on-board energy consumption being able to detect anomalies and simulate scenarios to optimise the energy consumption.

6.3.1.2. INDUSTRY CURRENT POSITION / BASELINE

Current maintenance activities or the RU are largely based on fixed maintenance intervals and corrective maintenance today. There is usually little real time information available regarding the different assets to support informed decisions about interventions and predictive maintenance. The selected systems play a significant role in contributing to maintenance efforts of the RU.

6.3.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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. However, the selected solution may not reach TRL9 maturity. A possible instance of deviation from TRL5/6 could involve prototyping the inclusion of extra sensors or utilizing "off-the-shelf" data acquisition and IoT/edge devices, which might later be integrated into dedicated new devices in a subsequent stage.

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 optimize 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

Correlating KPIs on FP level from Grant Agreement to which this use case contributes, are the following:

- Reduction of maintenance costs up to 10%
- 25% reduction of in-service failures

The use case aims at contributing to both of these 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.

6.3.2.2. KPI1 – REDUCTION OF MAINTENANCE COST

Short description

This KPI 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 KPI1

The KPI is mainly computed by measuring the following factors:

- Reduction in Cost of Working hours;
- Reduction of Cost of Spare parts.

The calculations can be done as follows:

$$KP1.1\ (\%\ material\ savings) = \frac{Material\ cost\ _{current\_method} - Estimated\ Material\ Cost_{new\_method}}{Material\ Cost_{current\_method}} \times 100$$

Where:

- *Current Method material cost* is the cost associated with the current material needed.
- *Estimated new method material cost* is the cost associated with the predicted material needed with the new monitoring and data analysis.

$$KP1.2\ (\%\ time\ savings)\ = \frac{Time_{current\_method} - Estimated\ time_{new\_method}}{Time_{current\_method}} \times 100$$

Where:

- *Current Method Time* 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. KPI2 – 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 KPI looks at the availability and reliability of the assets in scope. By measuring improvements in these values, we can quantify the reduction of in-service failures.

How to compute KPI2

Availability, also known as operational availability, is expressed as the percentage of time that an asset is operating, compared to its total scheduled operation time.
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.

The improvement of these aspects can be measured as follows:

$$KP2.1\ (\%\ Availability\ Improvement) = \frac{Availability_{current\_method} - Estimated\ Availabilty_{new\_method}}{Time_{current\_method}} \times 100$$

Where:

- *Current Method availability* is the cost associated with current maintenance strategy.
- *Estimated new method availability* is the availability expected with the new monitoring and data analysis.

$$KP2.2\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current\_method} - Estimated\ Reliability_{new\_method}}{Time_{current\_method}} \times 100$$

Where:

- *Current Method reliability* is the cost associated with current maintenance strategy.
- *Estimated new method reliability* is the reliability expected with the new monitoring and data analysis.

These general KPIs 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. UC 5.4: Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries & Brakes (ES)

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 data from the HVAC, doors, and brake systems of the Euskotren fleet, which 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 preventive maintenance, 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 predictive maintenance.

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 we are starting 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 optimize 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, predictive maintenance optimises the use of resources, increases efficiency, and enhances safety while reducing costs.

6.4.2. UC5.4: demonstrator's KPI

6.4.2.1. List of KPIs and related justification for the choice

Analysing the Grant Agreement, the following KPIs have been identified as related to this Use Case:

- Reduction of maintenance costs up to 10% (10% is the estimated target)**;**
- Reduction of in-service failures up to 25% (25% is the estimated target).

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.

6.4.2.2. KPI1 - 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 KPI1

$$KPI_1\ (in\ \%) = \frac{Maintenance\ cost_{current\ maintenacne\ strategy} - Estimated\ Maintenance\ cost_{new\ maintenance\ strategy}}{Maintenance\ cost_{current\ maintenacne\ strategy}} \times 100$$

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. KPI2 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 can result in mission cancelation delays... In-service failures can be caused by a variety of factors including wear and tear of components, environmental factors. To report an impact on Inservice failures the calculation can be done comparing the level of in-service failures before and after the change of the maintenance strategy.

How to compute KPI2

$$KPI_2\ (in\ \%) = \frac{Estimated\ in\!-\!service\ failures_{\ current\ maintenance\ strategy} - Estimated\ in\!-\!service\ failures_{new\ maintenance\ strategy}}{Estimated\ in\!-\!service\ failures_{\ current\ maintenance\ strategy}} \times 100$$

Where:

- $Estimated\ in - service\ failure\ _{current\ maintenance\ strategy}$ is the estimated disruptive failures based on an FMECA using the current maintenance strategy
- $Estimated\ in - service\ failures_{new\ maintenance\ strategy}$ 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

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

6.5.1. Overall aim of the Use Case

The final goal of this UC 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 to that, the target is to be able to predict as much as possible traction failures before they occur. The aim is to increase service availability.

6.5.1.1. PROBLEM TO BE SOLVED

Tomorrow's powertrains must make use of predictive maintenance data to reduce possession costs by optimizing the number of maintenance operations on customer side and minimise equipment redundancies during design on manufacturer side – which could lead to reduce acquisition 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 theses 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.

6.5.1.2. 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, it leads to an insane wiring system inside the traction cubicle. Moreover, this kind of solution highly increase 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.

6.5.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The Use Case target is to evaluate the capability of the proposal. Indeed, we need to define if with our new architecture we can drive semiconductors for traction purpose at the same time we monitor them for traction component health management.
For semiconductors, the state of 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 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.
For the 2nd CALL, to allow this information (semiconductor manufacturer junction temperature measurement sensing) to be used by traction smart maintenance algorithms (located in traction control electronics), there is a need of being able to connect semiconductor thermal sensors to traction control electronic with a minimum 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).

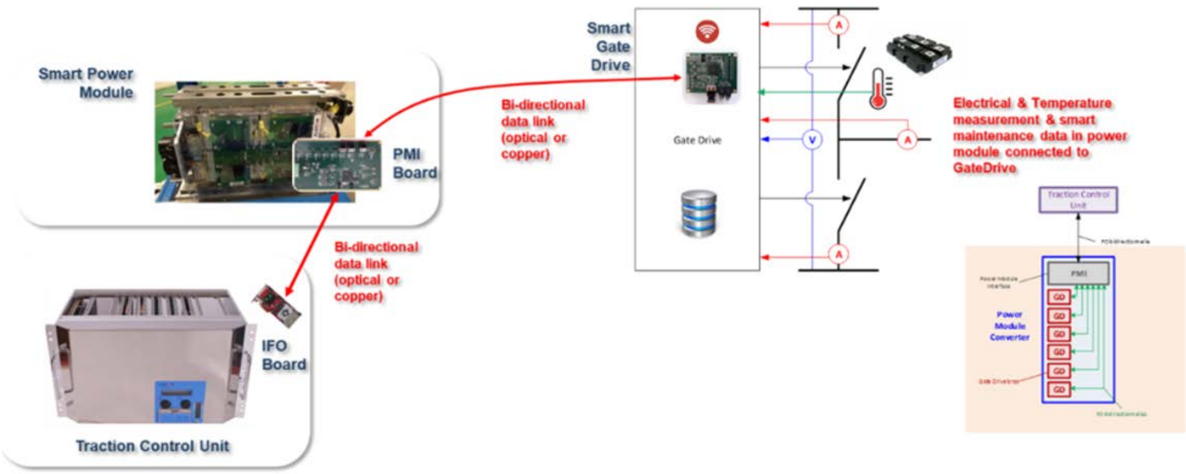


Figure 1: Traction control unit hardware and gate drive communication link

6.5.1.4. 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 a fixed step). 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 him to build its train fleet maintenance plan according to traction purposes.

6.5.2. UC6.1: demonstrator's KPI

6.5.2.1. LIST OF KPIs AND RELATED JUSTIFICATION FOR THE CHOICE

This uses case matches with 1 KPIs:

- Increase the number of monitored subsystems.

These technologies allow to add to the train component monitoring table the semiconductors, the switchgears, the bearings, the heat exchangers...

6.5.2.2. KPI1 – INCREASE THE NUMBER OF MONITORED SUBSYSTEMS

Short description

For predictive maintenance, the more subsystems are monitored, the better the failures can be predicted. The increase of monitored subsystem number is simply the number of new measured signals dedicated to smart maintenance.

How to compute KPI1

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

$$\eta = N_w - N_o$$

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.

6.6. UC6.2: Traction Component Health Monitoring & predictive Maintenance

6.6.1. Overall aim of the Use Case

The final goal of this UC 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 to that, the target of this UC is to be able to predict as much as possible traction failures before they occur. The aim is to increase service availability.

6.6.1.1. PROBLEM TO BE SOLVED

Tomorrow's powertrains must make use of predictive maintenance data to reduce possession costs by optimizing the number of maintenance operations on customer side and minimise equipment redundancies during design on manufacturer side – which could lead to reduce acquisition 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.

6.6.1.2. INDUSTRY CURRENT POSITION / BASELINE

The current situation is that 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 observe 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.

6.6.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 in 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.
For the 2nd CALL, to allow this information (semiconductor manufacturer junction temperature measurement sensing) to be used by traction smart maintenance algorithms (located in traction control electronics), there is a need of being able to connect semiconductor thermal sensors to traction control electronic with a minimum 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 accomplish deep hardware changes in the control

electronics to make it compatible with this Big Data strategy (this is the concern of WP6-task 6.4.3).

Figure 2: estimator for semiconductor junction temperature

6.6.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Thanks to this innovation proposed within 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 a fixed time step). 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 its train fleet maintenance plan according to traction purposes.

6.6.2. UC6.2: demonstrator’s KPI

6.6.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

This use case matches with 3 KPIs:

- Maintenance costs reduction:
  - Indeed, as it allows to predict maintenance path, it will reduce maintenance operation to the „just enough” level (which means less useless operations)
- Increase service availability:
  - Since failures in operation will become more predictable, they could be avoided. This entails more reliable services
- Increase the number of monitored subsystems:
  - These technologies allow to add to the train component monitoring table the semiconductors, the switchgears, the bearings, the heat exchangers.

6.6.2.2. KPI1 – MAINTENANCE COSTS REDUCTION

Short description

The reduction of maintenance costs KPI is an estimation of the savings due to 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 KPI1

The estimation of the savings on maintenance costs must be done for each listed component shown above. These savings are the price difference between the preventive maintenance 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 preventive maintenance 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 summarized with the following formula:

$$\eta = (N_p - N_d)c_p$$

- 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

6.6.2.3. KPI2 – INCREASE OF SERVICE AVAILABILITY

Short description.

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

How to compute KPI2

This KPI can be calculated according to the following formula:

$$\eta = \frac{\tau_f}{\tau_0}$$

Where:

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

6.6.2.1. KPI3 – INCREASE THE NUMBER OF MONITORED SUBSYSTEMS

Short description
For predictive maintenance, the more subsystems are monitored, the best the failures can be predicted. The increase of monitored subsystem number is simply the number of new measured signals dedicated for smart maintenance.
How to compute KPI3
To compute this KPI the formula to use is the following one:

$$\eta = N_w - N_o$$

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

6.7.1. 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 virtualization and isolation techniques, the single physical communication infrastructure will be split into three virtual infrastructures to support three service types (control, command, and signalling; train control and monitoring; operator-oriented services) 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".

6.7.1.1. PROBLEM TO BE SOLVED

The telecom infrastructure deployed on board is currently wired and suffers maintenance issues due to mechanical efforts underwent at inter-carriage and inter-consist levels on cables and connectors.
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 is: considering on the fly inter consist virtual coupling at 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 here after:

- To be able to operate “on the fly” coupling (speed ~100km/h);
- To maintain high speed coupling (from 120 km/h at minima up to 320 km/h);
- To be able to define train composition;
- To avoid coupling with consists that should not be coupled;
- To avoid interferences between trains on adjacent tracks;
- To be resilient to interferences;
- To demonstrate a complete traffic flow isolation in between the different on-board networks (generation of overflow on one of the service types on the embedded network doesn’t impact higher safety level service types 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).

6.7.1.2. INDUSTRY CURRENT POSITION / BASELINE

In 90’s IEC-61375 TCN standard was proposed. At this time, the Train Control and Monitoring System (TCMS) was based on 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 had been replaced by Ethernet based networks (Ethernet consist network- ECN and Ethernet Train Backbone - ETB).

However, some important issues remain despite the increase of the throughput and the costs reduction, as the TCMS complexity, the consuming times (subsystem integration, commissioning, maintenance).

6.7.1.3. 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.

6.7.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

The objective of the use case is to provide a solution for coupling (inter-consist 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).

6.7.2. UC6.3: demonstrator's KPI

6.7.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

To contribute and justify the choice of the telecom technology for this use Case, the below KPIs are proposed. However, as the first deliverable of this project is to define "the users and functional specifications" hence the KPIs will be listed for this solution, the list of KPIs could be changed and new ones defined instead.
Here is the list of KPIs:

- Coupling Time & distance;
- Usual IP Metrics (Throughput, jitter, E2E Delay, PER …).

Additional KPIs could be identified.

6.7.2.2. KPI1 – COUPLING TIME & DISTANCE

Short description
The main objective of this KPI is to evaluate the time and the distance (directly linked to the time consuming for human operational) 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 KPI1
There is currently no formula for this KPI as the coupling, as of today, is only performed while trains are initially stopped.
This KPI 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.

6.7.2.3. KPI2 – 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 KPI2
Theses KPIs 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...)
- …

6.8. UC6.4: Adhesion estimation for management

6.8.1. Overall aim of the Use Case

The Use Case Adhesion estimation for management aim to design methods to estimate/measure the COF in real-time under real operation conditions to determine at every instant, 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 others) in increasing service availability and optimal capacity.

6.8.1.1. PROBLEM TO BE SOLVED

Properly estimating the value of the Coefficient of Friction (COF) is critically important for traction and braking and the minimization of wear, deformation, and rolling contact fatigue of rail and wheel. The increasing importance of rail transport in 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 wheel-rail changes with humidity, contamination/lubrication, roughness, the stress in the contact area, among factors.

6.8.1.2. 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. More advanced train-borne COF measurement methods can be developed with the technological development in the past 50 years in understanding and quantifying wheel-rail frictional rolling contact and sensing, data processing, identification, control, and actuation.

6.8.1.3. 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 estimating the traction/braking force from the relation between the electricity used/generated by the traction motor and the corresponding driving/resisting torque the motor generated. At the same time, methods to estimate the corresponding creepage of the wheel-rail rolling contact are being further developed. 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.
This system is first going to be tested in the V-Track test rig (1:7 – 1:5 scaled)[1] . In the framework of the ERJU, the target is to develop the method on trains in collaboration with rolling stock manufacturers. This will make possible in the future the actual deployment of 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.

6.8.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

In IN2TRACK3 project, adhesion estimation methodologies were conducted by simulation and lab tests (TRL3-4). In the FP3-IAM4RAIL project, we aim to further work on the development of the

[1] Naeimi M., Li Z., Petrov R., Sietsma J. and R. Dollevoet R. (2017). Development of a new downscale setup for wheel-rail contact experiments under impact loading conditions, Experimental Techniques (2018) 42: 1 – 17, https://doi.org/10.1007/s40799-017-0216-z

techniques on trials by simulation, lab tests and use of real-life data. The inclusion of actual characteristics of rolling stocks is a major challenge and to realised how the developed techniques can be apply for test experiments in the field.

6.8.2. UC6.4: demonstrator's KPI

6.8.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

In the demonstrator #2 Asset Management and Rolling Stock, we aim to contribute to the increase of service availability by reduction of in-service failures/faults by the development of algorithms for adhesion estimation.

6.8.2.2. KPI1 – IN-SERVICE FAILURES

Short description
From the KPIs about AM & Rolling Stock, this technology will have its major contribution to in-service failure, as when the technologies are implemented, the correct COF will allow for instance to estimate the accurate breaking distances, and thus, increasing safety and optimize better the railway capacity. New technologies such as ATO will also benefit from this innovation.
KPI 1 (AM & Rolling Stock): 25% reduction of in-service failures.
How to compute KPI1
Here are the measurable elements that will be used to measure KPI's:

- Accuracy of the traction/braking force from the relation between the electricity used/generated by the traction motor and the corresponding driving/resisting torque the motor generated;
- Accuracy of the estimation of the corresponding creepage of the wheel-rail rolling contact;
- Accuracy of the estimation of COF under controlled experimental conditions.

6.9. UC6.5: Wayside signalling equipment monitoring system

6.9.1. Overall aim of the Use Case

6.9.1.1. 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.

6.9.1.2. INDUSTRY CURRENT POSITION / BASELINE

Historically, railway cybersecurity issues have not been a priority, allowing for a scenario with limited or absent 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.

6.9.1.3. 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.

6.9.1.4. 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.

6.9.2. UC6.5: demonstrator's KPI

6.9.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

This uses case matches with 2 KPIs:

- Increasing compliance with current relevant industry cyber security standards such as ISA62443 or TS50701;
- Reduce the likelihood and consequences of the top ENISA threats.

6.9.2.1. KPI1 – 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 KPI1

Support at least a 15% of the cybersecurity requirements (SR) indicated in ISA62443-3.2 in the security level 3 (SL-3). There are 90 security requirements in Security Level 3.

6.9.2.2. KPI2 – 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 materialises or to contain the effects once it has materialised.

How to compute KPI2

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.

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

6.10.1. Overall aim of the Use Case

6.10.1.1. 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 or more trains operating in Germany. Intelligent algorithms shall be implemented to the bogie diagnostic solution enabling the detection of faulty bogie components.
Together with the train operator and the maintainer the benefits of this bogie diagnostic solution shall be elaborated and shall be maximized.

6.10.1.2. 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.

6.10.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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

6.10.1.4. 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.

6.10.2. UC6.6: demonstrator's KPI

6.10.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

- KPI1: Successful application of SMO bogie diagnostic solution to at least one train operating in Germany
- KPI2: Integration of the results of SMO bogie diagnostic solution into the maintenance process

6.10.2.2. KPI1 – APPLICATION OF SMO BOGIE DIAGNOSTIC SOLUTION

Short description

KPI1 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 KPI1

KPI1 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. KPI1 represents exactly this availability of results.

6.10.2.3. KPI2 – INTEGRATION OF RESULTS TO MAINTENANCE PROCESS

Short description

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

How to compute KPI2

KPI2 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.

6.11. 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.

6.11.1. Overall aim of the Use Case

6.11.1.1. 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.

6.11.1.2. 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 optimize them.

6.11.1.3. 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.

6.11.1.4. 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.
Analysing the energy consumption and building model, related anomalies can also be detected.

6.11.2. UC6.7: demonstrator's KPI

6.11.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The following KPIs are considered:

- KPI 1- Accuracy of the energy consumption model.
- KPI 2- Expected improvement in energy reduction.

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

6.11.2.2. KPI1 – ACCURACY OF THE ENERGY CONSUMPTION MODEL

Short description
The KPI will measure in terms of percentage how similar the energy consumption provided by the model is compared to the actual energy consumption.
How to compute KPI1
This KPI will be measured using real data of one of the NSR (Atlantic climate type) fleets. The actual energy consumption will be measured using these data. In addition to that, relevant data about how each train is being operated at particular point in time will be used to compute the energy consumption provided by the model. Then, both quantities will be compared.

6.11.2.3. KPI2 – EXPECTED IMPROVEMENT IN ENERGY REDUCTION

Short description
The KPI will measure the room for improvement regarding energy consumption the model
How to compute KPI2
This KPI will be measured using real data of one of the Dutch fleets. The actual energy consumption will be measured using these data. In addition to that, relevant data about how each train is being operated at particular point in time will be used to compute the energy consumption provided by the model. Then, both quantities will be compared. As long as possible, this reduction will be checked with actual data.

6.12. UC6.8: Smart maintenance scheduling tool

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

6.12.1. Overall aim of the Use Case

6.12.1.1. PROBLEM TO BE SOLVED

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, information coming from the different algorithms and data gathered from the fleet is dynamic in nature and its amount is vast, which make difficult to schedule and organize required maintenance tasks along with operational requirements. In this regard, an intelligent system able to handle this information is required to help operators to make sense of all this data and to decide which actions shall be taken. This will lead to a scenario in which the operators can exploit all the advantages and improvements of a condition-based maintenance program.

6.12.1.2. INDUSTRY CURRENT POSITION / BASELINE

Currently there is potential improvement in the asset management, and the way that the maintenance is schedule in the depots.
Also, in the warehouse management and its integration in the whole management.

6.12.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

In this use case a dynamic scheduler will be implemented. This dynamic scheduler will 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 optimizing multi-criteria objectives regarding cost and train availability.

6.12.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

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.

6.12.2. UC6.8: demonstrator's KPI

6.12.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The following preliminary KPIs have been identified:

- KPI1: % savings in maintenance cost.
- KPI2: Increase in fleet availability (%).

6.12.2.2. KPI1 – % 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 KPI will measure the savings in maintenance cost associated to the application of the Smart Maintenance Scheduling System in terms of percentage.

How to compute KPI1

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

6.12.2.3. KPI2 – INCREASE IN FLEET AVAILABILITY (%)

Short description

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

How to compute KPI2

This KPI will be measured 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-

6.13. UC7.1: Bogie Monitoring System (wayside – acoustic, 2D-3D images, video and laser)

Wayside acoustic data may carry information on the health condition of different bogie components. This use case has the potential to enhance the monitoring capability of the WP demonstrator, especially for bogie health monitoring.
This use case helps with the first main goal of the WP demonstrator; "collecting assets status data based on new data sources from multiple sensors and supported by common EU shared specifications". In this use case we will collect data from different technology sources, like video technology, train identification, noise technology and 3D scanning. Part of the works will be data capture from wayside technologies.

6.13.1. Overall aim of the Use Case

6.13.1.1. PROBLEM TO BE SOLVED

Train maintenance inspections on bogies are critical to avoid service disruptions due to failing trains. Currently, train maintenance inspections are done manually and periodically.
Rolling stock owners / maintainers 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, etc, 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.
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 the different technologies: acoustic, 2D-3D images, video and laser that allow to know the bogies' status.
This information can support the increase of security, the reliability, and the reduction of maintenance costs.

6.13.1.2. INDUSTRY CURRENT POSITION / BASELINE

Currently, 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 train service. This limits the potential of HABD for CBM.
Compared to temperature, acoustic data are capable of providing earlier indication for bearing potential failure. Thus, wayside acoustic monitoring is believed more attractive for CBM, in the sense that it wins more time for planning maintenance activities and resources. Currently, there are only very limited suppliers of wayside acoustic solutions for axle bearing monitoring.

6.13.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Wayside acoustic data may carry information on the health condition of different bogie components, not only limited to axle bearings. To study the potentials of wayside acoustic monitoring for further bogie components, the following sub-problems are expected to be addressed by the demonstrator.

- Perform tests with known degraded bogie components.
- Record wayside acoustic data and the related operational data (train number, train speed, axle no., etc.).
- Perform data analysis offline (in office) to check if the known component degradation can be detected.

6.13.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

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
  - Leakage
- Leaking shock absorbers
- Cables (loose/damaged/broken)
- Meta data (train type, location, timestamp etc.)

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

The proposed innovation has the following potential positive influences.

- For rolling stock owners / 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

6.13.2. UC7.1: demonstrator's KPI

6.13.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

It is suggested to consider 2 KPIs. KPI1 is more related with the field tests, while KPI2 is a high-level industry KPI which is defined in PRIME.

- KPI1: Accuracy (of detecting faulty bogie components)
- KPI2: Degree of network utilisation – all trains (KPI ID 92 in PRIME)

6.13.2.2. KPI1 – 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 KPI1

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

$$\text{Accuracy} = (TP + TN) / (TP + TN + FP + FN)$$

Where:

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

6.13.2.3. KPI2 – DEGREE OF NETWORK UTILISATION – ALL TRAINS

Short description.

Utilization is an essential measure of the performance of 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).

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

How to compute KPI2

This KPI is defined as the average daily train-km on main track related to main track-km.

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

This use case helps with the first main goal of the WP demonstrator; "collecting assets status data based on new data sources from multiple sensors and supported by common EU shared specifications".

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

6.14.1. Overall aim of the Use Case

6.14.1.1. PROBLEM TO BE SOLVED

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 critical work 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.
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.

6.14.1.2. INDUSTRY CURRENT POSITION / BASELINE

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 condition.

6.14.1.3. 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.

6.14.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

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).

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.

6.14.2. UC7.2: demonstrator's KPI

Not available in this stage.

6.15. UC7.3: General physical anomaly detection Monitoring System (wayside – video and 3D images)

Development, Monitoring, data collecting and data analysis. 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 determinate for example rolling stock exceeded gauges.

6.15.1. Overall aim of the Use Case

6.15.1.1. PROBLEM TO BE SOLVED

Train maintenance inspections for the detection of general physical anomalies, as example rolling stock exceeded gauges, are critical to avoid service disruptions or infrastructure damages.
Currently, train maintenance inspections are done manually and periodically. Within IAM4RAIL it will be possible to monitor the health of the assets without stop the train (so more availability and over maintenance reduction).

6.15.1.2. INDUSTRY CURRENT POSITION / BASELINE

Currently there are many tasks to maintain a good health in these systems, however sometimes with the current methodologies is easy to make over maintenance (so over costs) and is hard to always ensure the good condition for operation.

6.15.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The measurable objectives will be:

- video and 3D images*;*
- Data analysis.

6.15.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

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 result, we can expect increased availability and reduced maintenance requirements.

IM will be more safety because this system monitoring train performance and avoid any failure because it could be anticipated.

6.15.2. UC7.3: demonstrator's KPI

6.15.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The metrics proposed to measure the effective improvement in this use case are along the following lines:

- savings in effort spent on visual inspections of other elements or systems rather than pantograph and bogie;
- Volume of detected anomalies via new wayside inspection technologies.

6.15.2.2. KPI1 –EFFORT SPENT IN VISUAL INSPECTIONS

Short description
Dedicated hours per month, to perform visual inspections.
How to compute KPI1
KPI1 = Σ hours for visual inspection in a month

6.15.2.3. KPI2 – ANOMALIES DETECTED WITH NEW TECHNOLOGIES

Short description.
Number of anomalies detected with the new wayside inspection technologies.
How to compute KPI2
KPI2 = Σ detected defects via new inspection techniques.

6.16. UC7.4: Railway checkpoint use case (ES)

Railway checkpoint use case in Spain is the demonstrator that will be developed in two or three different locations in the Spanish Railway Network, taking into account cross-border, mixed traffic (passengers and freight), two gauges (Iberian and Standard) and conventional and High-speed trains.

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. These teams work 24 hours a day without failing and, most importantly, if they are connected to machine learning, continually learning 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 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 lathe maintenance or wheel replacement with a considerable level of precision.
At the same time, a significant reduction in preventive maintenance costs is expected, since the maintenance bands will be adjusted when necessary and will not be carried out by kilometres travelled, as has been done up to now.
Use case development level:

- CAF solution: it is in the prototype development phase;
- TALGO Solution: they are executing the civil works to install the equipment on the track.

6.16.1.2. INDUSTRY CURRENT POSITION / BASELINE

Currently all inspection work is 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 digitize these processes is through automated inspection solutions.
By storing this information in the cloud and utilizing an algorithm, decision about what to do with this train can be made; for example it will be possible to determinate whether to take the train out of the service and send it to re-profiling or change carbon band.

6.16.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The measurable objectives will be:

- Measurement of wheel parameters sh, sd and qr for safety purpose;
- Check it wheel tread status;
- Check it pantograph status: carbon band width;
- Measurement wheel diameter.

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.

6.16.2. UC7.4: demonstrator's KPI

6.16.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

Three significant KPIs, namely KPI1 - Wheel Defects, KPI2 - Wheel Profile Defects, and KPI3 - Pantograph Defects, have been identified to assess critical aspects of train performance and maintenance.

These KPIs serve as valuable tools for railway operators to optimize maintenance efforts as well as minimize safety risks.

6.16.2.2. KPI1 – WHEEL DEFECTS

Short description

Number of derailments per million of kilometres. The root cause for this derailment will be some failure in the wheel, this failure could be related to profile or tread. This KPI relates to PRIME KPI Catalogue.

How to compute KPI1

In this KPI1 we use the KPI number 7, in safety dimensions, significant accident, but this accident is due to a wheel profile issue.

$$KPI1 = \frac{\#\, number\ of\ derailments\ due\ to\ the\ wheel}{\#\, kilometers -\ train} \times 100$$

6.16.2.3. KPI2 – 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. In this way we save maintenance cost and workshop uses. This KPI relates to PRIME KPI Catalogue is Degree of network utilisation – all trains because if we have less train in workshop to re-profile, we have more train running on track with passengers.

How to compute KPI2

This KPI2 is related to KPI ID 62 Maintenance expenditures in relation network size,

$$KPI2 = \frac{\#\, number\ of\ reprofile\ km}{\#\, kilometers - train} \times 100$$

6.16.2.4. KPI3 – 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, it is 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 transport, since infrastructure maintenance costs will fall, and more reliable, since annoying and unpredictable hitches will not occur.
How to compute KPI3
This KPI3 is related to KPI ID 62 Maintenance expenditures in relation network size,

$$KPI3 = \frac{\#\, number\ of\ hook - ups}{\#\, per\ numer\ km - \ train} \times 100$$

6.17. UC7.5: Railway checkpoint use case (NL)

The description of this use case is not available in this stage of the project.

6.18. UC7.6: Data path diagram Use Case

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

6.18.1. Overall aim of the Use Case

6.18.1.1. 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 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, so that a quick implementation of CBM Use Cases is not possible.

6.18.1.2. INDUSTRY CURRENT POSITION / BASELINE

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

6.18.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Not applicable.

6.18.1.4. 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 concrete security requirement) are transparently highlighted at an early stage, thus preventing a show stopper 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).

6.18.2. UC7.6: demonstrator's KPI

6.18.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The KPI associated to this use case is the "Reduction of the timespan".

6.18.2.2. KPI1 – REDUCTION OF THE TIMESPAN

Short description

Reduction of the timespan for the implementation of safety relevant CBM Use Cases into the productive maintenance environment.

[Delta]ts = time saved from the beginning of handling the safety requirements for software components of the CBM DataPath until the finalization of the safety certification report

How to compute KPI1

[Delta]ts = ts0 – ts1

Where:

- ts0 = timespan from the beginning of handling the safety requirements for software components of the CBM DataPath until the finalization of the safety certification report ("Sicherheitsnachweis") – without making use of the generic safety case methodology.
- ts1 = timespan from the beginning of handling the safety requirements for software components of the CBM DataPath until the finalization of the safety certification report ("Sicherheitsnachweis") – whilst making use of the generic safety case methodology.
- [Delta]ts = ts0 – ts1 = time saved from the beginning of handling the safety requirements for software components of the CBM DataPath until the finalization of the safety certification report

6.19. UC7.7: Data Analytics for Railway Checkpoints Use Case

This use case helps with the second main goal of the WP7: "capturing parameters helping to improve knowledge of rolling stock health status and apply the required actions in real time". In this use case we will perform different analysis with data coming from both on-board sensors and trackside assets (e.g., axle counters, S&C, balises, signals and overhead line) related to health assets condition to obtain significant results for preventive maintenance.

6.19.1. Overall aim of the Use Case

6.19.1.1. PROBLEM TO BE SOLVED

Train maintenance inspections are critical to avoid service disruptions caused by failing trains. Currently, the inspection of trains requires a significant amount of manual work, which hinders proper examination of each train at short intervals. Furthermore, manual work results in occasional human error, causing potential oversight of (pre)defects or anomalies.

6.19.1.2. INDUSTRY CURRENT POSITION / BASELINE

Currently, the inspection of trains requires a significant amount of manual work, hampers the ability to conduct thorough and frequent train inspections. Additionally, manual work is prone to occasional human error, leading to the potential oversight of (pre)defects/anomalies.

Through the collection of data regarding the state of assets (using different sensors located on the checkpoints), the main objectives of data analysis are:

- Improving the knowledge of rolling stocks status, which could help to optimise the rolling stocks maintenance, and being able to apply actions in real time.

- Reinforcing the control of vehicles, improving the capacity of main lines and freight corridors. This could be achieved by reducing the incidents and the time invested in workshops/maintenance.

6.19.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The developed models will be able to identify assets to keep track of them and detect the defects corresponding to those assets. Assets identification, following the work done in past EU projects as FR8Rail, and aligned with FP5, will focus on identification codes detection. The defects analysed are listed as follows:

- Graffiti and similar damages that can difficult the identification of assets, covering identification codes such as UIC for wagons and ILU for loading units. This task was contemplated in past EU projects as FR8Rail III;

- General damages detection: making use of computer vision technologies, as contemplated in FR8Rail III, improved with IA techniques (such as Deep Learning);
- Pantographs defects:
  - Low thickness of carbon bars,
  - Chipping/crumbling of carbon bars,
  - Broken/deformed arms/horns.
- Bogies defects:
  - Axle bearings:
    - Missing/loose bolts,
    - Leakage.
  - Leaking shock absorbers,
  - Cables (loose/damaged/broken).

6.19.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Using the newest technologies, (computer vision) models can be developed to detect (pre)defects/anomalies on trains to support /automate the manual inspection process.

6.19.2. UC7.7: demonstrator's KPI

6.19.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The KPIs are intended to measure the performance of the checkpoint systems in detecting different defects on assets, such as graffiti or general damages.

6.19.2.2. KPI1 – ASSET IDENTIFICATION ACCURACY

Short description

Accuracy Rate of identification codes recognition. To keep track of the status of assets, the first step is to identify those assets. This task can be achieved by recognising the identification codes such as UIC for wagons and ISO/ILU for load units.

The Accuracy rate tends to measure the quantity of assets that has been correctly identified, focusing on codes recognition accuracy.

How to compute KPI1

To check the accuracy in recognising and identifying assets the following formula will be used:

$$KPI1\ \%\ (asset\ identification\ accuracy) = \frac{CP}{NP}\ x\ 100$$

Where:

- *CP: Correct Predictions, number of codes that has been correctly detected (every character in the code has been correctly identified).*
- *NP: Total Number of Predictions carried out by the system.*

Considering the above formula, a positive result would imply an accuracy of 70% of higher, that is, keeping track of the 70% of analysed assets.

6.19.2.3. KPI2 – GRAFFITI DAMAGE DETECTION ACCURACY

Short description.
Accuracy Rate of graffiti damages detection. Once an asset has been identified, it can be analysed to have an insight of its status. One critical point, previously addressed in FR8Rail, is the recognition of graffiti.
The Accuracy rate tends to measure the quantity assets (wagons) damaged with graffiti.

How to compute KPI2
To check the accuracy in detecting graffiti defects the following formula will be used:

$$KPI2\ \%\ (graffiti\ detection\ accuracy) = \frac{TP_g - TN_g}{TP_g + TN_g + FP_g + FN_g}\ x\ 100$$

Where:

- TP_g: *True Positives in graffiti detection. Number of wagons with graffiti correctly detected*
- TN_g: *True Negative in graffiti detection. Number of wagons without graffiti, where the system did not detect any.*
- FP_g: *False Positive in graffiti detection. Number of wagons without graffiti, where the system detected a graffiti.*
- FN_g: *False Negative in graffiti detection. Number of wagons with graffiti, where the system did not detect any.*

Considering the above formula, a positive result would imply an accuracy of 80% of higher, that is, in the 80% of wagons the detection was correct.

6.19.2.4. KPI3 – GENERAL DAMAGES DETECTION ACCURACY

Short description.
Accuracy Rate of graffiti damages detection. Once an asset has been identified, it can be analysed to have an insight of its status. This KPI tends to measure the performance of the system in detecting general damages.
The Accuracy rate tends to measure the quantity assets (wagons) damaged.

How to compute KPI3
To check the accuracy in detecting damages defects the following formula will be used:

$$KPI2\ \%\ (damages\ detection\ accuracy) = \frac{TP_d - TN_d}{TP_d + TN_d + FP_d + FN_d}\ x\ 100$$

Where:

- TP_d: *True Positives in damages detection. Number of wagons with damages correctly detected.*

- TN_d: *True Negative in damages detection. Number of wagons without damages, where the system did not detect any.*
- FP_d: *False Positive in damages detection. Number of wagons without damages, where the system detected a graffiti.*
- FN_d: *False Negative in damages detection. Number of wagons with damages, where the system did not detect any.*

Considering the above formula, a positive result would imply an accuracy of 80% of higher, that is, in the 80% of wagons the detection was correct.

6.20. UC7.8: Optimization of rolling stock maintenance Use Case

6.20.1. Overall aim of the Use Case

6.20.1.1. PROBLEM TO BE SOLVED

Maintenance is scheduled periodically with a set of intervals, because the status of the rolling stock is not always readily available.

6.20.1.2. INDUSTRY CURRENT POSITION / BASELINE

When certain parts of our rolling stock are automatically monitored with sensors and are updated more frequently, maintenance can be scheduled accordingly.

6.20.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Not applicable.

6.20.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

The analysis of Train Maintenance tasks aims to achieve cost and time reduction during various maintenance operations (preventive, predictive, CBM and corrective).

6.20.2. UC7.8: demonstrator's KPI

Not available in this stage.

6.21. UC7.9: CBM algorithms for freight

The results of this use case will be demonstrated in FP5 (potentially in the second call for projects), even though the activities take place in WP7 of FP3-IAM4RAIL.
**** NOTE: This Use Case is provisional. This description contains only the activities planned by CEIT, as the participation of other entities might be subjected to the availability of field data provided by FP5.***

6.21.1. Overall aim of the Use Case

6.21.1.1. PROBLEM TO BE SOLVED

(Freight) 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.

6.21.1.2. 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.

6.21.1.3. 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.
- 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).

6.21.1.4. 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.

6.21.2. UC7.9: demonstrator's KPI

6.21.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The impact of this Use Case is aligned with the general KPIs that apply to the demonstrator #2 (Asset Management & Rolling Stock)

- Reduction of maintenance costs up to 10%
- 25% Reduction of in-service failures
- 10% Increasing rolling stock availability respective reducing workshop downtime

To contribute to those high-level KPIs, the following specific KPIs are proposed for this Use Case:

- Detection of anomalies
- Diagnosis of anomalies

6.21.2.2. KPI1 – DETECTION OF ANOMALIES

Short description

Sensitivity of the anomaly detection algorithms, i.e. the amount of anomalies detected by the algorithms with regards to a ground-truth (synthetic) dataset.

How to compute KPI1

$$KPI1 = \frac{\#\ of\ anomalies\ detected\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

6.21.2.3. KPI2 – DIAGNOSIS OF ANOMALIES

Short description

Sensitivity of the anomaly diagnosis algorithms, i.e. the amount of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to a ground-truth (synthetic) dataset.

How to compute KPI2

$$KPI2 = \frac{\#\ of\ anomalies\ diagnosed\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

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 uses cases are listed in Table 3.

UC ID d	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 optic fiber	WP9/DO4
9.3	Track geometry and S&C condition monitoring	WP9/DO4
9.4	Infrastructure monitoring solutions	WP9/DO4
9.5	Prescriptive maintenance solutions	WP9/DO4
10.1	Linking (new) monitoring technologies to asset management issues	WP11/DO4
10.2	Fusion of (on-board and wayside) monitoring data for an enhanced fault detection and diagnosis	WP11/DO4
12.1	Multiscale monitoring of civil assets	WP11/DO4
12.2	Bridges and earthworks assets management aided by geotechnics	WP11/DO4
12.3	Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	WP11/DO4
12.4	Data Analysis for condition monitoring	WP11/DO4

Table 3: Cluster D: Use Cases

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

This use-case will contribute to strengthening existing tools for 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 play an important role in taking 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 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, utilising novel 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 accurate assessment of the infrastructure health and assist in reliable data-driven decision making.

The developed tools will provide decision support towards of choice of minor maintenance, major maintenance, or reinvestment in the infrastructure to ensure that the primary functions are fulfilled.

7.1.1. Overall aim of the Use Case

7.1.1.1. PROBLEM TO BE SOLVED

Many of the Norwegian railway bridges are near or over end of design life. The remaining service life of existing railway bridges must be determined to ensure 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 on one hand based on regular inspection to understand the current state and on the other by use of historical statistical data and models to forecast degradation and thus service 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. Models are used to represent loading, the 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 is widely available and applicable to the present problem in service 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 renewals 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. To acquire this new data, rather than relying on one organization increasing sensor usage, the policy is to leverage multi-source and multi-organization data capture. Core developments in this task includes:

- 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

ST 8.2 will design instrumentation for the use case, Lundamo bridge in Norway. Furthermore, it will establish numerical procedures for determining and quantifying uncertainty in model-based evaluation of bridge service life and demonstrate efficacy 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.
Obtain data from measurements on different components of bridges in traffic and data from simulations of models 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 towards quantification of 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.

These tasks will contribute towards:

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

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.

We target improving the accuracy of the estimated state of the infrastructure from measurements and assessment through 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 estimates 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 that no technology is implemented (baseline) versus the scenario when the full information provided by the implemented technologies provide. The latter will be performed by measuring direct cost in combination with project savings. The combination of CAPEX and OPEX reduction of IMR together with higher accuracy in infrastructure state estimation, will directly contribute to the overall demonstrator KPIs:

- Accuracy of estimated response from modelling of bridge response due to traffic loads;
- Overall cost of operation (CAPEX and OPEX).

7.1.2.2. KPI1 – ACCURACY OF ESTIMATED RESPONSE TO TRAFFIC LOADS BASED ON THE BRIDGE MODELLING

Short description

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

How to compute KPI1

The KPI will be computed by comparing measured and estimated response 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 accuracy of numerical models.

7.1.2.3. KPI2 – 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 the estimation of remaining service life. The reduction in the overall costs will have a cascading effect in improving the availability without compromising on the primary functions of the bridge.

How to compute KPI2

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

7.2. UC8.2: Holistic long term asset management

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

7.2.1. Overall aim of the Use Case

7.2.1.1. PROBLEM TO BE SOLVED

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. Main objective of railway AM is to provide 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 in order to facilitate required dependability with optimized utilization of resources.

7.2.1.2. INDUSTRY CURRENT POSITION / BASELINE

Objective of railway AM is to maintain required level of dependability from infrastructure assets with minimum use of resources. Value of proposed decision supports are determined on improvement of dependability and resource utilization. Baseline for study stems from available data at respective IM.

7.2.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Demonstrator provides three types of decision support:
<u>D1 Management of dynamic maintenance programs and resource effective execution</u>
Optimizing the utilization of resources requires decision support tools that today is lacking 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 management of dynamic maintenance programs and resource effective execution within maintenance concept will provide:
T8.1.1 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.
T8.1.2 Analytics rendering and visualization of spatial-temporal data. Algorithms for translating various localization 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 visualization / HMI.

D2 Maintenance optimization in a dynamic maintenance program

On the iron ore line there is a need for improvement of maintenance concept in terms of better coordination between traffic operation, reinvestment activities and maintenance planning. Maintenance programmes need to become more flexible in order to facilitate a more rational maintenance concept.

Track and S&Cs are linear assets, they age differently, are installed on different occasions, experience varying loads which causes them to degrade differently throughout the network. The fixed maintenance plans and schedules often does not consider this variation of degradation across the network. Hence there is a need of a more dynamic maintenance programme.

Objective is to develop a system that describes RAMS parameters for the track as functions of assets' status, components, and traffic, hence serve as decision support for maintenance optimization in a dynamic maintenance program.

Because of the uncertainties involved in degradation of distributed assets, discrepancies between data gathered from CMMS (Computerised Maintenance Management Systems), and modelling & simulation, this use case aims to demonstrate at TRL6 (technology demonstrated in relevant environment) as compared to TRL8 (system complete and qualified).

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 up to real-time support of the TMS.

The objective is to setup 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.

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 utilized (if desired) or even greater dependability. Such development contributes to fulfilment of infrastructure managers main objective, as well as sustainability objectives, it also strengthens the railways market position VS other modes of transportation.

7.2.2. UC8.2: demonstrator's KPI

7.2.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

This use case identified the following KPIs; Availability and total maintenance cost (representation of resources utilized).

7.2.2.2. KPI1 – AVAILABILITY

Short description
Availability is the ability to provide train slots according to timetable.
How to compute KPI1
The availability is calculated by :

$$MUT/(MUT+MDT)$$

where MUT is Mean uptime and MDT is mean downtime.

7.2.2.3. KPI2 – TOTAL MAINTENANCE COST (RESOURCES USED)

Short description
Change in total maintenance cost before and after implementing the optimized schedule suggested by the application
How to compute KPI2
KPI is calculated as a percentage change in total maintenance cost before and after implementation of optimized schedule

7.3. UC9.1: Sensing railway superstructure system components

This UC provides sensing solutions for track superstructure at the component level. In detail:
Intelligent sleeper: A new concept of 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.
On-board 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 different modelling approaches are examined, and the resulting implications on the design of objects and attributes and their relationships form the basis for flexible interfacing to translate between different models.

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 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 involves capturing the essential characteristics of each component; 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 main function is maintaining the track gauge and transmitting the loads from the rail to the ballast uniformly. They also provide transverse stability to the track through their friction with the ballast. To build one kilometre of 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 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 type of monitoring to be able to carry out better planning of maintenance works, help in decision-making or improve traffic safety.

In this way, 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 on-board LIDAR measurements makes possible the estimation of key parameters of the ballast layer such as profiles and volumes. Still, the technology must be validated and embedded into existing maintenance management tools.

Interface BIM and Design model for the contact line: An appropriate model of a complex real-world situation is often 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 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. Certain 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 also 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 Few-Layer Graphene (FLG) 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 will help increase traffic safety, as it will allow the IM to identify possible defects and anticipate failure 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 in an optimised way.

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.

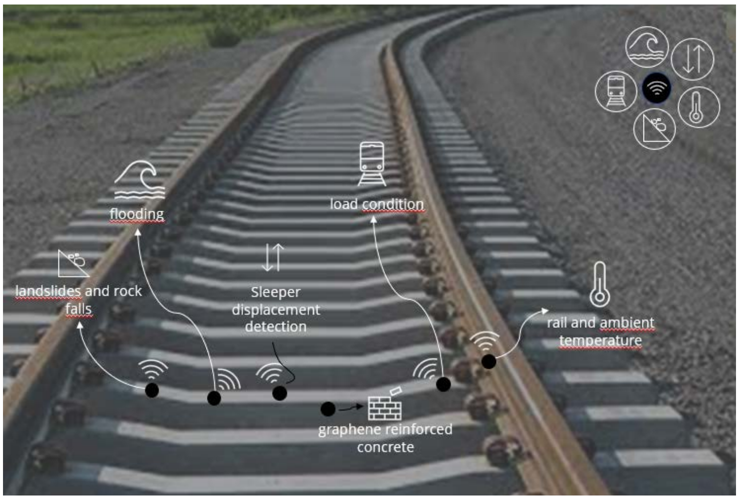


Figure 3: Concept of smart sleeper reinforced with graphene as an additive.

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/added value 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 rather challenging with 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 IFC 4.3 Rail, which is w.r.t. overhead lines a very scarce approach. Consequently, BIM model exchange for overhead contact lines is currently mostly reduced to the exchange of 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. In society nowadays, one of the main challenges is to achieve more sustainable infrastructures, and to this end, graphene is being introduced into concrete as an alternative to polluting cement. Moreover, by incorporating complete sensorisation in the sleepers, we are able, on the one hand, to obtain precise information on the real 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 (system complete and qualified).

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.

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 our 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 to 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 with the sleeper sensing are as follows. Obtaining a material with better resistance, durability and conductivity properties will result in the development of railway assets that will have 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. To be 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.

On-board LIDARs for Ballast: The expected improvement is by integrating the estimated parameters of the ballast layer in the decision-making of ballast replacements. Then, we expect to have better-informed decisions based on a more updated and accurate estimation of key parameters of the ballast.

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 as well as into design applications. Finally, higher reusability of implementations to translate BIM models from one to another and to design applications.

7.3.2. UC9.1: demonstrator's KPI

7.3.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The KPIs are intended to measure the reduction of maintenance costs and the reduction of failures due to the incorporation of graphene in the sleeper composition and the inclusion of full sensorisation in the sleeper.

7.3.2.2. KPI1 – REDUCTION OF THE MAINTENANCE COST

Short description

The main objective of this KPI 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, so maintenance costs will be lower.
- Incorporating a complete system of sensors in the sleepers allows us to know exactly and in real time the state of the railway assets. 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 possible early defect detection and provide sufficient time for planning optimisation of the maintenance operation.

How to compute KPI1

To check the savings in maintenance costs, the following formulation will be used. As an example of the use case of the intelligent sleeper:

$$KP1\ \%\ (cost\ savings)\ = \frac{(MC_{t.s.} \times WL_{t.s.}) - (MC_{g.s.} \times WL_{g.s.})}{(MC_{t.s.} \times WL_{t.s.})} \times 100$$

where:

- $MC_{t.s.}$: Estimated annual maintenance costs for the normal concrete sleeper.
- $WL_{t.s.}$: Estimated lifetime in years of the normal concrete sleeper.
- $MC_{g.s.}$: Estimated annual maintenance costs for the graphene concrete sleeper.
- $WL_{g.s.}$: Estimated lifetime in years of the graphene concrete sleeper.

Considering the formula, a positive result indicates a saving in maintenance costs when using the graphene concrete sleeper, while a negative result implies an increase in maintenance costs.

Relation to IAM4RAIL's project KPIs

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

KPI ID	IMPACT IN WP9 KPI	WHY?
KPI 1	Contribution to the target of reduction of maintenance costs up to 10%	By incorporating graphene in the concrete of the sleeper and the complete sensorisation, we are obtaining a material of greater strength and durability, which means less maintenance work and, therefore, a reduction in maintenance costs.

7.3.2.3. KPI2 – REDUCTION OF IN-SERVICE FAILURES

Short description

The main objective of this KPI 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 being a material with better properties, it will have 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 exactly 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 KPI2

To check the reduction of in-service failures, the following formulation will be used. For example, for the intelligent sleeper case:

$$KP2\,\%\,(reduction\ of\ failures)\ = \frac{(F_{t.s.} - F_{g.s.})}{F_{t.s.}} \times 100$$

where:

$F_{t.s.}$: Number of in-service failures in 10 years using the normal concrete sleeper.

$F_{g.s.}$: Number of in-service failures in 10 years using the graphene concrete sleeper.

Considering the formula, a positive result indicates a reduction in in-service failures when using the graphene concrete sleeper, while a negative result implies an increase in in-service failures.

Relation to IAM4RAIL's project KPIs

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

KPI ID	IMPACT IN WP9 KPI	WHY?
KPI 2	Contribution to the expected 25% reduction of in-service failures	By incorporating graphene in the concrete of the sleeper and the complete sensorisation, we are able to know the real state of the sleeper so that predictive maintenance can be carried out and failures in service can be reduced.

7.4. UC9.2: Railway infrastructure monitoring using optic fiber

This Use Case demonstrates the application of distributed sensing based on fiber 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 fiber data is analysed and focused on monitoring the superstructure. Then, train identification and intrusion detection using DAS/DTS in existing optical fiber installations are developed. Finally, dark fiber solutions are developed for vibrations, damaged wheels, rock fallouts, and the integrity of trains and embankments.

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.
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).
Development of new technologies for distributed sensing, based on fiber optics, for train monitoring, detection and identification of trains, and events detection, use physics-based technologies to enhance the management of assets and their maintenance. The information obtained by the distributed sensing system can be relevant to determine asset status and enhancing the results obtained in maintenance tasks. By including the measurements of this technology in prescriptive maintenance and optimized 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 fiber optics sensing technology. New fiber 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 (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 the fiber optics contains information from the infrastructure. A deep analysis of some parameters can indicate the current condition of the railway track.
Further, technologies utilizing Distributed Acoustic Sensing (DAS) with fiber optics have been developed over the past decade for various applications. The technology utilizes backscattered light from the interaction between light and matter in the core of the fiber to measure changing properties at different positions along the fiber. The technology employs different approaches, leading to different performances for each part of the use case. DAS systems can be implemented by installing new fibers or utilizing existing data cables. DAS systems can also be implemented in a fiber optics that are already used for telecommunication purposes or in unused fiber (dark fiber). In this Use Case, we will mostly work with dark fibers.

7.4.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The specific use case aims to develop a fiber optic-based system to determine the location of the trains and intrusion detection methods based on Distributed Acoustic Sensing and Distributed Temperature sensing (DAS/DTS) technology using existing optical fiber installations. The fiber optics cable, running parallel to the railway, consists of multiple fiber optics. Each fiber 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 the technology for distributed acoustic sensing is sufficiently mature, its implementation in railway systems on a large scale has been limited. Utilizing existing railway fiber optics cables allows for cost-effective installations. However, their installation primarily focuses on data transmission rather than DAS applications, and 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 analysis of the measurement signal may fall within the range of TRL2/3.
Regarding intrusion detection, there are DAS systems deployed in real-world applications such as intrusion detection along a perimeter, leak monitoring along pipelines, monitoring of sub-sea cables, or seismic monitoring. However, significant challenges remain before DAS can be implemented in routine railway operations. The systems previously developed have been tested as prototypes in a relevant or even real-world environment, reaching a TRL 6/7. Future implementations would acquire a TRL 8, being certified in real-world tests.

7.4.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Aligned with the objectives of WP9, within the scope of IAM4RAIL, the main problems that need to be addressed by this specific use case refer to the agility in taking maintenance actions on assets. The distributed sensing system with fiber optics technologies allows real-time information about the railway state and events that may occur on it. Monitoring the status of assets and retrieving data on events can be useful for further analytics 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, fiber 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.

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.

7.4.2.2. KPI1 – % TRAINS DETECTED

Short description
This KPI will describe the sensitivity of the system in the task of detecting trains in a certain configuration of measurement.

How to compute KPI1

$$\%Trains\ Detected = \frac{\#\ Detections}{Total\ \#\ of\ trains}\ x\ 100$$

7.4.2.3. KPI2 – % CORRECT INTRUSION EVENTS

Short description.
The precision of the system detecting intrusion events. i.e., of all the events the system detected, how many were real events?
How to compute KPI2

$$\%Correct\ Intrusion\ Events = \frac{TP}{TP + FP}\ x\ 100$$

- *TP: Number of real events detected.*
- *FP: Number of detections that weren't intrusions.*

7.4.2.4. KPI3 – DETECTION OF INFRASTRUCTURE ANOMALIES AND ASSETS MONITORING

Short description
Monitoring systems will be improved and used to detect anomalies such as rock falls, embankment movements and localized intense vibrations along the track that could lead to a later incident.

How to compute KPI3

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. For embankment movement monitoring, the baseline is that we do not have available technology, so we will rely on manual inspection. The intense vibrations usually are not understood or detected, so we will rely on the inspections triggered by fiber optics that led to a maintenance action.

7.4.2.5. KPI4 – DETECTION OF VEHICLE ANOMALIES

Short description

KPI4 covers the characterization and estimation of vehicle anomalies, in particular flat wheels.

How to compute KPI4

KPI4 is to be calculated as follows.

$$\%Anomalies\ Detected = \frac{\#\ Detections}{Total\ \#\ of\ anomalies}\ x\ 100$$

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 S&Cs. More specifically, its target includes the following:

- To improve the accuracy of the prediction of the track geometry condition of the track, look 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 numeric health condition and maintenance indexes (THI and TMI) that allow IMs to prioritize entire turnout replacements and the maintenance and replacement of individual components.
- To improve the detection of rail head surface defects, track and S&Cs quality using low-cost smartphones and validation data from on-board sensing solutions (such as video images and acceleration).

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.

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 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. State-of-the-art methods and tools can solve anomaly detection problems and prediction. In the project, we will evaluate their performance using measurement data from commercial trains (for smartphone technologies), SNCF track monitoring trains, and the Trainlab of DB in Germany.
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 is 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 taking 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 Turnout Health and Maintenance Indexes (THI and TMI) that weights and combines 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 prediction of the track geometry indexes 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 localization 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).
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 considers an integrated approach that advances the prioritization 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 the 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.
- Develop methods to identify the number of rail defects per distance and limit the number of false positives.
- Create 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 the validation of the measurements on a certain type and model of smartphone.
- Definition of the Plain track geometry defect fingerprint using Machine Learning algorithms.
- Turnout physical modelling using Multibody simulation and Finite Element Analysis and understanding the impact forces.
- Defining interpretable turnout health and maintenance indexes (THI and TMI).

Security of the switch & crossing inspectors is of concern, who 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 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. In addition, the turnout health and maintenance indexes (THI and TMI) will support the prioritization of Turnout replacements as well as the Turnout components replacement.

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 telephone and a set of instructions can do the needed measurements. Solving the key research challenges by an automated system on an inspection train means 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. The whole switch or crossing can be inspected after a single passing of the inspection train, and images of consecutive inspections can be compared directly. With automated detection of the running surface rail defects, the workload during visual inspections will reduce (but remain necessary for other types of defects). The IM will have access to more reliable data 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 for running these analytics by automating the process from data cleansing to work cycle detection and forecasting the 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 support objectively 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 optimize 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 that it provides a consistent and objective method of prioritizing turnout maintenance on a major line segment, region, territory or even system-wide. This is particularly important on a busy rail line such as one where there is a high-number 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, necessitate the urgent identification of turnouts that require immediate or future maintenance. Moreover, a single Turnout Health Index (THI) is utilized 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 real value. Prioritization 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) prioritize specific maintenance activities as a function of specialized 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 scheduled on a priority basis based on a numeric ranking of those conditions addressed by the specific maintenance activity.

7.5.2. UC9.3: demonstrator's KPI

7.5.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The Use case contributes to achieving the Key Performance Indicator of the overarching demonstrator #4 "Asset Management of Infrastructure Operation" and its KPI "VI. reduction of maintenance costs targeting 10% in specific use case".

7.5.2.2. KPI1 – OPTIMISATION OF TRACK WORK PRIORITISATION TARGETING 10%

Short description

The specific KPI is based on the number of planned KMs shifted backwards, forwards, 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 backwards or forward translates into work optimization.

How to compute KPI1

The following formula is used to calculate the KPI1 related to subtask 9.3.2.

$$KPI1 = \left| \frac{CBPW_{UC}^{BW} + CBPW_{UC}^{FW} + CBPW_{UC}^{NEW}}{CBPW_{B}} - 1 \right|$$

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 detect automatically 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. KPI2 – OPTIMISATION OF TURNOUT WORK PRIORITISATION TARGETING 10%

Short description

The specific KPI is based on the number of maintenance works and/or inspections that will be prioritized based on the new Turnout Health and Maintenance indexes compared to the current maintenance and inspection regime. A positive delta illustrates an increase of 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 KPI2

The following formula is used to calculate the KPI2 related to subtask 9.3.3.

$$KPI2 = \left| \frac{CBWP_{UC}}{CBWP_{B}} - 1 \right|$$

where:

UC, means use case scenario

B, means baseline scenario where the prioritized activities are based on the current turnout conditions and standards

CBWP, means the number of condition-based work priorities

7.5.2.4. KPI3 – PERFORMANCE OF INSPECTION SOLUTIONS

Short description

For subtask 9.3.1, we evaluate the performance of technologies and methods by considering the following:

1) 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) Quantify statistical and frequential differences between a smartphone and the reference system
4) The mean time is needed to analyse the images and videos per type and category of switches and crossings.
5) This KPI 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.

How to compute KPI3

The following methods are used to calculate the KPIs 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 difference of the acceleration 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 KPI 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: 1) Currently, visual track inspection performed by people on the track is the baseline for railhead defect detection and infrared. 2) For smartphones, the baseline is the very expensive and complex on-board sensing technologies.

7.6. UC9.4: Infrastructure monitoring solutions

This UC provides monitoring solutions for railway infrastructure. It covers technologies, algorithms and models required to apply advanced structural health monitoring solutions and validation campaigns in railway environments. The sensing technologies in this Use Case are being tested under various conditions and scenarios to assess their current capabilities, extended capabilities and limitations.

7.6.1. Overall aim of the Use Case

7.6.1.1. PROBLEM TO BE SOLVED

Railway infrastructure must be kept in acceptable condition under different scenarios of degradation mechanisms, considering the most updated knowledge about the particular types of failures in all its different components. Common problems affecting railway assets can include failures with origin in the usage of infrastructure components, failures in the rolling stocks, events due to exogenous factors such as third parties and weather conditions, etc. State-of-the-art sensing technologies are needed to keep managers of the infrastructure and railway operators well informed about, among others, the safety and reliability of the railway infrastructure. As a shift to railways from other transportation modes (such as private cars) is one target of the rail sector in Europe, providing safer and reliable services is crucial to keep current users and to gain the trust of possibly new users.

Thus, health condition monitoring and 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 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 to include the repairs or replacement of these components during the routine maintenance slots.

In this Use Case, we aim to develop integrated and robust approaches to monitor and maintain railway infrastructures continuously. But as a consequence, the database constructed from continuous data monitoring becomes larger over time, which is particularly challenging when dealing with multiple measurement sources and new sensing technologies that are not yet in the standards. Further, new technologies require validation campaigns under different scenarios and track conditions with the support of alternative sources of information to thoroughly verify the presence (or not) of defects. In this Use Case, we are users of technologies with TRL levels between 4 and 7. We further develop them by testing them under new conditions and investigating possible extended capabilities in combination with different data sources.

7.6.1.2. INDUSTRY CURRENT POSITION / BASELINE

With the developments of sensors and information technology, health conditions in railway infrastructure get monitored continually by using sensors installed in the rolling stock (e.g., rail and pantograph monitoring), in areas adjacent to the track (e.g., switch engine monitoring) and crowd sensing (e.g., with mobile phones that measure vibrations, temperature, pressure, etc.). The baseline in this Use Case is the actual practice by the corresponding monitoring activity. In some cases, manual inspections are the current standard. In other cases, no monitoring solution has been used so far from on-board sensing, and in others, we have state-of-the-art technologies available for which their capabilities can be analysed and extended to obtain holistic assessments from the monitoring campaigns.

Previous projects (such as IN2SMART and IN2TRACK) 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. In this Use Case, the TRL level of the techniques considered is between TRL 4 to TRL 6. Further field tests and various improvements are still necessary for the technologies to increase the effectiveness and interpretability of the measurement results. Higher detection rates and fewer false detections are needed to trust the measurement sources and then embed the sensing technologies into the asset management solutions with accurate data to make predictions and propose maintenance activities.

7.6.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

This Use Case focuses on defining data models, interfaces, regular collection, and data pre-processing from various sources, such as monitoring, inspections, and TMS. Then, it develops, improves, and validates sensing technologies necessary for the prescriptive maintenance of track 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 –are available from managers of the infrastructure that conduct these with measurement vehicles to estimate the general properties/conditions of the track.
- 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 for the estimation of 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).

To monitor the lateral alignment, twist and gauge and detect anomalies in the track design are considered by upgrading the monitoring system and data. For the sub-problem of quantification of lateral alignment, an investigation of a 'non-optical', magnetic field measurement system, called the Lindometer system, will be performed. Since the hunting motion governs the major relative displacement, this investigation aims to determine if this motion could be detected in a magnetic field signal from a sensor mounted on a vehicle. Furthermore, the same technology will address another sub-problem related to rail defects, such as degraded insulation joints.

Monitoring the dynamic properties of railway tracks is crucial to improving and supporting condition-based rail infrastructure maintenance. The railway track transfer function is an adequate representation of track dynamic properties. However, current technologies do not allow estimating such a transfer function from moving vehicles. Given the gap in transfer function measurement of railway tracks, we propose a methodology to estimate railway track transfer functions over a wide frequency range from a moving vehicle. Accelerometers are employed to estimate the dynamic train load to railway tracks, and a Laser Doppler Vibrometer (LDV) is used to scan railway tracks and measure their vibration response as the vehicle moves. While ABA has a higher TRL level for rail defect detection (TRL7), its combination with LDV to estimate the dynamic properties of the track has not been tested so far. We consider first laboratory tests in a scaled test rig (V-track of TUDelft). Then, tests in the CTO measurement train of TUDelft will be conducted to analyse major implementation challenges and determine how complementary LDV can be to the already high TRL level technology ABA (Axle Box Acceleration).

In addition to that, adding sensors or specific components for track monitoring could be difficult on an already existing train fleet. For this reason, we aim to evaluate the feasibility of analysing track geometry with existing sensors available directly on the train (speed sensors, traction motor phase current, etc.) to provide a track monitoring solution thanks to a software update only.

7.6.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Monitoring all 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 prediction itself is part of UC 9.4 Infrastructure monitoring solutions while making use of the sensing information is part of UC 9.5 Prescriptive Maintenance.
This Use Case provides the fundamentals and important building blocks for prescriptive maintenance. Characterisation of anomalies and root cause analysis provides the information necessary to address the root cause before correcting the defects. This supports the shift from addressing symptoms to addressing root causes.

7.6.2. UC9.4: demonstrator's KPI

7.6.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

This use case is linked with UC9.5. In this use case, the focus is on the sensing technologies, while in UC9.5 the focus is the prescriptive maintenance solutions. The following KPIs are defined to measure the objectives of the use case.

- Detection of anomalies in track geometry.
- Completed measurement campaigns.
- Comparison with trackside and hammer tests.

The assessment aims to be carried out in different countries, aiming to compare with the baseline provided by current practices in the railway lines tested.

7.6.2.2. KPI1 – DETECTION OF ANOMALIES

Short description
Monitoring systems will be improved and used to detect rail surface defects and track design anomalies. In addition to monitoring data, as-built information is analysed to support the detection of anomalies in track design. Inspection systems and data are used to detect anomalies in track geometry. We estimate that 75% of anomalies should be detected in this use case.
How to compute KPI1
KPI1 is to be calculated as follows.

(number of anomalies detected / number of anomalies inspected) * 100

Inspected anomalies are detected by visual inspections and evaluation of track data.

7.6.2.3. KPI2 – COMPLETED CAMPAIGNS

Short description
In this use case, the Lindometer will be tested for different applications. Two types of measurement campaigns will be performed. One where the Lindometer is mounted on a manually operated railway trolley and one where the Lindometer is mounted on a train. The analysis will be

performed within use case 9.5.

How to compute KPI2

Since this use case focuses on gathering data from measurement campaigns, the KPI could be described in terms of successfully completed campaigns.

7.6.2.4. KPI3 – COMPARISON WITH TRACK SIDE MEASUREMENT AND HAMMER TESTS

Short description

The combined use of LDV and ABA for the estimation of track transfer functions is currently at a low TRL level. First, evaluation in laboratory conditions is to be tested to see the relation of the estimated transfer function with traditional measurements such as trackside vibration and hammer tests. Then, field tests in the CTO Train of TUDelft will be conducted to assess the difficulties of reducing noise.

How to compute KPI3

KPI3 is calculated by a comparative analysis between the signals obtained with the new measurement procedure (ABA and LDV) and traditional approaches such as hammer tests and trackside vibration. Dominant frequencies and other responses features and characteristics are to be evaluated and compared to their counterparts obtained with the traditional approaches.

7.7. UC9.5: Prescriptive maintenance solutions

This UC provides fundamentals for prescriptive maintenance design. It covers technologies, algorithms and models for the application of advanced data-driven maintenance solutions for railway infrastructure.

7.7.1. Overall aim of the Use Case

7.7.1.1. PROBLEM TO BE SOLVED

In view of the increasing demands on the railway system, effective maintenance strategies are a key factor in ensuring the required availability of the tracks. In this UC, we focus 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, we can increase the efficiency and sustainability of the railway system via maintenance design and increase the knowledge about the root causes for track deterioration, and predictions of deterioration are necessary.

The IN2SMART and IN2SMART2 projects addressed fundamentals for intelligent maintenance of rail infrastructure. The IN2TRACK projects addressed techniques for monitoring and modelling railway tracks aiming to explain the root cause and the most effective intervention/maintenance action for different phenomena. These projects include topics such as improved monitoring technology and evaluation, detection of anomalies in track geometry and rail surface, prediction

of track geometry, and evaluation of transition geometry in S&C's. The TRL level of the techniques considered in this UC is between TRL 4 to TRL 6.
Further field tests and various improvements are necessary for actual deployment in railway environments and professional use. For example, to avoid "false positive" cases where a fault is detected but does not exist. In the case of anomalies, not only detection but also characterization and recording of the condition is necessary to take the right 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.

7.7.1.2. INDUSTRY CURRENT POSITION / BASELINE

The most common current practice of infrastructure managers is to react 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 nowadays challenges in railway systems, which is not only to guarantee a level of availability but also to be sustainable, as individual faults tend to recur after a short time.

7.7.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

- Monitoring the lateral alignment, twist and gauge and detecting anomalies in the track design.
- Characterization of the rail surface anomalies and monitoring of the state.
- Detection of root causes for track degradation.
- Monitoring of transition geometry.
- Decision support of track maintenance by estimating track stiffness and transfer functions of railway tracks.

7.7.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Monitoring and inspection of all 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 prediction itself is part of UC 9.4 Infrastructure monitoring solutions.
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.
This UC provides fundamentals and important building blocks for prescriptive maintenance.

7.7.2. UC9.5: demonstrator's KPI

7.7.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The following KPIs are defined to measure the objectives of the use case.

- The correlation between anomalies and track deterioration is detected in 50% of section with local deteriorations.
- Characterization of anomalies in the rail surface at 50%.
- Prediction of track geometry deterioration.

As described above, detecting and characterizing anomalies form the basis for root cause analysis. Once the root causes are known, eliminating the detected anomalies leads to increased track availability and performance.
The KPI's of this use case measure the increase in the automatic detection and characterization of the anomalies to use this information in planning maintenance.
The assessment is aimed to be carried out on a specific section of the rail freight corridor. Particular technologies and methodological solutions will be tested in different countries, aiming to compare with the baseline provided by current practices in the railway lines they are tested.

7.7.2.2. KPI1 – CORRELATION BETWEEN ANOMALIES AND DEGRADATION

Short description
The correlation between anomalies and track deterioration shall be identified and evaluated.
In this use case, anomalies are to be assigned to 50% of the local track deterioration.
How to compute KPI1
KPI2 is to be calculated as follows.
(Number of local degradations / number of detected anomalies) * 100

7.7.2.3. KPI2 –CHARACTERISATION OF ANOMALIES

Short description.
KPI2 covers the characterization and estimation of the state of anomalies with a focus on

- Insulated joints
- Welded joints
- Substructure
- Track structure response

In this use case, a characterization of 50 % of the anomalies is to be carried out.

How to compute KPI2
KPI2 is to be calculated as follows.
(Number of characterized anomalies / number of detected anomalies) * 100

7.7.2.4. KPI3 – PREDICTION OF TRACK GEOMETRY DEGRADATION

Short description

KPI3 covers the prediction of track degradation which is one of the most important building-block for prescriptive maintenance. A sufficient validity of the prediction is the key for the acceptance of the method by the asset managers and the base for an efficient maintenance planning.

In terms of maintenance planning and manager of infrastructure standards, the accuracy of the prediction for one year should be in the range of 10% for 90% of the analysed sections.

How to compute KPI2

The prediction will be compared with the actual deterioration and the deviations between prediction and measurements classified.

7.8. UC10.1: Linking (new) monitoring technologies to asset management issues

This use case contributes to demonstrator #4 (Asset Management & Infrastructure) of the project by 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 on-board sensors, to gather diagnostic and prognostic information. By utilizing 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 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 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 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.

7.8.1. Overall aim of the Use Case

7.8.1.1. 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 identifying patterns that can be seen and linking them to specific issues.

7.8.1.2. 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 recognizes 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 utilization 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 optimize 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.

7.8.1.3. 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.

7.8.1.4. 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 caters to 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 as a whole to anticipate and tackle these issues before wider deployment, resulting in minimized disruptions, optimized 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.

7.8.2. UC10.1: demonstrator’s KPI

7.8.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

Management & Infrastructure)

- Reduction of maintenance costs up to 10%
- 25% Reduction of in-service failures

To contribute to those high-level KPIs, the following specific KPIs are proposed for this Use Case:

- Detection of anomalies
- Diagnosis of anomalies

7.8.2.2. KPI1 – Detection of anomalies

Short description
Sensitivity of the anomaly detection algorithms, i.e. the amount of anomalies detected by the algorithms with regards to ground-truth datasets.

How to compute KPI1

$$KPI1 = \frac{\#\ of\ anomalies\ detected\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

7.8.2.3. KPI2 – Diagnosis of anomalies

Short description

Sensitivity of the anomaly diagnosis algorithms, i.e. the amount of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to ground-truth datasets.

How to compute KPI2

$$KPI2 = \frac{\#\ of\ anomalies\ diagnosed\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

7.9. UC10.2: Fusion of (on-board and wayside) monitoring data for an 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 exploit 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.

7.9.1. Overall aim of the Use Case

7.9.1.1. PROBLEM TO BE SOLVED

The problem at hand 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 hampers accurate and timely fault detection, leading to increased maintenance costs, operational disruptions, and potential safety risks.

This use case addresses the 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 asset issues through the utilization 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 utilizing 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 nature. 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.

7.9.1.2. 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 capture 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.

7.9.1.3. 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 utilize multi-sensor and multi-vehicle modular architectures for data acquisition, this includes collecting the data from the 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.

7.9.1.4. 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 optimize maintenance planning. Ultimately, the innovation improves the overall asset reliability, reduces maintenance costs, and enhances the operational performance of the rail infrastructure subsystem.

7.9.2. UC10.2: demonstrator’s KPI

This section is just a starting point! Draft

7.9.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The impact of this Use Case is aligned with the general KPIs that apply to the demonstrator #4 (Asset Management & Infrastructure)

- Reduction of maintenance costs up to 10%
- 25% Reduction of in-service failures

To contribute to those high-level KPIs, the following specific KPIs are proposed for this Use Case:

- Detection of anomalies
- Diagnosis of anomalies

7.9.2.2. KPI1 – Detection of anomalies

Short description

Sensitivity of the anomaly detection algorithms, i.e. the amount of anomalies detected by the algorithms with regards to ground-truth datasets.

How to compute KPI1

$$KPI1 = \frac{\#\ of\ anomalies\ detected\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

7.9.2.3. KPI2 – Diagnosis of anomalies

Short description
Sensitivity of the anomaly diagnosis algorithms, i.e. the amount of anomalies diagnosed (e.g. classification and severity) by the algorithms with regards to ground-truth datasets.

How to compute KPI2

$$KPI2 = \frac{\#\ of\ anomalies\ diagnosed\ by\ algorithms\ and\ confirmed\ in\ ground\ truth\ data}{\#\ of\ anomalies\ in\ ground\ truth\ data} \times 100$$

7.10. UC12.1: Multiscale monitoring of civil assets

7.10.1. Overall aim of the Use Case

7.10.1.1. PROBLEM TO BE SOLVED

FS Group 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 decision-making of IM operators. 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 16,7821 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 f viaducts (7%).

Hydrogeological risk
Hydrogeological instability is caused by weather conditions and affects both Italian territory and population. Railway infrastructure, with over 16,000 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 of 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.

7.10.1.2. INDUSTRY CURRENT POSITION / BASELINE

Civil infrastructure monitoring (railway bridges)

RFI monitors the entire railway network and conducts inspection visits for bridges, viaducts, and underpasses. Corporate regulatory framework since 2014 mandates specific procedures and operating methods for 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. Purpose of inspection is to identify, quantify, and characterize 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. Post-processing phase follows 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 rainfalls 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 seldomly 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. 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 line 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 prioritized based on survey results evaluated by maintainers.

7.10.1.3. 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 show aerial technology is feasible and effective for civil monitoring. Advantages include physical accessibility and time savings, as well as 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.

7.10.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Civil infrastructure monitoring (railway bridges)

FS aims to automate 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 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 feasibility and effectiveness of satellite-based monitoring techniques. These results will be used to further develop high/expected TRL for satellite-based monitoring.

7.10.2. UC12.1: demonstrator's KPI

7.10.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

KPI1 and KPI2.

7.10.2.2. KPI1 – BRIDGE PLATFORM -REDUCTION OF MAINTENANCE COSTS UP TO 10%

Short description

This KPI 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 KPI1

KP1 computes time and cost savings for inspection and post-processing data using new technological system (support drones and AI). To evaluate this KPI we can use the following formula.

$$KP1\ (\%\ time/cost\ savings) = \frac{Time/Cost_{traditional\_method} - Estimated\ time/cost_{new\_method}}{Time/Cost_{traditional\_method}} \times 100$$

- 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 KP1 is positive, it indicates that the estimated time/cost for the new method is less than the traditional method.

7.10.2.3. KPI2 – BRIDGE PLATFORM - REDUCTION 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.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 KPI2

The number 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 data.

$$KPI\ 2(\%\ disruption) = \frac{LTVn}{LTVt} x\ 100\ \%$$

- LTVt: Number of total traffic disruption caused by **traditional** inspection on bridges
- LTVn: Number of traffic disruption caused by **new** method approach.

7.10.2.4. KPI3 – REDUCTION OF ON TRACK DATA COLLECTION TIME

Short description

This KPI aims to check whether time and cost of inspection of the track and its surrounding 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 procedure, and mitigation actions.

How to compute KPI3

KP3 estimates time and cost savings for data collection before and after application of new monitoring approach based on remotely acquired data. To evaluate this KPI we can use the following formula.

$$KP3\ (\%\ time/cost\ savings) = \frac{Time/Cost_{traditional\_method} - Estimated\ time/cost_{new\_method}}{Time/Cost_{traditional\_method}} \times 100$$

- Traditional Method Time/Cost is time/cost required for conventional data collection
- Estimated new method Time/Cost is time/cost required to gather still needed data after applying new monitoring approach

If KP3 is positive, it indicates that the estimated time/cost for the new method is less than the traditional method.

RELATION TO IAM4RAIL'S PROJECT KPIS

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

KPI ID	IMPACT KPI (GA)	Description
KPI 1	- Reduction of maintenance costs by 10% - Increase digital and IA-based solutions for railway maintenance by 20% - Reduction on the need for human interventions in 10% (**Life cycle costs**)	Technologies developed in this FA introduce drones and digital/IA solutions to reduce maintenance time and human intervention.
KPI 2	- Increase of availability in 10% **(Flexibility and punctuality)**	This KPI relates to traffic disruption/speed reduction, impacting operability of the line by delaying/reducing number of trains in service. Studying this KPI, the time that the section is in temporary speed limitation will be reduced, so the train service will improve.
KPI 3	- Reduction of maintenance costs by 10% - Reduction on the need for human interventions in 10% - Holistic approach for railway maintenance increase of use in 10 %	This KPI relates to time/cost reduction for track data collection with new monitoring system using remotely acquired data. Global technological leadership supported by a combination of innovation and technical standards, defining innovative maintenance decision-making concepts. The harmonisation and simplification of

	- Data analytics methodologies increase of use in 10% - Decision support solutions applicable to new solutions **(Life cycle costs & Competitiveness)**	maintenance by applying and integrating advanced monitoring approaches, data analytics methodologies and decision support solutions.

7.11. UC12.2: Bridges and earthworks assets management aided by geotechnics

This use case is structured by three tasks:

(1) EO data acquisition and processing.
(2) Ground data processing.
(3) Algorithms and platform for asset management.

7.11.1. Overall aim of the Use Case

7.11.1.1. 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 damages 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 assumed 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 a specific slope movements that has a long history of problems associated with instabilities even before the construction of the railway line in 1880. This area presents high frequency of rainfall, 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, it has been selected for this demonstrator the slope of tunnel 40, located between PP.KK. 277+100 to 277+457 of the Palencia-La Coruña line, since it has the characteristics described above as currently active landslides.

We would like to set up a predictive maintenance tool based in a low-cost sensors network that allows us to know the slope movement to identify the progressive damage it is causing on our railway line and act with stabilizing measures and compare results with 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 different images taken in each time interval.
The new sensors, inclinometers that are planned to be installed on the slope and the satellite images, the historical geotechnical data 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.

7.11.1.2. 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 specialized 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 this slope, the current Maintenance System is based on the realization of the reading of measuring instruments such as inclinometers, piezometers, obtaining the data every four months.

7.11.1.3. 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 the development of a first tool in order 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 (stabilization 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, other objective is to verify that no movements occur once the projected stabilizing measures have been implemented.

7.11.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Advantages over corrective action:

(1) The impact on railway operation is minimized, due to the lack of establishment of restrictions, usually speed restrictions, which could serve as a parameter that quantifies 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 minimized.
(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 supports to identify the optimal moment of replacement of the bearings before the failure or the blockage of them occurs.
To address this, it seems necessary to design an architecture based on local monitoring in bearings 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 to provide modal parameters.
In addition, some accelerometers are to be installed in the transition areas of the bridge in both edges. They will allow to realise 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 can 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 the inclinometers, both the existing ones and those that would be installed by the Conventional Network Project Management when the stabilization project is executed in order to meet another objective, to analyse how effective are the measures adopted for slope stabilization, once it is executed after approximately one and a half years.
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 different images taken in 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 stabilizing measures implemented are working properly.

7.11.2. UC12.2: demonstrator's KPI

7.11.2.1. 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 optimized 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 bearings replacement in bridges (KPI 1, KPI 2 and KPI 4)
- Predictive maintenance tool for the monitoring of slope with active movements (KPI 1, KPI 2, KPI 3 and KPI 5)

7.11.2.2. KPI1 – FAILURE MODE PREDICTABILITY

Short description
This KPI hereby described focuses on determining the frequency and characteristic traces of failures that evolve in time (i.e., which undergo a degradation process), since this type of failures are the ones that can, in principle, be predicted by models.
How to compute KPI1
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.

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 1	- Reduction of maintenance costs up to 10%. - 25% reduction of in-service failures.	Knowing the predictability of the failure method of the asset can be made a more exhaustive and concrete maintenance plan, planning the actions to be carried out (inspections) so it will lead to a reduction in maintenance costs, and it will improve the train service since it will not be interrupted so continuously due to that correct preventive planning.

7.11.2.3. KPI2 – 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 KPI2

Speed restrictions caused by failures in POT bearings on bridges and by problems of slope movements 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.

$$KPI\ 2 = \frac{TTLa}{TTLt}\, x\ 100\ \%$$

- 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%.

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 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.

7.11.2.4. KPI3 – Cost reduction of instrumentation equipment for earthworks

Short description

The main objective of this KPI 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 KPI3

To calculate the reduction of the costs in the instrumentation equipment of the slope, it is essential to know the cost of the previous monitoring instruments and from this data, see the evolution with respect to the years, that is, establish a comparison between 2 successive years.

Steps to follow:

(1) Obtaining the historical costs for each year of the instrumentation devices of the hillside.
(2) Obtaining the costs associated with the network of low-cost sensors for each year.

$$KP\ 3 = \left(\frac{COSTS_{\ n} - COSTS_{\ n-1}}{COSTS_{\ n-1}}\right) x\ 100\ \%$$

Where:

- n = current year in which the comparison is to be made
- n-1 = year before to the current year

Finally, as an interpretation of results, if the value of the KP3 indicator is negative, it means that costs have been reduced compared to the previous year.

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 3	-Reduction of maintenance costs up to 10%.	Exact knowledge of the costs of the instrumentation equipment and its effectiveness would reduce maintenance costs reducing unnecessary ones.

7.11.2.5. KPI4 – Reduction of costs in the pot bearings replacement

Short description

The application of this KPI is proposed to analyse the reduction of 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 with public tenders.

How to compute KPI4

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.

$$KPI\ 4 = \left(\frac{COSTEW - COSTPT}{COSTPT}\right) x100\ \%$$

- COSTEW: Cost Emergency Work to replace POT bearings.
- COSTPT: Cost Public tender to replace POT bearings + monitoring costs.

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 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.

7.11.2.6. KPI5 – Effectiveness of slope stabilization measures

Short description

When severe instabilities occur in an earthwork, measures are designed in order to solve this stability issue. Sometimes, these stabilizing measures are not fully effective, and problems continue to occur.

Therefore, the main objective of this KPI is to measure the degree of effectiveness of these stabilizing 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 KPI5

The objective here is to verify whether there are movements, deformations once the stabilization measures have been executed, for this, the trend of the data from the low-cost sensors installed before and after the stabilizing measures will be studied.

$$KPI\ 5 = \left(\frac{\mathrm{Tb} - \mathrm{Ta}}{\mathrm{Tb}}\right) x100\ \%$$

- Tb: Trend sensor data before measurements
- Ta: Trend sensor data after measurements.

Interpreting the results, if the KPI is equal to 100% it will mean that the stabilization measures implemented have been correct and it will not be necessary to do any other type of action on the hillside.

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 5	-Reduction of maintenance costs up to 10%. -25% reduction of in-service failures.	If the stabilizing measures were fully effective, the maintenance work of the line would be significantly reduced since the instabilities caused losses of levelling, 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.

7.12. UC12.3: Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels

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 damages 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.

7.12.1. Overall aim of the Use Case

7.12.1.1. 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 is increasing 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 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.

7.12.1.2. INDUSTRY CURRENT POSITION / BASELINE

Evaluation of mechanical properties of sub-ballast layers and subsoil

For mechanical characterization of sub-ballast layer and sub-soil and to diagnosis the soil support for the risk of subsidence, we use classical geotechnical and geophysical method which are punctual, not accurate in some case and not compatible with the constraints of the railway. This work will help us to gain a better knowledge of our infrastructure, to adapt and to reduce maintenance operation 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 specialist by using special trains but without digital technologies. Damages are detected visually and by using a hammer.

New tunnel inspection systems have developed the last few years. These systems are mainly based on photography, lidar and infrared thermography technologies. They offer opportunity to ensure a realistic and very high-definition representation of the tunnels, in 2D and in 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 assets 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 aid in identifying and characterizing 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 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 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.

7.12.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Evaluation of mechanical properties of sub-ballast layers and subsoil

To characterize the mechanical behaviour of sub-ballast /sub-soil and monitor areas with sinkhole hazard we aim to:

- Develop an active seismic surface waves method and creation of a toolbox (methodology, equipment, software, …) allowing guide choices in terms of design, monitoring and maintenance. This will be tested on specific sites on high-speed line.
- Develop a passive seismic surface waves method to characterize the mechanical properties of the shallow subsurface, analyse the variation of the shear velocity due to cavity in the

subsurface and study the influence of hydrogeological context on the shear wave velocity analysis. This will be tested on 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 the expectation on the railway/industrial side for the exploitation of technical results and the adaptation expected on maintenance and works

High efficiency tunnel inspection systems and predictive maintenance for tunnel

The aim is to deploy new inspection technologies and to predict the evolution of tunnel degradation.

The tasks necessary for the achievement of the objective of this demonstrator include.

- Concerning the utilization 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 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

Passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels

The tasks necessary 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 economic estimates associated with the process.

7.12.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

This work by inframanagers (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 operation;
- propose an adapted design to the situation;
- check that the work has been carried out properly;
- optimize the maintenance operations in terms of methodology an economic point of view;
- ensure the safety and operability of the tunnels.

7.12.2. UC12.3: demonstrator's KPI

7.12.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The KPIs are intended to measure the reduction of maintenance time and cost of a new technological methods for sub-ballast and sub-soil characterization and monitoring, inspection and predictive maintenance of Tunnel and tunnel convergence monitoring with Passive Contactless Magnetic Microwire Sensor

7.12.2.2. KPI1 – Reduction of maintenance times

Short description

The main objective of this KPI is to check whether the time needed to perform a measurement:

- 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 KPI1

For the two first demonstrator which aim to reach the TRL 7, the estimation of the KPI1 for the two SNCFR demonstrator will adopt the following formula:

$$KP1\ (\%\ time\ savings) = \frac{Time_{tradicional\_method} - Estimated\ time_{new\_method}}{Time_{tradicional\_method}} \times 100$$

- Traditional Method Time is the time required to maintenance and works including investigation by the traditional method.
- Estimated time new method is the time required to maintenance and works including investigation by the new method.

For the third demonstrator, 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 KPI we can use the following formula.

$$KP1\ (\%\ time\ savings) = \frac{Time_{tradicional\_method} - Estimated\ time_{new\_method}}{Time_{tradicional\_method}} \times 100$$

- Traditional Method Time is the time required to perform an inspection by the traditional method.
- Estimated time new method is the time required to perform an inspection by the new method.

If KP1 is positive: 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 KP1 is negative: 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.

Relation to IAM4RAIL's project KPIs

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

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 1	Reduction of maintenance costs up to 10%.	• By develop an active seismic surface waves method and creation of a toolbox (methodology, equipment, software, …) allowing guide choices in terms of design, monitoring and maintenance. Sites test: high-speed line. Develop a passive seismic surface waves method to characterize the mechanical properties of the shallow subsurface, analyse the variation of the shear velocity due to cavity in the subsurface and study the influence of hydrogeological context on the shear wave velocity analysis. Sites test: conventional line with gypsum dissolution hazard context. • By 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 operations with the greatest possible anticipation and accuracy. • By utilizing 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.

7.12.2.3. KPI2 – Reduction of the maintenance cost

Short description

The main objective of this KPI is to check whether the reduction of maintenance cost is achieved by:

- reducing number and type of corrective maintenance operations and adapt the solution of rehabilitation to the context;
- Reducing the tunnel inspections times and number of repair operations per year;
- 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 corrective action if necessary.

How to compute KPI2

For the two first demonstrator which aim to reach the TRL 7, the estimation of the KPI2 for the two SNCFR demonstrator which will be tested in a relevant environment, will be done by the following formula:

$$KP2\ \%\ (cost\ savings) = \frac{Equ.cost_{t.m.} - Equ.Esti_{n.m.}}{Equ\ cost_{t.m.}} \times 100$$

- Traditional Method cost is the cost required to maintenance and works including investigation by the traditional method.
- Estimated new method cost is the cost required to maintenance and works including investigation by the new method.

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 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 KPI we can use the following formula.

$$KP2\ \%\ (cost\ savings) = \frac{(Equ.cost_{t.m.} + Wf.cost_{t.m.}) - (Equ.Esti_{n.m.} + Wf.Esti_{n.m.})}{Equ\ cost_{t.m.} + Equ\ cost_{t.m.}} \times 100$$

- Equipment costs 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 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 new method of an inspection of an inspection $Wf.Esti_{n.m.}$): This is the expenditure related to the time and human effort required to perform the inspection.

If KP2 is positive: 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.). KP2 is negative: 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.

<u>Relation to IAM4RAIL's project KPIs</u>

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

KPI ID	IMPACT IN WP12 KPI	WHY?
KPI 2	Reduction of maintenance costs up to 10%.	• By using and adapting the geophysical method combined with the geotechnical data and the context of the site; This will help us to be more accuracy on the diagnostic and anticipate/adapt the type of maintenance. • By 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 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 act only in what is necessary.

7.13. UC12.4: Data Analysis for condition monitoring

7.13.1. Overall aim of the Use Case

7.13.1.1. PROBLEM TO BE SOLVED

Monitoring and inspection are generally performed over the whole railway lines 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 field works. The monitoring and inspection results support evaluating the quality of work, which is essential in competitive maintenance tendering processes. 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 necessary data and minimize operations start delays while giving helpful information to construction teams through various measurements and checks (e.g., tunnel, catenary, track, substructure, earthworks) while not 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). Further, manual control and inspection use much manual labour, and track access, is relatively dangerous in confined spaces, especially around overhead electrification.

Nowadays, sensing technologies allow the monitoring of large-scale railway infrastructures and critical civil structures (such as bridges) with data collection and processing times that can be achieved in real-time and provide almost continuous updates. Digital infrastructures (such as Digital Twins) can be used to find root causes and analysis of problems, prediction of 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. For embankments and bridges, when inframanagers are not implementing sensing solutions is equivalent to missing great opportunities that digitalization gives to have updated information about these railway components. For instance, a bridge reaching its nominal service life could require an early renewal to prevent sudden failures and minimize as many service disruptions as possible. Also, the investments for the complete replacement of a bridge could be postponed by some years when the monitoring system indicates the safety conditions still allow it. In this use case, we implement sensing technologies for bridges and monitoring of embankment stability.

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.

The Netherlands: The Dutch railways are highly occupied, so we are evaluating on-board monitoring of embankments 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. Further, additional data sources will be assessed to find complementary data to obtain better estimations of the embankment stability. Tentative railway lines: Dordrecht – Lage Zwalage and Delft-Schiedam.

7.13.1.2. INDUSTRY CURRENT POSITION / BASELINE

Today 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 they also require track access. Today's methods for monitoring and inspection are subjected to variable data quality, often based on text and subjective judgments without clear evidence. Further, 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. We rely on historical data for baseline definition and analysis.

7.13.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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.
The use case is to automatize 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 relation with embankment stability. The full understanding of the complementary provided by new on-board data with historical data will allow the development of an indicator of stability issues. In the Norwegian railways, we will analyse high-danger areas with a focus on bridges. 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 increasing the quality of results wrt. verification of performed work, especially by third parties.

7.13.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

The Dutch and the Norwegian inframanagers do not have the tools being analysed to be developed in this project. Major renewal costs can be further optimized when the initiative on monitoring embankments and bridges is successful. For instance, a well-informed priority list can be created to sort out which bridges must be renewed first, which require earlier renewal, and which can last beyond the expected life service. A risk map based on embankment stability information developed in this project can be created for major track works required. Hotspots and the expected behaviour of the embankments can be embedded 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 studying methods and models for structural assessment management. The numerical model will allow introducing and analysing faults from train-based track measurements and artificial anomalies. Further, 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 by 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 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 also constitute a basis for upgrading/ strengthening remedies if needed.

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 service 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, we will establish a numerical model of embankment stability in a chosen transition zone on the Often line inspired by the ongoing project in In2Track3 in Sweden. We will characterize the degradation mode and response of the system to the passage of different trains over time. Finite Elements model, discretization 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 optimize the track structure dynamic stiffness in railway superstructure and substructure. In transition zones such as tunnels, bridges, culverts, etc.) for both existing railways and the design of new railway tracks. 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 CTO train of TUDelft. 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.

7.13.2. UC12.4: demonstrator's KPI

7.13.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The demonstrator, where the use case is placed, aims to reduce maintenance costs by up to 10% and 25% reduction of in-service failures. The means of verification: Algorithmic and statistical approach over the demos operational time 1) Maintenance expenditures accounted comparison with baseline in similar periods, 2) control of percentage for the number of affected trains according to PRIME affected train (by an asset failure) definition SIS-EN 13306:2010.
In the Netherlands-Norway use case, we aim to reduce the cost of ownership. The rationale is that the split between OPEX and APEX may not be so clear since early detection 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. Secondly, we target improving the accuracy of the estimated state of the infrastructure from measurements and assessment through proposed methods. As for verification, we aim to estimate maintenance costs by comparing the case that no technology is implemented (baseline) versus the scenario when the full information provided by the implemented technologies provide. The latter will be performed by measuring direct cost in combination with project savings. The combination of CAPEX and OPEX reduction of IMR together with higher accuracy in infrastructure state estimation, will directly contribute to the overall demonstrator KPIs.

1. CAPEX and OPEX cost
2. Detectability of incipient known failures

7.13.2.2. KPI1 – CAPEX and OPEX cost

Short description

Deviation from predicted CAPEX and OPEX cost for infrastructure under assessment.

How to compute KPI1

to maintenance, repair, and renewal. For ease of comparison, the KPI will be evaluated annually. Therefore, the total costs per annum, for the bridge section indicated below:

- Traditional Method Cost - is the cost of maintenance by the traditional method.
- Estimated Cost of new method is the cost for maintenance based on the decision support provided by the outcomes of this project.

The KPI is calculated as:

$$KPI1\ (\%\ cost\ savings)\ = \frac{Cost\ _{traditional\_method} - Estimated\ Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$$

If KP1 is positive: 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 an overall cost reduction maintenance, however, if KP1 is negative: Indicates that the estimated cost for the based on the new approach is greater than the cost required for the traditional method.

7.13.2.3. KPI2 – Detectability of incipient known failures

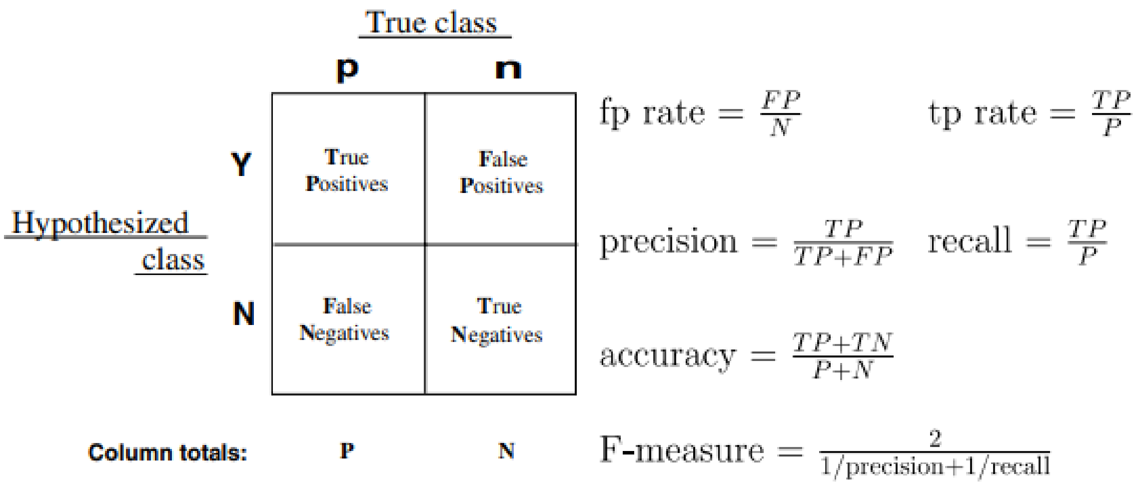
Short description

At baseline, incipient faults are either detected through regular inspections (noticed, reported, and assessed by ad-hoc inspection) or, worst case, through failure 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 between inspection intervals, help plan field inspection intervals more accurately, and give time to plan and execute maintenance actions at a lower overall cost without compromising safety.

How to compute KPI2

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). Thus, the KPI will be calculated as a temporal quantification of incipient fault detection at different locations. A standard 2x2 confusion matrix will be calculated for each fault type[2]

[2] T. Fawcett. «An introduction to ROC analysis.» *Pattern Recognition Letters*, vol. 27, pp. 861 – 874, 2006.


True class
p
n
Y
N
Hypothesized class
True Positives
False Positives
False Negatives
True Negatives
Column totals:
P
N
fp rate = FP / N
tp rate = TP / P
precision = TP / (TP+FP)
recall = TP / P
accuracy = (TP+TN) / (P+N)
F-measure = 2 / (1/precision+1/recall)

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 4.

UC ID	Title	Relevant WP/DO
15.1	Decision support systems for railway station asset management	WP14/15/DO5
15.2	Virtual Certification	WP14/15/DO6
15.3	Demonstration of track visual inspection by unmanned means (drones)	WP14/15/DO6
15.4	BIM model as support to communicate and populate the Station's Asset Management System	WP14/15/DO6

Table 4: 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 Twin.

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 organizations 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 optimized 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 optimize 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 optimize the allocation of resources to meet demand.

2. Incident response systems: Incident response systems provide real-time 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 minimize 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 optimize 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 real-time 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 optimize station operations and improve passenger experience.

Overall, decision support systems for railway stations are essential tools for station managers to make informed decisions and optimize 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 optimize 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 real-time information to station staff. The system also uses computer vision technology to analyse real-time video feeds from CCTV cameras to detect passenger flows and congestion patterns within the station.

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 characterized 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 being considered for the railway station asset management system will be intelligent analysis of videos recorded by CCTV cameras. In particular, it will be used to support the cleaning process (detection of rubbish, dirty surfaces, detection of overflowing bins, etc.). The work will use state-of-the-art virtual reality simulation technologies to create a digital 'station model' that will provide a source of data for learning and testing of vision algorithms, including those based on deep neural networks. Using this approach will make it fairly easy to acquire a diverse set of training data (to simulate a variety of situations), as well as to carry out initial testing of the system. Moreover, the simulation to reality gap assessment and the development of methods to reduce it will also be part of the proposed work. The digital model created will then be able to 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. They come 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 centralized repository that allows for the storage and management of large volumes of structured, semi-structured, and unstructured data 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 visualization, and business intelligence tools.

One of the primary benefits of a data lake is that it allows organizations to store and process large volumes of data from various sources in a cost-effective manner. It also enables organizations 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 revolutionize railway stations, particularly in their everyday usage devices such as elevators, door openers, escalators, and lighting. By utilizing 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 optimize 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 realize the potential of predictive maintenance systems in railway stations.

8.1.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

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.
Identification and analysis of station processes will allow for the recognition of significant KPIs related to the strategy and the implemented strategic goals. The proposed innovation will primarily be identified new KPIs, which 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 in order to improve economic, strategic and organizational efficiency.

What will the improvements be?
Linking various information and identifying key KPIs will definitely improve the station asset management system.

- KPIs will allow you to 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 you to track the progress or decline of results for a given goal,
- Continuous monitoring will enable efficient response to KPIs levels and faster decision in the event of alarming trends, changes in KPIs levels,
- KPIs will be considered in a structure where the main focus will be KPIs of the main process.

KPIs provide knowledge that enables quick decisions and prioritization 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 perfect 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 Use Case contributes to achieving the Key Performance Indicator of the overarching demonstrator #5 "Asset Management & Digital Twins", which is defined in [5, p. 140] as "VIII. The number of assets managed and monitored by Digital Twins is increased by 25 %." In addition, it also contributes to the overarching demonstrator #4 "Asset Management of Infrastructure Operation" and its KPI "VI. reduction of maintenance costs targeting 10% in specific use case".
Although the task was not initially linked to the overarching demonstrator #4 in the contract negotiation phase, it makes sense to highlight this natural connection here.

8.1.2.2. KPI1 – The number of assets covered by predictive maintenance increased to 25 %

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 KPI focuses on measuring the growth in the implementation of predictive maintenance strategies across assets within an organization. Predictive maintenance involves using data analysis, machine learning, and other advanced technologies to anticipate potential asset failures and schedule maintenance proactively, maximizing equipment uptime and reducing costly unplanned downtime.
The goal of this KPI 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, optimize maintenance schedules, increase operational efficiency and reduce overall maintenance costs.
How to compute KPI1

$$KPI1 = \frac{N}{M} \cdot 100\%$$

N - Total number of assets covered by predictive maintenance: This indicator measures the number of assets in the organization that are actively monitored and maintained using predictive maintenance techniques.
M – Total number of assets identified in 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.

N = number of assets covered by predictive maintenance
M – number of assets identified in project to be supported by predictive maintenance
Target value N = M*0.25

8.1.2.3. KPI2 – The number of accessibility assets covered by predictive maintenance increased to 50 %

Short description

Accessibility improvements at railway stations are crucial because they promote inclusivity and ensure that transportation 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 transportation 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, minimizing 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.

$$KPI2 = \frac{N_a}{M_a} \cdot 100\%$$

N_a - Total number of accessibility assets covered by predictive maintenance: This indicator measures the number of assets in the organization that are actively monitored and maintained using predictive maintenance techniques.

M_a – Total number of accessibility assets identified in 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 $N_a = M_a*0.25$

How to compute KPI2

No formula at the moment.

8.1.2.4. KPI3 – AVERAGE TIME OF CLEANLINESS INCIDENT DETECTION REDUCED BY 25%

Short description.
Benefits of the decision support system would be:
The KPI 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 KPI 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 KPI 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 organization seeks to respond more quickly to incidents, improve cleanliness standards, mitigate potential safety risks, and enhance overall operational efficiency.

How to compute KPI3

$$KPI3 = \left(1 - \frac{\hat{T}_{dss}}{\hat{T}}\right) \cdot 100\%$$

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 KPI3 = 10%

8.2. UC15.2: Virtual Certification Framework

The implementation of this use case will execute a complete instance of the virtual certification process for specific asset, to include track, by using technologies and methods developed in WP14 e WP15 tasks:

- 14.2 Track Condition data fusion in Point Clouds definition
- 14.3 Track Substructure Modelling and Simulation definition
- 14.4 Virtual Certification for railway infrastructure
- 15.1 Track Condition data fusion in Point Clouds
- 15.2 Track Substructure Modelling and Simulation
- 15.3 Virtual Certification for railway infrastructure verification and preparatory works for the second call

The use case tells a story that exemplifies the synergic use of advanced asset survey techniques and data processing, Digital Twin for data sharing, asset simulation to support conformity assurance and blockchain for process tracing and certification handling.
The use case implementation will stage the exchanges among IM, maintainers and validators

pursuing the asset certification by following the narrative:

1. IM exposes data asset as foundation for its Digital Twin in a common data environment.
2. IM performs track survey, update and enriches the Digital Twin, processes track status and triggers maintenance action.
3. Maintainer access asset data, plans and performs maintenance (this is out of the scope of the use case).
4. Maintainer updates and enriches the Digital Twin, requires verification of conformity.
5. Validator accesses asset data and performs the asset simulation as part of the full set of required verifications (which are out of the scope of the use case), issues statement of conformity.

The physical implementation of the use case will extend over different locations hosting the target assets.

8.2.1. Overall aim of the Use Case

8.2.1.1. PROBLEM TO BE SOLVED

The Virtual Certification acts as a common final purpose to align different initiatives that by themselves address a variety of basic needs of the IM by the use of Digital Twin.
Certificate issue and management: Railway companies need to issue, manage, and verify a huge number of certificates from stakeholders, in order 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 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 it is required. When many suppliers are hired to manufacture a product or complete 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.
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-, organization 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 leaves room for great inconsistency and inefficiency 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 normative specify the requirements for conformity assessment, although a certain degree of choice is left to validators on how to identify 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, undetected non-conformity. Alternatively, asset delivery time and cost may increase in the effort to overcome such limitations. Asset simulation is expected to alleviate this condition.

Digital Twin: Instead of having multiple systems for retrieving asset information, this use case allows Infrastructure Managers using a unique environment to access all information related to the digitalised assets, explore asset locations inside the point cloud and display the track conditions in synchronisation. This will increase and support further digitalisation of the assets and support proper decision making as well as work scheduling.
Track Substructure modelling and simulation: This use case aims to model the behaviour of the substructure based on the different operational and track infrastructure conditions. In this manner, IMs can assess in advance how current conditions can evolve in the future and proactively respond and mitigate the risks. The simulated forces and how these are distributed to the substructure will act as an additional complementary and insightful data stream for the IMs to support objectively their maintenance decisions and explore the real root-cause of the events.

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 those limitations.
2. Certificate retrieval, analysis and update: existing systems for certification management are heterogeneous, limited in terms of availability, dependency on third parties and time consumption. 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 the 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.

Digital Twin: Despite the evolution of the surveying mapping as well as the mechanised diagnostic systems, yet the outputs of these inspections remain separated in SILOs without being fully integrated. The implementation of the Track infrastructure Point Cloud viewers nowadays can be considered detached from the diagnostic information attributed to the infrastructure. Infrastructure managers must use different systems and tools to access this information which makes the inspection and verification process of the digitalised assets as well as their condition time-consuming and cost demanding. Therefore, a unique environment where all these information can be linked and integrated is of imperative importance for supporting the inspection preparation of the required maintenance work.
Track Substructure Modelling and Simulation: Understanding how the substructure of the track behaves under different loading conditions and speeds and most importantly how substructure condition correlates to track geometry defects requires development of the substructure physical model whose outputs will be linked to the actual conditions of the track. The development of an interface which will be able to present and overlay the simulated outputs with the real conditions of the track will allow IMs to review how the distributed forces impact the track and hence prescribe the appropriate maintenance work.

8.2.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

To be granted access to the railway infrastructure, an IM/RU must certify that a product, system, or process is in compliance with industry, legal and regulatory standards, safety requirements, and specifications. Compliance needs to be demonstrated through the production of appropriate evidence of conformance to Notified Body (NoBo) when certifying compliance with TSIs (Technical Specification for interoperability), Designated Body (DeBo) when applying the National Rules of a member state and to Assessment Body (AsBo) when providing safety related evidence of conformity with Common Safety Methods for Risk Assessment (CSM-RA).
This Use Case focuses on certification management for safety certificates following a relevant maintenance intervention on track by addressing the following sub-problems:

- Integration between the digitalised infrastructure with immersive point clouds and track condition diagnostic data using a unique Web-based platform reaching a TRL7.
- Track Substructure modelling and simulation of the generated forces on the substructure based on the track geometry irregularities that have been identified based on EN 13848 series.

- Synchronisation of the simulation outputs with the Track Condition data in a unique web-based environment reaching TRL7
- Certification process tracing using blockchain technology reaching TRL6.
- Organization of shared data as Digital Twin reaching TRL6.

8.2.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Enriching the Digital Twin with diagnostic sensor data and assets' simulated behaviour, point clouds and blockchain technology allows stakeholders to automatically store, retrieve and verify certificates.
Use of **blockchain** for certification process tracing and certificate management: digitizing information is not sufficient to increase efficiency, productivity, and quality if the workflow in which digitalized information is managed is inefficient.
Blockchain is a distributed ledger technology that can address these problems, considering 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 optimize 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 optimization.
Use of **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 the access rights. It is an enabling technology supporting the general improvement of all workflows build upon it.

This use case increases safety on the track (less boots on tracks) by enabling the remote inspection of track geometry and verification of track geometry defects.
Use of Track Substructure Modelling and Simulation: supports infrastructure managers (IMs) to monitor the condition of the substructure and the impact of the contact forces generated by the wheel-rail-track interaction. This enables concurrently the correlation between the simulated forces distributed to the substructure with the presence and propagation of track geometry defects recorded by the diagnostic vehicles. In this manner, IMs will obtain a complementary data stream that will support proper root-cause analysis and advance objective decisions towards prescriptive maintenance…

In general terms, we propose to alleviate all the IM problems considered in chapter 8.2.1.1 by making digitalization pervasive in the workflows. Currently, the number of assets managed by 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 solutions in the Use Case contribute to the objectives of the demonstrators #5 "Asset Management & Digital Twins" and #6 "Design and Manufacturing" by integrating the process of certification management, asset simulation and asset data monitoring on a common Digital Twin. The KPI to measure the achievement of the Use Case objectives are:

- KPI1: the number of assets managed and monitored by Digital Twins is increased by 25%.

8.2.2.2. KPI1 – THE NUMBER OF ASSETS MANAGED AND MONITORED BY DIGITAL TWINS IS INCREASED BY 25 %

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 KPI1

The following formulas is used to calculate the KPI1:

$$KPI1 = \sum aA$$

Where:

UC, means use case scenario.

aA, means asset Anomalies detected during the digitalisation process.

8.3. UC15.3: Demonstration of automatic track visual inspection by unmanned means (drones)

8.3.1. Overall aim of the Use Case

8.3.1.1. 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 (possibly in a special testing vehicle) can be time-consuming, costly, detrimental to normal operations and sometimes hazardous. Drones, with their ability to fly and 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 present 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 infrastructure managers themselves to conduct the visual inspection, rather than skilled specialist drone pilots who would not always be available at short notice in an unplanned scenario.

Furthermore, in order to achieve higher cost effectiveness, IM needs algorithms for the processing of visual and other data to match them to existing infrastructure models and identify new suspicious states of assets. These algorithms need to be trained on images taken from the same vantage points that a drone would occupy rather than from the typical height of a testing vehicle. In short, IM needs drones that can fly mostly automatically with limited supervision, communicate efficiently with the control post, recharge quickly in the field to finish relatively long missions, and feed data to algorithms that can quickly match them with integrated models of the infrastructure.

8.3.1.2. 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 what 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 authorization 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 continually send large amounts of data and to maintain the related field equipment 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 air.

8.3.1.3. 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 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 the collected data to match other digital models of infrastructure and provide input for infrastructure management decisions,
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 of 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 certified by the civil aviation authorities. For item 2, the same web-based interface will be integrated with digital maps of the existing infrastructure to allow streamlined waypoint definition and mission planning. For item 3, a generalized 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 two test tracks with different operational conditions.

8.3.1.4. 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 environmental impact of these inspections. Savings calculated by (Plowman Craven, 2023) for the related use case of surveying include 20% savings of time, 30% savings of costs and 85% savings of CO_2 emissions compared to traditional methods. Surveying is generally more labour intensive 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.
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).

8.3.2. UC15.3: demonstrator's KPI

8.3.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The Use Case contributes to achieving the Key Performance Indicator of the overarching demonstrator #5 "Asset Management & Digital Twins", which is defined in (EU-Rail Governing

Board, 2022, str. 140) as "VIII. The number of assets managed and monitored by Digital Twins is increased by 25 %." In addition, it also contributes to the overarching demonstrator #4 "Asset Management of Infrastructure Operation" and its KPI "VI. reduction of maintenance costs targeting 10% in specific use case".
Although the task was not initially linked to the overarching demonstrator #4 in the contract negotiation phase, it makes sense to highlight this natural connection here.

8.3.2.2. KPI1 – THE NUMBER OF ASSETS MANAGED AND MONITORED BY DIGITAL TWINS IS INCREASED BY 25 %

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 they 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 has to 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 period, e.g. over three months. In such a setup, there would typically be a single routine field visit 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 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 KPI1
The KPI will be computed using the formula:

$$KPI1 = \frac{VMTF_{UC} + \sum_{AC} k_{ACi} VMAF_{ACi_{UC}}}{VMTF_B + \sum_{AC} k_{ACi} VMAF_{ACi_B}} - 1,$$

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 take into account relative density of the asset class on the track. The assumption is that the frequency will increase relative to baseline while achieving KPI2, i.e. overall cost reduction.

8.3.2.3. KPI2 – reduction of maintenance costs targeting 10% in specific Use Case

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 itself (primarily by reducing the amount of in-person transportation and staff time necessary to achieve it), but also the cost of the disruption which the repair addresses (degraded track velocity and/or capacity), and the cost of the monitoring necessary under traditional conditions (e.g. fixed point cameras and routine in-person inspections). In particular, the reduction of the mean repair time translates into direct savings for the infrastructure manager.

How to compute KPI2

The KPI will be assessed using three components according to the formula:

$$KPI2 = 1 - \frac{MRC_{UC}+MDC_{UC}+MMC_{UC}}{MRC_B+MDC_B+MMC_B},$$

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 weight in the mean will be determined by expert assessment and historical data.

8.4. UC15.4: BIM model as support to communicate and populate the Station's Asset Management System

The implementation of this use case will provide the main support to create an accurate Digital Twin. The BIM model must contain all the geometric and asset data to be used by the asset management system and the DT solution.

8.4.1. Overall aim of the Use Case

8.4.1.1. PROBLEM TO BE SOLVED

There are many problems concerning the operation and maintenance, most of time the information is not complete, or structured. The infrastructure manager wastes a lot of time sorting, organizing, and capturing information to create a useful data base. Several times the

information is not located in the same place, and we have a poor interoperability. One of the most important problems to solve is to have a functional station and a global digital solution that concentrates all the station's information, connected, with real time data 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 necessary 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 support.
The main problem to be solved is to improve the Asset management process by winning in efficiency and efficacy, which will be traduced in a better station performance, reducing operation and maintenance costs, winning time and better decision-making strategy.

8.4.1.2. INDUSTRY CURRENT POSITION / BASELINE

This use case proposes an integrated approach that combines BIM and asset management methodologies to optimize the performance and longevity of infrastructure assets. We will define a process, the technologies to use and the involved persons.
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 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 to organize site's information after delivery. According to The National Institute of Building Sciences (NIBS) and costs can reach between 23,000 and 36,000 euros (Freeman 2009).
A study by The National Institute of Standard and Technology (NIST) estimates losses of about 14.4 billion Euros in the USA. These losses are associated with poor interoperability of information and 2/3 (67%) of losses are generated in the operating process, 8.2 billion are due to the resolution of

interoperability problems, manual capture of information, while 2.2 billion due to verification audits, repeated information, software maintenance, updates, restart of work due to poor information and error prevention; moreover the cost of a poor performance of the technicians and the FM team is 1.5 billion.
CMMS (Computerized Maintenance Management System) is used below its usual performance due to low updating and poor information sources.

8.4.1.3. 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 organization's efficiency, financials, and overall operations.
This inefficiency can be also produced by an inaccurate inventory because the system is not adapted to see the discrepancies between physical assets and database, 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 represents 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 Digital Twin
-Respect 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 TRL8/9 will be the uncertainties regarding its long-term performance and durability in real world, the demonstrator can cover a limited perimeter while the TRL8/9 demonstrator will cover more use case to be deployed in the real world.
The user feedback in TRL6 will be limited to the stakeholders of the demonstrator and in TRL8/9 we can have feedback from real users and stakeholders, in real operation during a relevant time period.

8.4.1.4. 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 target measurable objectives of the work are achieved, the benefits or improvements of using a digital twin supported by BIM will be a game changer for the IM. The IM will adopt better asset management practices to increase productivity and extend the useful life of equipment, he will optimize the use of resources, including materials, and energy with important cost savings, he be able to operate the station more efficiently reducing time waste.
The use of digital twin can facilitate the data-driven decision-making, robust management solution will 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 digital twin provides a virtual representation of the physical asset, and he can access to a detailed 3D models and simulations allowing to visualize 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 IM, this collaboration approach enhances problem-solving capabilities and fosters a culture of continuous improvement within the maintenance team.

8.4.2. UC15.4: demonstrator's KPI

8.4.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

KPI1: The number of assets managed and monitored by Digital Twins is increased by 25 %.
KPI2: Data quality treated in the Digital Twin
KPI3: Time reduction to create a database for asset management.

8.4.2.2. KPI1 – The number of assets managed and monitored by Digital Twins is increased by 25 %

Short description
The KPI indicates that there has been a 25% growth in the monitoring ***of assets*** compared to the actual assets monitoring in Digital Twin.
How to compute KPI1
No formula at the moment.

8.4.2.3. KPI2 – Data quality treated in the digital twin

Short description
The KPI "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 utilized. This KPI2 will also measure the conformity of the BIM model according to the requirements of the BIM Execution Plan
How to compute KPI2
No formula at the moment.

8.4.2.4. KPI3 – Time reduction to create a data base for asset management

Short description

The KPI "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 KPI focuses on reducing the time required to collect, collate, and organize asset-related data into a centralized and structured database, which is critical for the creation of a digital twin, and to populate the asset management system.

How to compute KPI2

No formula at the moment

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 additive manufacturing repair processes (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 5.

UC ID	Title	Relevant WP/DO
16.1	Green tracks and turnouts	WP16/DO6
16.2	Resilient and sustainable lines	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
18.6	Purchasing railway maintenance robots	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 5: Cluster F Use Cases

9.1. UC16.1: Green tracks and turnouts

9.1.1. Overall aim of the Use Case

9.1.1.1. PROBLEM TO BE SOLVED

Railway transportation is the most environment friendly form of transportation but has high emission of CO2 during production and operation. Optimization 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, squats in rail and understanding the real condition of rail material.

9.1.1.2. INDUSTRY CURRENT POSITION / BASELINE

Concrete is a common material in the railway e.g. for sleeper system, although it is damaging to the climate due to energy intensive cement production which also produces high carbon dioxide. The cement industry is responsible for about 8% of global carbon dioxide emissions, which is more than double those from flying or shipping. Current cement type commonly used has a high CO2-content and global warming potential (GWP). Replacing the cement type would result in significant reduction in CO2 during sleeper production.

Today's rail standards prescribe several different mechanical tests for securing the properties of the rails. However, all of this concern the virgin rail material, e.g. the properties before any rolling contact fatigue loading has occurred. 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.

To maintain serviceability of the railway system all sub-systems need to function in various weather conditions. 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 CO_2 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 MEASURABLE OBJECTIVES

Maintenance free sleeper system for tracks and turnouts
The total lifespan of infrastructure subsystems (e.g.: turnouts,) can be limited by one single component. Regarding turnouts, the limited lifetime of ballast beds can be crucial and related maintenance processes are additional major cost drivers for railway infrastructure companies and reduce the availability. Furthermore, the settlement processes occurring with conventional

turnout systems are very unequal in regards of their special distribution which makes turnouts especially prone to need maintenance in form of tamping or a change of their ballast bed before the estimated product lifetime has ended.

Maintenance reducing squat resistant rail demonstrator

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.

Test methods, requirements and certification of materials for rail

Rail standards prescribe several different mechanical tests for securing the properties of the rails but does only consider the properties before any rolling contact fatigue loading has occurred. 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 requirements after run-in, also hinder a fair comparison between different rail materials 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.

Emission free turnout heating system

Transportation by railway is environment friendly compared to other transportations but besides 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 CO_2 per turnout and year. Geothermal turnout heating that meets the railway-related demands in terms of safety, robustness or reliability hold 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

Maintenance free sleeper system for track and turnout

Especially system critical railway infrastructure in congested areas around highly populated cities would profit enormously if a newly developed system would improve 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, settlement processes shall be minimised. Settlement processes occurring in turnouts shall be distributed much more homogeneous over the whole turnout then 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 no or very little tamping operations through its entire product lifetime, which would increase for the entire turnout as well. Developed sleepers has optimized bearing area, minimised settlement process, and less need for tamping operations through the entire product lifetime.

Maintenance reducing squat resistant rail demonstrator
Development of new steel grades for railway operation will contribute significantly to eliminate the problem of squats. The 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 concentrated high 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%.

Test methods, requirements and certification of materials for rail
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. Further, complementing rail standards with property requirements after run-in could help in design and homologation of new rail materials.

Emission free turnout heating system
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 validation of the geothermal technology via installing a turnout which is equipped with the geothermal heating system at a frequently used railway line will be executed. Special focus is laid on monitoring the correct functioning 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. Furthermore, operational aspects shall be dealt which such as the development of a drilling technology which is ideal for the use at electrically powered railway systems and is integrated into a railway vehicle to ensure efficient transport to different drilling sites.

9.1.2. UC16.1: demonstrator's KPI

9.1.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

- 20% time reduction from design to manufacturing
- 20% cost reduction in parts and assets

9.1.2.2. KPI1 – 20% 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 KPI1

To compute the KPI1, time needed with traditional methods for design and manufacturing of relevant railway assets in the work package as well as maintenance operations will be estimated and compared to project result. Estimated values will be provided by manufacturers and infrastructure managers for the traditional methods and in the use case for the new methods. The KPI can be evaluated using the formula below.

$$KPI1 = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$$

A positive KPI1 indicates that the estimated time for the new method is less than the time required for traditional methods.

9.1.2.3. KPI2 – 20% COST REDUCTION

Short description

Compared to the current state of the art the developed Use Cases will contribute to 20% cost reductions in design and manufacturing of railway parts and maintenance operations in track.

How to compute KPI2

To compute the KPI2, costs of traditional methods for design and manufacturing of relevant railway assets in the work package as well as maintenance operations will be estimated and compared to project result. Estimated values will be provided by manufacturers and infrastructure managers for the traditional methods and in the use case for the new methods. The KPI can be evaluated using the formula below.

$$KPI2 = \frac{Cost_{traditionl\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$$

A positive KPI2 indicates that the estimated cost of the new method is less than the cost of traditional methods.

9.2. UC16.2: Resilient and sustainable lines

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. The use case includes enhanced decision-making in track infrastructure considering climate change impact.

9.2.1. Overall aim of the Use Case

9.2.1.1. PROBLEM TO BE SOLVED

The use case will provide a more realistic understanding of dynamic effects on bridges and allow existing bridges to be upgraded in order to support higher allowable axle loads without strengthening or replacement. This will also allow for more cost-efficient design of new bridges. The use case includes enhanced decision-making in track infrastructure considering climate change impact.

9.2.1.2. INDUSTRY CURRENT POSITION / BASELINE

Bridge dynamics

Recent research suggests that current values given in standards for bridge resonance and dynamic amplification factor are overly conservative. There is a potential for some existing bridges to allow for 20% more load than in current requirements.

Scour-flood tools

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 limitations such as the vulnerability of all railway assets has not been integrated in the tool and knowledge of asset vulnerability is often limited to one water level due to lack of scaled data.

Trackbed reinforcement using geogrids

Geogrids are barely used in trackbed 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.

A predictive approach to assess the flood risk for the French railway infrastructure asset management (PLATIPUS)

The French network is covered by 10 000 waterway infrastructures. Since the current infrastructure maintenance policy was defined in 1978, the frequency of incidents due to severe flooding events is increasing and cannot be prevented in advance. The infrastructure manager spends around 4 million euros per year for maintenance work.

9.2.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Higher payload by improved DAF
Dynamic effects from passing trains are often accounted for by a dynamic amplification factor, e.g. in EN 1991-2 Annex C. Part of the dynamic effects are often attributed to the wheel-rail contact forces and highly depends on the track irregularities and the vehicle suspension system. Recent research suggest 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 assure that no adverse effects occur due to passing trains at 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.

Scour-flood tools
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.

A predictive approach to assess the flood risk for the French railway infrastructure asset management (PLATIPUS)
Climate change increases the frequency of heavy raining which have led to increased damages in the railway infrastructure due to severe flooding events, erosion and scour. Maintenance and prediction of risks in the infrastructure needs to be enhanced to ensure the conditions of the network and safe train operations.

Trackbed reinforcement using geogrids
Track exploitation efficiencies are partially linked to the presence of disorders in the trackbed. 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.

9.2.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

Higher payload by improved DAF
The project aims to use digitalisation to develop train-track-bridge interaction models for realistic estimates of dynamic effects on bridges. The models will be improved by long-term monitoring on

selected bridges, available data of recorded track irregularities and possibly on-board train data. 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 strengthening or replacement and new bridges may be designed more cost-efficient.

Bridge resonance

The project aims to use digitalisation to increase the understanding 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.

Scour-flood tools

A tool was created to help build the crisis management documents at SNCF. The tool was initially used to determine the level of exposure to flood events on embankments and cuttings and has been extended to other systems. Analysis have been made at a national scale where 50% of strategic lines exposed to floods have been studied. The tool will be further developed with the purpose to consult non experts in the use of data on vulnerability and flood hazards and for capitalizing the risk of flooding for experts within the organization.

A predictive approach to assess the flood risk for the French railway infrastructure asset management (PLATIPUS)

The objective is to maintain the infrastructure with respect to risk of scour and prevent train operations from de-railing. A database of water-way infrastructure considering various parameters will be developed. To evaluate the sensitivity of the structures, scour risk prediction will be generated by machine learning. Realtime monitoring during flooding will alert and stop the circulation of train on-time.

Trackbed reinforcement using geogrids

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.

9.2.2. UC16.2: demonstrator's KPI

The same of UC16.1 see chapter 9.1.2.

9.3. UC17.1: In-situ AM repair machine for rails, switches and crossings

<u>In-situ AM repair machine for rails, switches, or crossings:</u> 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.

9.3.1. Overall aim of the Use Case

9.3.1.1. PROBLEM TO BE SOLVED

Some of the damages caused by 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.

9.3.1.2. 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 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.

9.3.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 minimizes 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.
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.

9.3.1.4. 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.

9.3.2. UC17.1: demonstrator's KPI

9.3.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

25% Extension of remaining life of the rail, Switch&Crossings elements

9.3.2.2. KPI1 – Extension of remaining life of the rail

Short description
The use of an automated AM technology leads to a significant time reduction in contrast to the currently used manual welding process.
How to compute KPI1
Comparison of the lifetime of a railway rails, Switch&Crossings elements using the current repair build-up welding process to the lifetime using the AM repair Laser-DED process. Comparison of the costs from the current manual repair build-up welding process to the costs of the AM automatic repair process.

9.4. UC17.2: AM repair machine for wheels

9.4.1. Overall aim of the Use Case

9.4.1.1. 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 AM method to "remanufacture" the wheel.

9.4.1.2. 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.

9.4.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Alternative solution to return in services the wheels by using Additive Manufacturing (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.).
On later stages will implement AM repair machine to "remanufacture" worn wheels.

9.4.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

To stablish AM methods as alternative for the current state of the art, we need to tackle first the technical uncertainty of using non-conventional manufacturing method for safety component like the wheel, and therefore to use manufacturing method not considered right now inside the standard EN 13262 Railway applications - Wheelsets and bogies - Wheels - Product requirements.
To do that, intensive characterization campaign of mechanical properties achieved using different technologies 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 results of the test should allow identifying the best process and material combination for wheel repairing.
Once technical viability is assured, next step is to work on the cost-effective solution, where to install the repair machine and so on.

9.4.2. UC17.1: demonstrator's KPI

9.4.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

Extension of remaining life

9.4.2.2. KPI1 – Extension of remaining life

Short description
Extension of remaining life of the wheel
How to compute KPI1
Test at lab scale to estimate the endurance of repaired wheel.

9.5. UC17.3: In situ repair of track metallic assets

Repair and reinforcement by laser technology

9.5.1. Overall aim of the Use Case

9.5.1.1. 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.

9.5.1.2. 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.

9.5.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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.

9.5.1.4. 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.

9.5.2. UC17.2: demonstrator's KPI

9.5.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

25% Extension of remaining life of the rail, Switch&Crossings elements

9.5.2.2. KPI1 – Extension of remaining life

Short description

KPI 1- For repair: Extension of remaining life.

The durability of the repaired components is expected to be increased, as the new laser treatments will allow:

- To reduce thermal stressing and dilution of weld seams, on difficult to process materials such as common manganese steels, e.g. on frogs.

- To minimise defects (cracks, pores, burns) generated during recovery processes on previously repaired component areas with cracks, deformation, porosity and thermal stress.

How to compute KPI1

Comparison of the lifetime of a railway rails, Switch&Crossings elements using the current repair build-up welding process to the lifetime using the AM repair Laser-DED process. Comparison of the costs from the current repair build-up welding process to the costs of the AM repair process.

9.6. 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 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).

9.6.1. Overall aim of the Use Case

9.6.1.1. PROBLEM TO BE SOLVED

For the repair of railway crossings, MMAW (Manual metal arc welding) is widely spread. The significant amount of manual work and the small number of the available filler metals are characterizing 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.

9.6.1.2. 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.

9.6.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 laboratory (TRL 4) and this will lay the foundation for an AM repair process for railway crossings.

9.6.1.4. 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 possibly 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.

9.6.2. UC17.4: demonstrator's KPI

9.6.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

- KPI1 - For repair: Extension of remaining life 25%
- KPI2 - 20% time reduction (from design to manufacturing)
- KPI3 - 20% cost reduction

9.6.2.2. KPI1 – 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 noticeable extended compared to a usual repair.
How to compute KPI1
Comparison of the lifetime of a railway crossing using the current repair build-up welding process to the lifetime using the AM repair welding process.

9.6.2.3. KPI2 – 20% time reduction (from design to manufacturing)

Short description
The use of an automated AM technology leads to a significant time reduction in contrast to the prevailing manual welding process. Therefore, also demonstrators are faster available for testing purposes.
How to compute KPI2
Comparison of the manufacturing time from the current repair build-up welding process to the time of the AM repair welding process.

9.6.2.4. KPI3 – 20% cost reduction

Short description.
Expensive metal alloys are only used where it is necessary regarding the function. Everywhere else cheaper standard alloys can be used in form of semi-fines goods. Thus, the concept of the combination of semi-fines goods and the use of the WAAM process only for the relevant areas will also be time and therefore cost saving.
How to compute KPI2
Comparison of the costs from the current repair build-up welding process to the costs of the AM repair welding process.

9.7. UC17.5: Additive Manufacturing of large interior flame-retardant polymer spare part

The demonstrator is a large interior flame-retardant polymer component. The component must follow the EN-45545-2 standard and reach the R1-HL2 requirements. The dimensions of the part will be about 1m. The component can be a driver's cab desktop, a command panel or 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.

9.7.1. Overall aim of the Use Case

9.7.1.1. PROBLEM TO BE SOLVED

RU maintain 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 RU.

9.7.1.2. 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 part are limited by the capacities of printers. The capability of large printers needs to be demonstrated and compared to railway specification and standards.

9.7.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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.

9.7.1.4. 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.

9.7.2. UC17.5: demonstrator's KPI

9.7.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

- KPI1 - 20% time reduction (from design to manufacturing)
- KPI2 - 20% cost reduction in parts and assets

9.7.2.2. KPI1 – 20% 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 be divided by 6 with additive manufacturing processes.
How to compute KPI1
For the demonstrator, the lead time between conventional and additive processes will be compared.

9.7.2.3. KPI2 – 20% 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 KPI2
The demonstrator costs produced by conventional process and additive manufacturing will be compared.

9.8. UC17.6: Digital warehouse

The Digital Warehouse will focus on methods and technologies railway operators can use to procure or manufacture spare parts on-demand.

9.8.1. Overall aim of the Use Case

9.8.1.1. 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 identify 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.

9.8.1.2. 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 thru 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 start to introduce additive manufacturing for the manufacturing of spare parts, and it's use for serial parts.

9.8.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 which materials and additive manufacturing technologies can be used in the railway sector. Integrate knowledge of the overview as input of the identification process

9.8.1.4. 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.

9.8.2. UC17.6: demonstrator's KPI

9.8.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

- KPI1 - 20% time reduction (from design to manufacturing)
- KPI2 - 20% cost reduction in parts and assets

9.8.2.2. KPI1 – 20% TIME REDUCTION (FROM DESIGN TO MANUFACTURING)

Short description
The digital storage of the digitals 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 KPI1
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.

$$KPI1 = t_{saving} = \frac{t_{traditional} - t_{digital\ warehouse}}{t_{traditional}}$$

9.8.2.3. KPI2 – 20% 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 till all parts of an order batch are used
- Opportunity savings due to reduced lead times etc.

How to compute KPI2

$$C_{total} = \frac{C_{spare\ part\ order}}{N_{parts\ in\ order}} + \frac{C_{spare\ part\ order}}{2} * \left(\frac{i+l}{100}\right)^{\frac{N_{parts\ in\ order}}{D_{yearly\ average\ demand}}} - C_{oppertunity\ savings}$$

The cost between a standard order with classical minimum order quantities will be compared to a reduced order quantity enabled by a digital warehouse.

9.9. 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.

9.9.1. Overall aim of the Use Case

9.9.1.1. 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 measurements systems or due to the difficulties to transport them at the right location) the traditional means of inspection (measuring trains...) cannot be mobilized or not in such a flexible way as required to carry out particular surveillances. IM 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 prioritize 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.

9.9.1.2. 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.

9.9.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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, optimize maintenance activities, and result in long-term cost savings. This integrated approach revolutionizes 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, characterized 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 old one 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.

Localization: These different sub-uses involve the localization of the robot on the longitudinal axis of the track, especially in contexts where localization by GNSS is not possible (tunnels). The robot will embark a localization 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 prioritize 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.

9.9.1.4. 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 prioritization 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.

9.9.2. UC18.1: demonstrator's KPI

9.9.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

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.

9.9.2.2. KPI1 – 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 KPI1

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 lite time is 2 time 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).

$$C_{WF} = \#\,workforce \times 8 \times 200 \times \#\,work\,session\,per\,day \times 100 C_{NRJ} = NRJ\,Cost\,for\,1\,hour\,of\,operation \times 8 \times 200 \times \#\,work\,session\,per\,day\,\#\,insp.track\,length = operational\,rate \times 8760 \times service\,life \times average\,insp.speed Cost\,per\,km = \frac{C_{WF} + C_{PURCH} + C_{MAINT} + C_{NRJ}}{\#\,inspected\,track\,length}$$

Where:

$C_{WF} = \#\,workforce \times 8 \times 200 \times \#\,work\,session\,per\,day \times 100$

$C_{NRJ} = NRJ\,Cost\,for\,1\,hour\,of\,operation \times 8 \times 200 \times \#\,work\,session\,per\,day$

$\#\,insp.track\,length = operational\,rate \times 8760 \times service\,life \times average\,insp.speed$

9.9.2.3. KPI2 – 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 KPI2

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.

$$kpi2\_0 = \frac{\#\,of\,false\,positive\,detections}{\#\,of\,real\,defects}$$

$$kpi2\_1 = \frac{\#\,of\,false\,negative\,detections}{\#\,of\,real\,defects}$$

9.10. UC18.2: Automated installation of ERTMS balises and axle counters

The use case is to integrate current technology and combine it for rail related purposes. It demonstrates how the current state of technology benefits its application and how future robots could enhance that.

9.10.1. Overall aim of the Use Case

9.10.1.1. PROBLEM TO BE SOLVED

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 in the Netherlands. Furthermore, the current signalling systems has reached its limitations. Therefore, the ambition is to accelerate the roll out of ERTMS and hopefully complete it by 2040.

9.10.1.2. INDUSTRY CURRENT POSITION / BASELINE

The current 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 application of robots will expand the capacity.

9.10.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Track work is typically heavy work physically and mentally. The work is typically carried out at night when amount of traffic is low. The equipment used by trackworkers are heavy and powerful. The work method requires track works to bend over or work on their knees.
Robots can work any time, are powerful and able to manoeuvre and position themselves. Therefore, robot can do heavy repetitive work for the installation. The use case is to mount the ERTMS balise and axle counter on the track. Operators will be relieved from lifting any heavy equipment or handling powerful tools.

9.10.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

The infra manager expects that if the robot is a success, more robots will be developed for the construction and maintenance of its infrastructure. The infra manger hopes that the availability will be sufficient to ensure that the track network can be renewed and maintained at stable/lower construction and maintenance prices.

9.10.2. UC18.2: demonstrator's KPI

9.10.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

The list of KPIs is chosen based on the contribution that the robot can provide for Strukton. First of all, its use is the most important factor. Second, the effect it has on tenders determines its economic value. Third, the benefit on health and safety by letting the robot execute heavy repetitive work that is otherwise done by humans.

9.10.2.2. KPI1 – 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 problem of

- Lack of staff
- Improve health conditions
- Quality of end-results in terms of recorded output and quality insurance

Problems above are based on signals from government, universities and financial institutions.
How to compute KPI1
This KPI is more in terms of statement of the stakeholders qualifying the end results. Criteria to be included are:

- Are the robots autonomous: do they use robotised principles
- Do they perform the task they are supposed to
- Is the development a contribution for future developments

9.10.2.3. KPI2 – TENDER OFFER

Short description.
When tenders are proposed for the installation of axle counters and balises. The robot will affect the tender offer.
How to compute KPI2

$$[KPI\ 3.3]\ \text{tender offer development} = 1 - \frac{\text{tender offer price with robot}}{\text{tender offer price conventional}}$$

9.10.2.4. KPI3 – 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 KPI2

$$[\text{KPI } 3.4] \text{ shifts by robot development} = 1 - \frac{\text{shifts performed by robot}}{\text{shifts performed by humans}}$$

9.11. 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 DO 7.

9.11.1. Overall aim of the Use Case

9.11.1.1. PROBLEM TO BE SOLVED

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.

9.11.1.2. INDUSTRY CURRENT POSITION / BASELINE

In France in 2020, the disinfection due to the Covid-19 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 COVID19 infection. Many solutions have been provided from IM and RU to react immediately in the evolving crisis, and many of them have been forced by the contingency without rational time for evaluating pros and cons from the economic or engineering point of view. In this perspective, a more systematic approach with well-designed robotics solutions that can better face ordinary or critical disinfection problems could minimize process costs.

9.11.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 we are working with the TRL6, it would be accepted that it might need a human intervention one time out of five.

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 we are targeting a 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.

9.11.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

A mobile disinfection robot can be useful for professional and safe sanitation of large 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 sanitized;
- **Low disinfection time** in 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.

9.11.2. UC18.3: demonstrator's KPI

9.11.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

A possible list of KPIs which can be easily related to a disinfection robot within Railway's environments are the following:

1. **D**isinfection **T**ime (**DT**)
2. **D**isinfection **C**ost (**DC**)

All these measurable KPIs 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.

9.11.2.2. KPI1 – DISINFECTION TIME (DT)

Short description

If the robot is too slow, it will not give the expected service or too many robots will be needed (which will greatly increase the LCC).

The disinfection time of the robot (or multiple robots) should be around 20-25 min per train: We would the robot to disinfect 10 trains in around 4h (in some context this value corresponds to the maximum number of trains that are available for disinfection outside of rush hours, which is what saturates the robot's capacity).

This disinfection time is calculated with a robot speed of 0,4 m/s and a train of 400m.

$$\frac{400m}{\left(0{,}4\ \frac{m}{s}\right)} \div 60s \approx 20\ \mathrm{min}$$

Disinfection time can also depend on the shape factor of the environment where the robot shall operate, concerning the technology being used.

How to compute KPI1

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 sanitizing.

1. **In case of chemical compound**, the KPI can be calculated

$$DT = \frac{\text{Volume of the disinfection area}}{\text{Disinfection device flow rate}}$$

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)**, a specific formula is not used to calculate disinfection time, due to the fact that the time of exposure required depends on various factors, such as the intensity of UVR emitted by the device and the specific sensitivity of the microorganism being targeted. In 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, by using an experimental approach, the KPI can be calculated by considering the time passed for the whole process, then considering that time as effective after a demonstration that surfaces and volumes are sanitized (e.g.: by chemical analysis).

9.11.2.3. KPI2 – 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 KPI2

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 Life Cycle Cost (LCC) of the technical system (one or multiple robots) needed to ensure the disinfection time above indicated by the number of trains cleaned over the same period of time (N_{TRAINS}).

$$DC = \frac{\text{LCC of the technical system}}{\mathrm{N_{TRAINS}}}$$

The LCC will be determined in a later stage.

9.12. UC518.4: Train underbody inspection

ARGO (**A**utonomous inspection of **R**ollin**G** st**O**ck) will help maintenance crew 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, gate provide limited views of certain organs, for instance in the case of the train underbody. 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).

9.12.1. Overall aim of the Use Case

9.12.1.1. PROBLEM TO BE SOLVED

The overall problem to be solved by the Railway Undertaking (RU) thanks to introducing a train underbody inspection robot such as ARGO 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.

9.12.1.2. INDUSTRY CURRENT POSITION / BASELINE

Nowadays, 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 it is stopped 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 get increasingly complex. Even if they reduce the unavailability of rolling stock when the failure has a certain regularity of occurrence, it is not convenient to apply scheduled maintenance techniques when a fault is difficult to be predicted. Furthermore, manual inspections involve multiple risks and disadvantages, such as subjectivity in measuring and reporting data, risks related to workers' safety, possible oversights and defaults connected to the human error, and costs and time for both the process and staff training. Therefore, all these factors limit the effectiveness and efficiency of the current inspection process.
Therefore, ordinary maintenance processes represent a critical and fundamental aspect in order to ensure safety and efficiency in rail transportation. 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 onset 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.

9.12.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 summarized 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:
    - thickness of pads;
    - thickness of brake disk;
    - state of relevant surfaces from the mechanical point of view.
- Recognition of possible leaks of crucial components.

9.12.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

RU which are going to implement 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 of performing, integrating, and replacing some functions currently performed by operators - represents an intrinsic advantage in terms of safety and personnel costs, then optimization 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 itself with IoT (Internet of Things) which is starting to influence the public transportation.

Everything is reflected on the evolution of rolling stock maintenance plans from preventive to predictive. Predictive maintenance represents the killer application to compete within a globalized 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 accessing the train underbody;
- Enhancement of the inspection procedure by structured and tracked data acquisition;
- Make the inspection procedure possible in conventional train stations rather than in dedicated maintenance plants only.

9.12.2. UC18.4: demonstrator’s KPI

9.12.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

A possible list of KPIs which can be easily related to ARGO robot are the following:

Global KPI

1. **M**aintenance **C**osts (**MC**);
2. **M**aintenance **T**ime (**MT**);
3. **D**efects **I**ndex **(DI)**;

These measurable KPIs 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 shall be possible to consider only a specific group of rolling stock under observation.

		A	**B**	**C**
KPI1	**M**aintenance **C**osts (**MC**)			X
KPI2	**M**aintenance **T**ime (**MT**)			X
KPI3	**D**efects **I**ndex **(DI)**	X	X	

9.12.2.2. KPI1 – Maintenance Costs (MC)

Short description

This KPI 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 KPI1

This KPI can be calculated by the following division:

$$MC = \frac{C_{\overline{ARGO}}}{C_{ARGO}} \qquad [< 1]$$

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 shall be less than 1.

9.12.2.3. KPI2 – Maintenance Time (MT)

Short description.

This KPI can be a representative synthetic index aimed at considering an estimation of maintenance time that can be saved thanks to implementing the ARGO's tasks within possible upgraded maintenance processes. On the other hand, it could be read as an index of more availability of rolling stock.

How to compute KPI2

his KPI 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.

9.12.2.4. KPI3 – Defects Index (DI)

Short description

This KPI can be a representative synthetic index aimed at considering an estimation of defects that can be recognized thanks to implementing the ARGO's tasks within possible upgraded maintenance processes.

How to compute KPI3

This KPI 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.

9.13. UC18.5: Automated fixed crossing repair

In this first call, "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 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).

9.13.1. Overall aim of the Use Case

9.13.1.1. PROBLEM TO BE SOLVED

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. Taking into account 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.

9.13.1.2. 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 lower the LCC. The goal of automating this process offers the possibility of cost reduction, procedure acceleration and quality improvement, among others.

9.13.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

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 autonomic 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.

9.13.1.4. 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 quality improvement and reproducibility of results in total. "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.

9.13.2. UC18.5: demonstrator's KPI

9.13.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

KPI 1: Increased accuracy of inspections of 25%
KPI 2: Reproducibility of inspections of 25%
KPI 3: Cost reduction of the interventions by at least 10%

9.13.2.2. KPI1 – INCREASED ACCURACY OF INSPECTIONS OF 25%

Short description
The automated fixed crossing repair done by a stationary robotized welding platform will allow doing the geometry scanning and repair welding fully autonomic which will increase the accuracy of the automated repair process compared to the manual process.

How to compute KPI1
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:

$$[KPI1]\ Time\_finishing\ = \frac{T_{automated}}{T_{manual}} \leq 0,75$$

$T_{automated}$: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

9.13.2.3. KPI2 – 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 autonomic by the robot and will therefore enhance the reproducibility of the repair welding.

How to compute KPI2

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:

$$[KPI1]\ Geometry\_average\ = \frac{GA_{automated}}{GA_{manual}} \leq 0{,}75$$

$GA_{automated}$: 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

9.13.2.4. KPI3– 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 do the scanning, repair welding and monitoring of the intermediate layer temperatures fully autonomic by the robot and will be time saving and therefore cost saving.

How to compute KPI3

Comparison of the costs of the current manual repair build-up welding process to the costs of the automated repair welding process as follows:

$$[KPI3]\ Costs = \frac{C_{automated}}{C_{manual}} \leq 0{,}9$$

$C_{automated}$: Total costs of automated repair build-up welding process

C_{manual}: Total costs of manual repair build-up welding process

9.14. UC18.6: Purchasing railway maintenance robots

This use case does not appear to be central in the work package because it is not the subject of a demonstrator as such. Nevertheless, if we want robotics to continue to develop in the railway industry beyond ERJU, it is necessary to set up actions to structure an economic-industrial network.

9.14.1. Overall aim of the Use Case

9.14.1.1. PROBLEM TO BE SOLVED

Today, there is no real offer of railway maintenance robotics. The proposed products only cover a small part of the needs. However, the possible uses of robotics in the railway world and more

precisely for asset management are very varied. But so are the robots that can meet these needs. It is therefore to special machine developers that the railway sector must turn today. Nevertheless, a significant number of hardware or software components can be shared between these robots. If IM/ROs do not take advantage of this, the development of the robots they need (as special machines) will be time-consuming but above all extremely expensive. This is a major risk for the expansion of robotics.
Modularity, which is the technical tool allowing the reuse of components, does not organize itself. It is through a platform policy that the modularity can be used for the benefit of all actors.
If the driving forces of the railway sector do not organize it, either we will remain on a status-quo (and the robotisation of the sector will remain marginal) or one or two large players will organize it to their profit, strongly restricting competition and the dynamics of innovation.

9.14.1.2. INDUSTRY CURRENT POSITION / BASELINE

Nothing pre-exists in our industry.
However, we can learn from other industries with initiatives like ROS Industrial or SeRoNet.

9.14.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The first step is the selection of a common **middleware**. This is what first allows a high degree of reusability of components between the different railway robots of tomorrow. The objective is to select in common the middleware that meets our needs whether they are of a technical or non-technical nature.

It is then a software **overlay to the middleware** which must allow a fast integration of the components with powerful system engineering tools. Our goal is to define the modularity principles we want to take advantage of and prioritize them. We will then develop the tools supporting the essential functionalities.

Finally, it is thanks to a **marketplace** that the components and associated services can be easily distributed. Our goal is to develop a prototype of the marketplace.

9.14.1.4. INFLUENCE OF THE PROPOSED INNOVATION ON THE IM/RU PROBLEM

It is thanks to the marketplace that end-users or the integrators they have commissioned will be able to purchase the robot components needed to develop a new maintenance tool.
As the marketplace is focused on railway applications, the potential for component reuse will be natively high: a component successfully used by a IM in Spain is likely to be used with the same success by another IM in Belgium or Greece.
By segmenting functionality into different components, economic actors of all sizes (from start-ups to major groups) can be able to offer products. This is a guarantee of dynamism, openness of the offer and good quality/price ratio for the railway players.

9.14.2. UC18.6: demonstrator's KPI

9.14.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

With the engineering tools provided by the platform (like automatic glue code generation for fast components integration) and with the reuse of components between robots we will reduce the development costs of the robots and then contribute to SEO9.

9.14.2.2. KPI1 – RATIO OF LINES OF CODE THAT CAN BE AUTOMATED

Short description
Having graphical tools makes the software structure of the robot much easier to understand but the achievable gains seem to us more complex to bring out. We therefore choose to focus on automatic code generation.
Experience has shown (SeroNet project) that it is in the "setup phase" rather than in the initial code generation phase that software engineering tools like automatic code generation have the greatest potential for savings. Any change made to the generator is automatically reflected in all the systems managed.

How to compute KPI1
We would tend to want to express this indicator in the form of a ratio (number of auto-generated lines/number of total lines). Counting the lines of code of a robot is not so simple, however. Indeed, it is not uncommon for codes to call on libraries which can themselves call on other libraries and so on. The percentage of rows reused can sometimes be quite low. To avoid getting into very complex evaluation mechanics, we therefore propose to stick to the number of auto-generated lines.

We can express a ratio between the number of auto-generated lines and the number of lines coded by the developers of one of the IAM4RAIL robots alone without taking into account the number of lines called in pre-existing libraries.

Code reuse (which is a good practice) will therefore automatically raise this indicator.
Until now, the robots are developed without any automatic generation. The current baseline is therefore 0.

$$KPI1 = \frac{\#\ autogenerated\ lines\ of\ code}{\#\ lines\ of\ code\ directly\ generated\ for\ one\ robot\ by\ the\ developers}$$

9.14.2.3. KPI2 – REUSABILITY OF COMPONENTS

Short description.
In Shift2rail's MOMIT project, deliverable D1.2 expressed needs for asset monitoring. We propose to express the reuse potential of one or two components from the IAM4RAIL WP18 for robots that would match these needs.

How to compute KPI2

We will first look for the number of robots that seem relevant to cover the expressed needs. Then we will evaluate the number of robots in which the evaluated component can be used in a relevant way. The KPI will be expressed as a ratio between these 2 quantities.

The baseline is once again 0, because no modular approach exists to date.

9.15. 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.

9.15.1. Overall aim of the Use Case

9.15.1.1. PROBLEM TO BE SOLVED

Rail system maintenance activities often involve the use or handling of heavy technology or 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:

- 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.

9.15.1.2. 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 railways maintenance sector, as they are conceived for other "cleaner" industrial environments such as manufacturing or logistic repetitive operations. More specifically, the disadvantages found on current systems can be summarized as:

- When working at height, on railway-platform, fall harness and leash is required
- Practical tests also showed 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 that this creates physical problems
- Great "hook danger" on top of shoulder of exoskeleton. Dangerous because of work can be walking on moving trains and under catenary-components
- Too much resistance/friction with 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 into what happens in case someone falls (include leash) with fall harness and exoskeleton
- Building in into materials that do not conduct electricity.

9.15.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

Technology will be developed to improve human safety and skills in workplace through 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 specifically designed for railway-related operations.
More specifically, the targeted objectives can be defined as:

- Develop an exoskeleton for 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.
- Develop an exoskeleton for handling heavy materials (> 2 kg), very often operators transport, for a few meters heavy material to be assembled on the rolling stocks.
- Develop an exoskeleton ergonomic and compatible with other protective outfit common in railway maintenance.

There is still uncertainty regarding some aspects for the final TRL8/9 implementation of the exoskeleton in certain issues such as the analysis of the impact of the exoskeleton in case of worker falls and the materials use and the impact of active systems (batteries, actuators) on the working environment.

9.15.1.4. 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. 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.

9.15.2. UC19.1: demonstrator's KPI

9.15.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

Cost reduction of the interventions by at least 10%

9.15.2.2. KPI1 – Cost reduction of the interventions 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 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, directly influence on the cost of the intervention.

How to compute KPI1

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.

$$KP1 = \frac{Value_{traditional\_method} - Value_{new\_method}}{Value_{traditional\_method}} \times 100$$

- For the traditional method the value represents the answer of the operator to the questionnaire (rate scale) in relation to the traditional method (without the exoskeleton).
- For the new method the value represents the answer of the operator to the questionnaire (rate scale) in relation to the innovative method (with the exoskeleton).

If KP1 is positive: Indicates that the new method is more satisfactory for the operator than the traditional method.
If KP2 is negative: Indicates that the traditional method is more satisfactory for the operator than the new method.

9.16. 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 reducing time and cost of these operations.

9.16.1. Overall aim of the Use Case

9.16.1.1. 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 there are not always procedures that allow for easy detection of a failure.
In this scenario, the augmented reality 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.

9.16.1.2. INDUSTRY CURRENT POSITION / BASELINE

As already mentioned in the previous paragraph 2.1, currently the maintenance team are primarily driven by experience and the support.
Operators have paper and electronic manuals to support their activities that are less efficient and effective than the technology to be developed.
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.

9.16.1.3. SUBPROBLEM ADDRESSED BY THE USE CASE AND MEASURABLE OBJECTIVES

The Use Case addresses the need of technology to assist workers on complex and remote maintenance operations to reduce process cost, 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 can also be projected or real live data about, for example, the pressure in a pipe or the voltage on a cable (is not measured by the glasses themselves).
- **Train employees:** Through this technology, new employees can be trained faster, safer, more enthusiastic, 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 in the search for new personnel for the rail industry. This can be done through demonstrations at trade fairs and workshops at schools.

There is still uncertainty regarding some aspects for the final TRL8/9 implementation of the exoskeleton in certain issues such as dependence of good internet connectivity, battery live, compatibility with common glasses, etc…

9.16.1.4. 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 current IMs are 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 errors than can be done in these tasks by the use of the proposed technology.

9.16.2. UC19.2: demonstrator's KPI

9.16.2.1. LIST OF KPIS AND RELATED JUSTIFICATION FOR THE CHOICE

Cost reduction of the interventions by at least 10%

9.16.2.2. KPI1 – 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 KPI1 goal.
This KPI has also relation with the CAPACITY KPI from PRIME "Planned possessions (ID.43)", percentage of a network's available main track-km- days which are planned to be blocked possessions for IM's activities included in the yearly timetable, including maintenance, enhancement, and renewals.

How to compute KPI1

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). 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. We will also measure the number of errors carried out by the operator with and without the proposed technology.

For computing KP1, 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 KPI we can use the following formula.

$$KP1\ (\%\ time\ savings)\ = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$$

- Traditional Method Time is the time required to perform an inspection by the traditional method.
- New Method Time is the time required to perform an inspection by the new method.

If KP1 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 KP1 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.

Therefore, the cost of personnel (h/m. referred to activity on singular bridge span) is indicated below:

$$KP1\ (\%\ cost\ savings) = \frac{Cost_{\ traditional\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$$

- Traditional Method Cost is the cost required to perform an inspection by the traditional method.
- New method Cost is the cost required to perform an inspection by the new method.

If KP1 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 KP1 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) the document will 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**

The document will be updated during the project lifecycle, with the issue of a new Deliverable at M24 named D2.7.

11. References

LastName1 X. Y., LastName2 X. Y. – *Title* – YEAR, Publication (Vol., Issue)

12. 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 is to provide a remote and centralised interface to each and every subsystem involved, automatically collecting reports, functional parameters, logs, alarms and other diagnostic data, and storing them on the dedicated data platform. The collected data is then processed, cleaned and stored in a database in order 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 therefore 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 on the railway infrastructure are destined to the maintenance of assets. These assets, highly linked to signalling, are located and controlled from ADIF command centers, 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 centers 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 center 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:	As previously mentioned, assets' maintenance activities are not carried out predictively, anticipating the possibility of asset failure, but rather preventive maintenance (periodic inspections), as well as maintenance corrective, if the asset has already failed. Achieving predictive maintenance is very important because it would achieve, first of all, a significant cost reduction, since only what is necessary would be replaced, not as it is currently being done, which is carried out periodically or when the part has failed. In the case of acting on the railway asset once it has failed, it has the disadvantage of affecting rail traffic, so it is necessary to work in this direction in order to achieve economical and effective maintenance. In addition, circulation control centers receive no information about the asset except whether it is working or not, which increases work time intervals and response time.

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

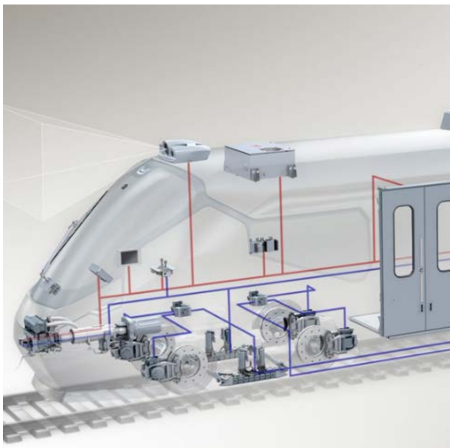
Demonstration Method:	Location:	Facilities:	Date:
Preliminary analytics design, completed with general architecture and validation process.	To be defined	To be defined	M18
Implementation of automatic data collection from the different wayside and infrastructure systems involved, with subsequent storage of data collected in the IAMS platform.	To be defined	To be defined	M24
Evaluation of first results coming from the analytics on assets' status prediction and collection of feedback for improvement	To be defined	To be defined	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	To be defined	To be defined	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 FP3 iam4Rail	5.1 6.2 6.3	All linked to the tasks on the left	UC ID:	5.1
			Int. Demo	
			Leading Partner	ALSTOM TRANSPORT SA (ATSA)

UC Name:	**Bogie Monitoring System (on-board)**
Type:	Monitoring & Analytics
Problem Statement:	Current practise in the rail industry is to perform the maintenance for the bogie components based on time and/or milage based intervals. The current practise is not economically optimized because the components are exchanged/replaced before the end of their lifetime. There is a risk that the component failure may happen between 2 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 WP aims to measure, acquire, collect, pre-process, transmit and store data in networks and ecosystems from onboard digital and analogic variables together with system alarms and other non-vehicle-based data sources. The tasks can be described as follows: - Identify monitoring strategies by simulation defining physical parameters suitable to detect wear/defects on main bogie components - Identify most promising monitoring technologies during roller rig tests focussing mainly on the drive (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.

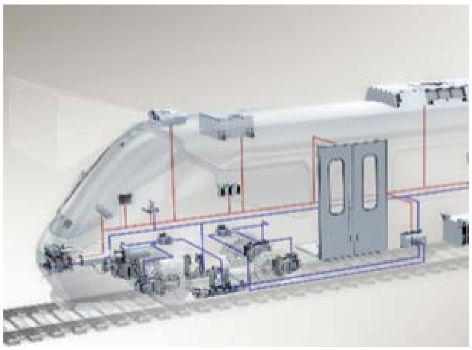
System Integration:

"Label":	Interfacing sub-task:	Interface:
Data	FP3: Task 9.4.3	Re-Use of WP6 on track Demo in 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 on 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	Netherlands	Lines tbd	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	5.3 6.3	6.3.2	**UC ID:**	5.2
			Int. Demo	
			Leading Partner	KNORR-BREMSE SYSTEME FUR SCHIENENFAHRZEUGE GMBH (KB)

		Image / Diagram
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.	

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 optimization. Examples are: ▪ HVAC: filter lifetime, compressor lifetime, refrigerant level and status ▪ Brakes: compressor lifetime and status. Process brake data monitoring 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 W31	Possible use case for federated data spaces

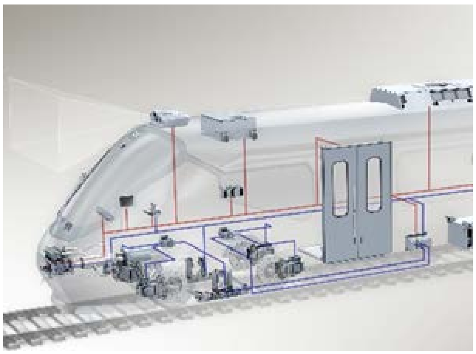
Demonstration Method:	Location:	Facilities:	Date:
Data monitoring, using on-board data aquisition, data transfer and data processing in the cloud	Spain	Renfe/Talgo Fleet S106	Until M36

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:						X		

Work package:	WP5-6 Task:	Sub-task:	UC detail	
WP5-6	5.4 6.3	6.3.3	UC ID:	5.3
			Int. Demo	
			Leading Partner	KNORR-BREMSE SYSTEME FUR SCHIENENFAHRZEUGE GMBH (KB)

UC Name:	**Health Monitoring & Analytics and ML algorithms development of HVAC, Sanitary Systems & Brakes, Traction & auxiliary system (NL)**
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 optimization. Examples are: ▪ HVAC: filter lifetime, compressor lifetime, refrigerant level and status ▪ Brakes: wear of friction material, compressor lifetime and status ▪ Sanitary Systems: freshwater level, wastewater level, wear and tear of vacuum sanitary system ▪ Traction & auxiliary system: create health indicators to detect anomalies in the early stage in these systems. Also, this point includes a DT (digital twin) for onboard energy consumption being able to detect anomalies and simulate scenarios 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	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	5.3 (related to 6.3)	6.3.2	UC ID:	5.4
			Int. Demo	
			Leading Partner	FAIVELEY TRANSPORT SAS (FT)

UC Name:	**Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes (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.

Image / Diagram

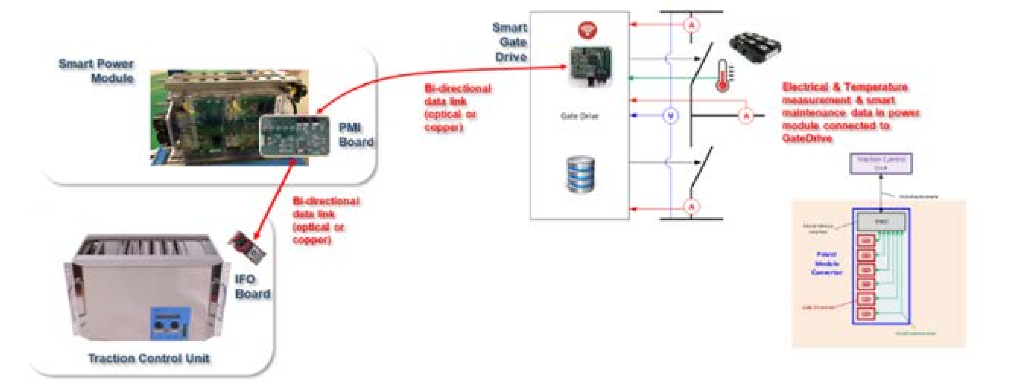
Description:	These tasks aim to implement data retrieval from the HVAC, Doors, and Brake systems of the Euskotren fleet, in order to enable further analysis and algorithm development.
How Does Solution Address Problem Statement:	Based on the data gathered from these systems and the maintenance workshops, 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 Euskotren fleets	Spain	Euskotren/CAF fleet	Until M48

	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 FP3 iam4Rail	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… If we need to connect each of them with insulation protection, it leads to an insane wiring system inside the traction cubicle… Moreover, this kind of solution highly increase 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. Tomorrow's powertrains must make use of predictive maintenance data to reduce possession costs by optimizing the number of maintenance operations on customer side and minimize equipment redundancies during design on 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 requires each their 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	

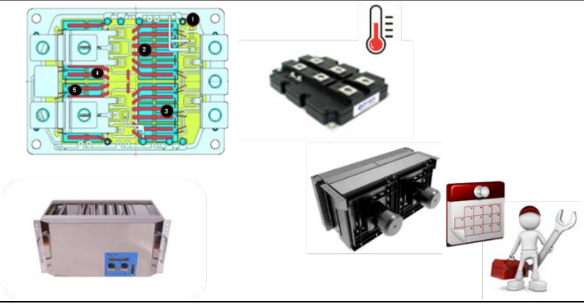
Description:	The Use Case target is to evaluate the capability of the proposal. Indeed, we need to define if with our new architecture we can drive semiconductors for traction purpose at the same time we monitor them for traction component health management. For semiconductors, the state of art of predictive 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 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 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 a fixed step). 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 him to build its train fleet maintenance plan according to 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	May 2024

	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**
Type:	Monitoring & Analytics
Problem Statement:	The current situation is that 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 observe 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 possession costs by optimizing the number of maintenance operations on customer side and minimize equipment redundancies during design on manufacturer side – which could lead to reduce acquisition 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.
Image / Diagram	

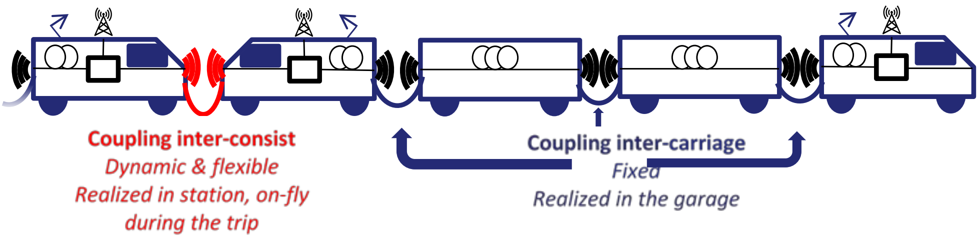
Description:	For semiconductors, the state of art of predictive maintenance requires the use of a measurement and/or an estimation of the semiconductor's internal temperature (i.e., junction temperature). This information will be provided by semiconductor manufacturers in the next years. The first call 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 withinFP3-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 a fixed step). 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 him 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 March 2023 Planned in January 2024
Train Tests	Netherlands	ICNG Train (NS) Test track area	Start in 2026 (to be confirmed)

	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 adaptative wireless telecom network**
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). But 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, some important weaknesses remain despite the increase of the throughput and the costs reduction, as some maintenance issues at inter coach and inter unit levels due to efforts applied on the cables/connectors at these places. To get rid of these limitations, wireless connection links are investigated in the frame 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.): the wireless communication shall therefore take care of the quality of 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 FP3-IAM4RAIL, 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	To be compiled	To be compiled	September 2026

	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 minimization of wear, deformation, and rolling contact fatigue of rail and wheel. The increasing importance of rail transport in 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 wheel-rail changes with humidity, contamination/lubrication, roughness, the stress in the contact area, among factors.

Image / Diagram

Description:	The Use Case Adhesion estimation for management aim to design methods to estimate/measure the COF in real-time under real operation conditions to determine at every instant, 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) in increasing service availability and optimal capacity.
How Does Solution Address Problem Statement:	In the FP3-IAM4RAIL, the basis of a new train-borne COF measurement method will be envisaged by estimating the traction/braking force from the relation between the electricity used/generated by the traction motor and the corresponding driving/resisting torque the motor generated. At the same time, methods to estimate the corresponding creepage of the wheel-rail rolling contact are being further developed. 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. This system is first going to be tested in the V-Track test rig (1:7 – 1:5 scaled). In the framework of the ERJU, the target is to develop the method on trains in collaboration with rolling stock manufacturers. This will make possible in the future the actual deployment of 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.

System Integration:

"Label":	Interfacing sub-task:	Interface:
Not available	To be defined	To be defined

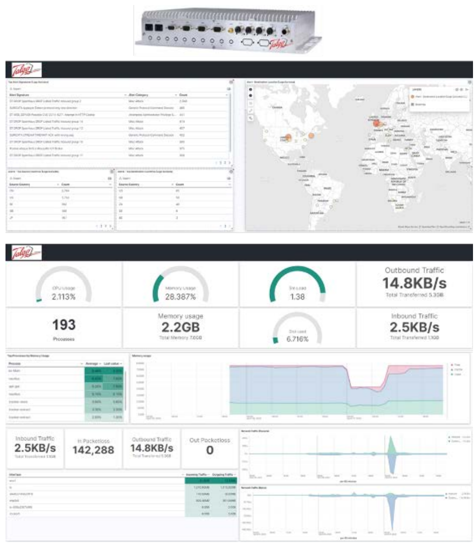
Demonstration Method:	Locations:	Facilities:	Date:
Simulation / Lab tests / Use of real-life train measurement data	TUDelft laboratory and the Dutch railways	V-Track test rig Measurement campaigns with train data from rolling stock manufacturers	M46

	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 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. 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:	The problem addressing will focus on develop a cybersecurity system for managing the top threats according to ENISA Threat Landscape (ETL) report in 2022, as well as to adapt 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 risks derived from the threats that affect them.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Cybersecurity	Sub-task 6.4.2	FP3 – WP6 – Task 6.4

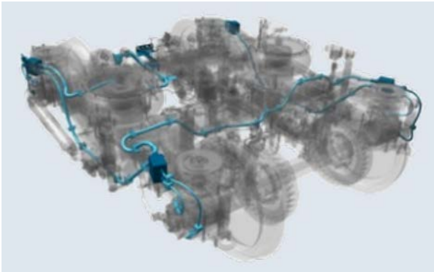
Demonstration Method:	Location:	Facilities:	Date:
Implementation of a cybersecurity MVP into a train as a real POC (Proof of Concept), collecting cybersecurity events and alerts. Cyberattacks will be simulated using a test battery previously defined by cybersecurity experts.	Talgo Train (details to be compiled)	Madrid – Spain Talgo factory	Summer 2025

	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	PATENTES TALGO SL (TALGO)

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 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.

Image / Diagram



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 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	To be defined

Demonstration Method:	Location:	Facilities:	Date:
Application of bogie diagnostic solution to train(s) operation in Germany	Germany (probably Baden Wurtemberg)		Approx. 2023-07 to 2023-10

	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…). Then, the results will be validated against real data gathered.
How Does Solution Address Problem Statement:	The output of the model will help operators to identify measures they can implement to minimize energy consumption by comparing drivers performance, units' performance and identifying the optimal speed profile.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Data from the different systems of the train in relation to energy consumption must be available and shared from the unit to the ground (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

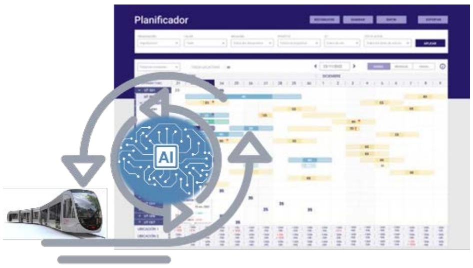
Demonstration Method:	Location:	Facilities:	Date:
Presentation of an Energy Digital Twin and related Dashboards containing data and directions once applied mentioned techniques to gathered train data. The Digital Twin will focus con NS Fleets.	Netherlands	NS / CAF SNG Fleet	Until M46

	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, information coming from the different algorithms and data gathered from the fleet is dynamic in nature and its amount is vast, which make difficult to schedule and organize required maintenance tasks along with operational requirements. In this regard, an intelligent system able to handle this information is required to help operators to make sense of all this data and to decide which actions shall be taken. This will lead to a scenario in which the operators can 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 optimizing 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 from the different systems of the train must be available and shared from the unit to the ground (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

Demonstration Method:	Location:	Facilities:	Date:
A planning proposal generated through SMS will be presented. The idea is to follow the guidelines proposed by the same, and measure the main maintenance KPIs, comparing the values under SMS and outside it, under traditional planning.	Spain	Euskotren/CAF fleet	Until M46

	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		UC ID:	7.1
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	**Bogie Monitoring System (Wayside – acoustic, 2D-3D images, video and laser)**
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 needs to reduce the maintenance costs. Currently, train maintenance inspections are done manually and periodically. Rolling stock owners / maintainers 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, etc, 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. 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 the different technologies: acoustic, 2D-3D images, video and laser that allow to know the bogies status. This information can support the increase of security, the reliability, and the reduction of maintenance costs.

Image / Diagram

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 analyzed to define patterns, bogie monitoring can be done automatically and more frequently. This will be done using the different technologies: acoustic, 2D-3D images, video and laser that allow to know the bogies' status. This information can support the increase of security, the reliability, and the reduction of maintenance costs.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Bogie Wayside Monitoring (BWM)	Sub-Task 7.3.1	Validation test of railway checkpoint on Spanish sections -> Task 7.2
BWM	Sub-Task 7.3.2	Validation test of railway checkpoint on Netherlands climate type sections -> Task 7.2

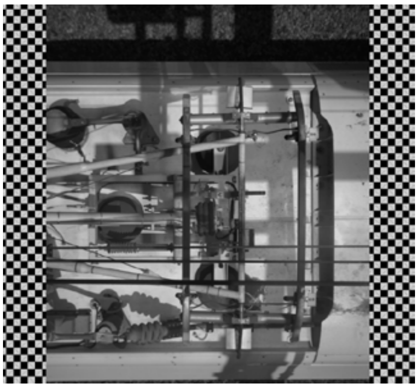
Demonstration Method:	Location:	Facilities:	Date:
Validate results using test data from bogies with known component condition	Sections in Spanish railway network Netherland railway network	Railway Checkpoint	To be compiled

	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		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 failing trains and the needs to reduce the maintenance costs. Currently, train maintenance inspections are done manually and periodically.

Image / Diagram



Description:	Development of different technologies installed on wayside to monitor the pantograph. Determine and record relevant data required for pantograph monitoring. Analyse these data to determine the pantograph status.
How Does Solution Address Problem Statement:	By collecting visual data of pantograph, which can be analyzed to define patterns, pantograph monitoring can be done automatically and more frequently. This will be done using the different technologies: video and 2D-3D images that allow to know the pantograph status. This information can support the increase of security, the reliability, and the reduction of maintenance costs.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP5-WP25-task25.4	Railway checkpoint Use cases and requirements

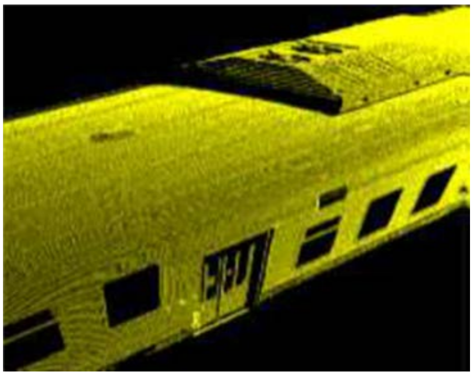
Demonstration Method:	Location:	Facilities:	Date:
By test in track with trains (wayside and onboard equipment)	- La Sagra (Workshop)	To be tested mainly in workshops and we would like to get data from the pantograph in commercial services	M36 (November 2025)

	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		UC ID:	7.3
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	**General physical anomaly detection Monitoring System (Wayside – video and 3D images)**
Type:	Development, monitoring, data collecting and data analysis.
Problem Statement:	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 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 these assets criticality and thanks to the systems under development we are going to be able to monitor their health with no need for stopping the train (so more availability and over maintenance reduction)

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP5-WP25-task25.4	Railway checkpoint Use cases and requirements

Demonstration Method:	Location:	Facilities:	Date:
By test in track with trains (wayside equipment)	- Workshop or main line	To be tested mainly in workshop and we would like to get data from the wayside equipment in commercial service	M36 (November 2025)

	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	7.3		UC ID:	7.4
			Int. Demo	
			Leading Partner	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)

UC Name:	**Railway checkpoint use case (ES)**
Type:	Demonstrator
Problem Statement:	Planned improvements: 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 teams work 24 hours a day without failing and, most importantly, if they are connected to machine learning, continually learning to anticipate the detection of failures and breakdowns. With this we can first obtain a very large database that will allow us to create algorithms to identify not only failures but also when it will be necessary to carry out maintenance on this rolling stock, for example, in the case of wheel flange measurement, Its measurement will be automatic and with the historical data and circulation forecasts it can identify with a fairly high precision when it will be the next time that it will be necessary to go around the lathe or to change the wheels. At the same time, a significant reduction in preventive maintenance costs is expected, since the maintenance bands will be adjusted when necessary and will not be carried out by kilometers traveled, as has been done up to now. Use case development level: • Caf solution: it is in the prototype development phase • Talgo Solution: they are executing the civil works to install the equipment on the track.

Image / Diagram

Description:	We will develop an automatic measurement system for wheels and pantograph: • Automatic measurement of wheel parameters: sd, sh and qr • Automatic measurement of the state of the pantograph: state of the carbon band, state of the horns, support bars, height, etc. • Wheel diameter measurement • Bearing condition analysis
How Does Solution Address Problem Statement:	With this develop we expect to increase safety and to have a better reliability, availability and to reduce the total maintenance cost

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP5-WP25-task25.4	Railway checkpoint Use cases and requirements

Demonstration Method:	Location:	Facilities:	Date:
By test in track with trains (wayside and onboard equipment)	- La Sagra (Workshop) - Cerro Negro (Workshop) - Beasain (Station) (under study)	To be tested mainly in workshop and would like to get data from the wheel and pantograph in commercial service	M36 (November 2025)

	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	7.3	7.3.2	UC ID:	7.5
			Int. Demo	
			Leading Partner	NS REIZIGERS BV (NSR)

UC Name:	Railway checkpoint use case (NL)
Type:	Demonstrator
Problem Statement:	Train maintenance inspections on bogies and pantographs are critical to avoid service disruptions due to failing trains. Currently, train maintenance inspections are done manually and periodically.

Image / Diagram
TBD

Description:	Availability of checkpoint (camera installation) in NL which can take images of pantographs and bogies
How Does Solution Address Problem Statement:	In the Netherlands there are two available camera installations (wayside checkpoints) that can take images of pantographs and bogies of passing trains at high speed (maximum of 140 km/h). Using this system, we can collect the necessary data for use cases 7.1 and 7.2

System Integration:		
"Label":	Interfacing sub-task:	Interface:
To be updated later	To be updated later	To be updated later

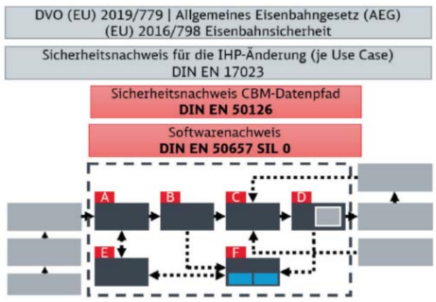
Demonstration Method:	Location:	Facilities:	Date:
How you will prove the developments	Places to be tested	Description of the type of track structure to be tested	Planned time(s) for the demonstrator

	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	7.4.1	UC ID:	7.6
			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 RU

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	To be compiled	Report, M20

	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	7.4.3	UC ID:	7.7
			Int. Demo	
			Leading Partner	INDRA

UC Name:	Data Analytics for Railway Checkpoints Use Case	Image / Diagram
Type:	Analysis	
Problem Statement:	Train maintenance inspections are critical to avoid service disruptions due to failing trains. Currently, the inspection of trains requires a lot of manual work, which impedes proper inspection of each train in short intervals. Furthermore, manual work results in occasional human error to overlook (pre)defects/anomalies. Through the collection of data regarding the state of assets and infrastructure (using different sensors located on the checkpoints), the main objectives of data analysis are: • Improving the knowledge of infrastructure and rolling stocks status, which could help to optimise the rolling stocks maintenance, and being able to apply actions in real time. • Reinforcing the control of vehicles and infrastructure, improving the capacity of main lines and freight corridors. This could be achieved by reducing the incidents and the time invested in workshops/maintenance. This Use Case has been addressed in previous EU projects such as FR8Hub and FR8Rail III. FR8Hub: development of a proof of concept for a checkpoint, based on Intelligent Video Gates. A logical architecture and structure of the output data was defined. The architecture consists of a data acquisition system (detection, cameras, and RFID), a data processing system and monitoring. The data acquired consists of codes to identify containers (ISO/ILU, BIC), codes to identify wagons (UIC) and placards to identify dangerous goods (IMDG, RID, ADR, UN number). A workflow for data sharing was defined, based on the Internet of Logistics concept. The concept allows the different participants of the supply chain to create, modify and read data. The workflow would allow to compare the data regarding assets in different points of the line, where an IVG is mounted. FR8Rail III: focused on image processing. The information obtained by the IVG system should be transparent for actors, to optimise transportation and reduce wastes in logistics. The architecture proposed consists of an IVG, which provides data in image and XML format. The data, containing relevant information of the assets, is then transmitted to a server (Deplide) that shares the information with consumers in XML and RCFM format. This data, coming from an IVG, is also consolidated with data from the IM and terminals. The data acquired consisted of the same codes as FR8Hub, and the sharing workflow was also based on Internet of Logistics standard.	

Description:	In the scope ofFP3-IAM4RAIL, an architecture for a railway checkpoint will be defined, integrating multiple IoT sensors and image acquisition systems for further data fusion and exchange. Also, a workflow for data acquisition, fusion, management and sharing will be defined. Develop an automated system that can detect (pre)defects/anomalies on trains using visual data.
How Does Solution Address Problem Statement:	The integration and fusion of sensors to obtain information from infrastructure and rolling stocks assets will enable to obtain relevant information about the state of assets, obtaining significant results in the perspective of maintenance. Using the newest technologies, (computer vision) models can be developed to detect (pre)defects/anomalies on trains to support / automate the manual inspection process. The models can be developed to detect specific

	(pre)defects or generic anomalies, such as:
	• Pantographs
	  o Low thickness of carbon bars
	  o Chipping/crumbling of carbon bars
	  o Broken/deformed arms/horns.
	• Bogies
	  o Axle bearings
	    ▪ Missing/loose bolts
	    ▪ Leakage
	  o Leaking shock absorbers
	  o Cables (loose/damaged/broken)

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
To be updated later	To be updated later	The data obtained in the checkpoint will include: Images, defects detected with image processing and DL models, track and rolling stocks condition information, obtained from a variety of IoT sensors such as axle counters, TDS (train detection system), weighing cell, temperature sensors …

Demonstration Method:	Location:	Facilities:	Date:
The developments will be proved in demonstrators, located in Spain and Sweden.	Sections in Spanish railway network Netherland railway network	To be compiled	To be compiled

	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	7.4.4	UC ID:	7.8
			Int. Demo	
			Leading Partner	PATENTES TALGO SL (TALGO)

UC Name:	Optimization of rolling stock maintenance Use Case
Type:	Optimization
Problem Statement:	Maintenance is planned periodically with a set frequency since the status of the rolling stock is not always known.

Image / Diagram

Description:	Optimize rolling stock maintenance: train maintenance tasks will be analysed to achieve a cost and time reduction during its maintenance operations (preventive, predictive, CBM and corrective).
How Does Solution Address Problem Statement:	When the status of parts of our rolling stock is determined automatically with sensors and are updated more frequently maintenance can be scheduled accordingly.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
IVG	FP3-WP7-task7.2 y 7.3	Railway checkpoint Use cases and requirements

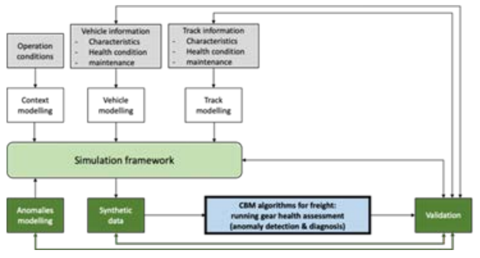
Demonstration Method:	Location:	Facilities:	Date:
By test in track with trains (wayside and onboard equipment)	- La Sagra (Workshop)	To be tested mainly in workshop and we would like to get data from the pantograph in commercial service	M36 (November 2025)

	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	7.4.2	UC ID:	7.9
			Int. Demo	
			Leading Partner	ASOCIACION CENTRO TECNOLOGICO CEIT (CEIT)

UC Name:	**CBM algorithms for freight**
Type:	Anomaly detection
Problem Statement:	The railway freight sector has nowadays a lot of potential to be the leader of clean transport (low CO2 emissions), but also has a great need to automate and digitize the operational and functional processes for a more efficient transport that can compete with other means of transport. Improve the maintenance, having in real time and in advance the health condition of some components of the rolling stocks is one of the challenges for the railway freight sector.

Image / Diagram



Description:	Development of algorithms for the assessment of the health condition of the bogie (and its components) of freight trains to enable CBM methodologies. No real data is foreseen for this activity. Rather, synthetic data representing different operational conditions will be used with the algorithms. This synthetic data will be equivalent to the operational data that might be gathered by real on-board sensors.
How Does Solution Address Problem Statement:	The algorithms will allow the assessment of the health condition 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)	FP5	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	N/A	N/A	N/A

	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	8.2.1	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, the 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 is widely available and applicable to the present problem in service life estimation of railway bridges.

Image / Diagram

Description:	The remaining service life of bridges play an important role in taking 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 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, utilising novel 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 and maintenance personnel accurate assessment of the infrastructure health 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, with a view to safely extending the asset life, thereby reducing renewals 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:
To be updated later	To be updated later	To be updated later

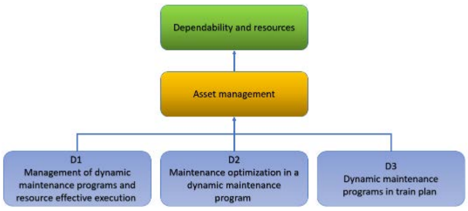
Demonstration Method:	Location:	Facilities:	Date:
Correlation measurement, modeling and simulations	At a conference or project meeting	Bridge structure	2025

	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. Main objective of railway AM is to provide 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 in order 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 is lacking 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 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 optimization in a dynamic maintenance program On the iron ore line there is a need for improvement of maintenance concept in terms of better coordination between traffic operation, reinvestment activities and maintenance planning. Maintenance programmes need to become more flexible in order to facilitate a more rational maintenance concept. Track and S&Cs are linear assets, they age differently, are installed on different occasions, experience varying loads which causes them to degrade differently throughout the network. The fixed maintenance plans and schedules often doesn't consider this variation of degradation across the network. Hence there is a need of a more dynamic maintenance programme. Objective is to develop a system that describes RAMS parameters for the track as functions of assets' status, components, and traffic, hence serve 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 up to real-time support of the TMS. The objective is to setup 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 WP32	API Interface for extracting the data from the existing database sources from Trafikverket through CDM mechanism

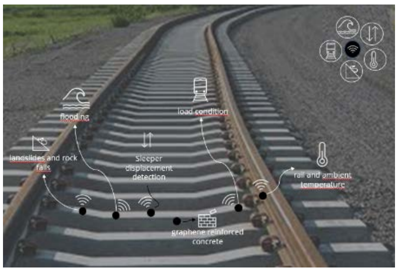
Demonstration Method:	Location:	Facilities:	Date:
Through cloud-based tool or standalone application	To be defined	To be defined	2026-05-31

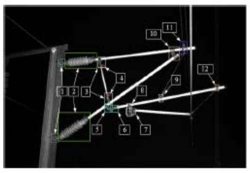
	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:					X			

Work package:	WP9 Task:	Sub-task:	UC detail	
WP9	9.1	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 interfaces 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, but also interfaces with different systems involved starting from the data acquisition system to the higher level of feature analysis with the extraction of key information useful 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, but also interfaces with different systems involved starting 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 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

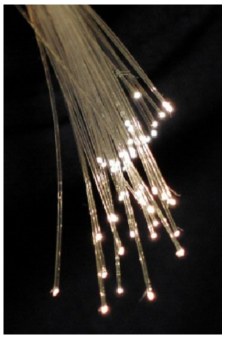
Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	To be compiled	To be compiled	Demonstrator: M37 (Dec 2025) Deliverable: M48 (Nov 2026)

	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	9.2.1 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:	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:
-	-	No interface reported

Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	To be compiled	To be compiled	Demonstrator: M37 (Dec 2025) Deliverable: M48 (Nov 2026)

	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	9.3	9.3.1 9.3.2 9.3.3	UC ID:	9.3
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

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 more than ever 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 be addressed includes evaluating low-cost solutions for monitoring track 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 in order 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; 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:
-	-	No interface reported

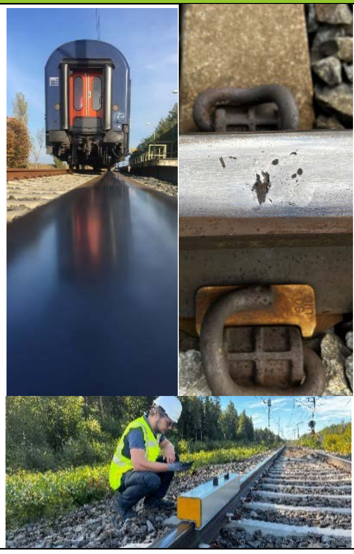
Demonstration Method:	Location:	Facilities:	Date:
Report on the approaches and validation results of innovation for track geometry and S&C condition	Data from Spain, Germany and France	Database from inframanagers in Spain, Germany and France SNCF track monitoring trains Trainlab of DB in Germany	Demonstrator: M37 (Dec 2025) Deliverable: M48 (Nov 2026)

	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	UC ID:	9.4
			Int. Demo	
			Leading Partner	DEUTSCHE BAHN AG (DB)

UC Name:	**Infrastructure monitoring solutions**
Type:	Sensing and interfaces solutions
Problem Statement:	Health condition monitoring and maintenance play an essential role in ensuring safety, availability and service reliability in 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 to include the repairs or replacement of these components during the routine maintenance slots.

Image / Diagram



Description:	In this Use Case we aim to develop integrated and robust approaches to continuously monitor and maintain railway infrastructures. But as a consequence, the database constructed from continuous data monitoring becomes larger over time, which is particularly challenging when dealing with multiple measurement sources and new sensing technologies that are not yet in the standards. Further, new technologies require validation campaigns under different scenarios and track conditions with the support of alternative sources of information to thoroughly verify the presence (or not) of defects. 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:	This Use Case focuses on defining data models, interfaces, regular collection, and data pre-processing from various sources, such as monitoring, inspections, and TMS. Then, it develops, improves, and validates 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 –are available from inframanagers that drive these with measurement vehicles to estimate the general properties/conditions of the track - 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 for the estimation of the transfer function of the railway track that accounts for inputs (loading) and outputs (frequency responses) - Axles rotational speed in order to evaluate if it is possible to retrieve vertical track defects throughout the train mechanical response to this defects (this mean using already available train speed sensors)

System Integration:		
"Label":	Interfacing sub-task:	Interface:
-	-	No interface reported

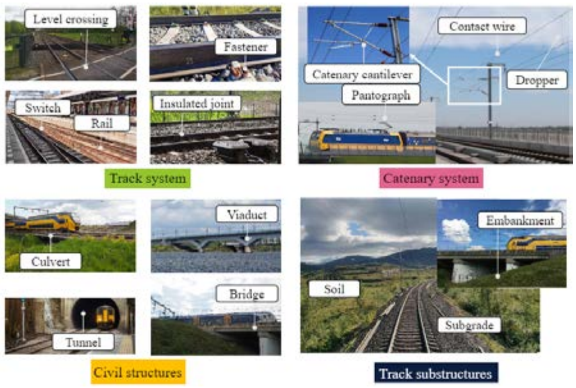
Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	Selected freight corridor Other locations for particular field tests in Germany, The Netherlands and Sweden.	Measurement trains Available monitoring data set Numerical evaluations	Demonstrator: M37 (Dec 2025) Deliverable: M48 (Nov 2026)

	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	9.4	9.4.3 9.4.4 9.4.5 9.4.6	UC ID:	9.5
			Int. Demo	
			Leading Partner	DEUTSCHE BAHN AG (DB)

UC Name:	**Prescriptive maintenance solutions**
Type:	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 nowadays 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.

Image / Diagram



Description:	In view of the increasing demands on the railway system, effective maintenance strategies are a critical factor at ensuring the required availability of the tracks. In this Use Case, we focus 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, we can increase the efficiency and sustainability of the railway system via maintenance design and increase the knowledge about the root causes for track deterioration, as predictions of deterioration are necessary.
How Does Solution Address Problem Statement:	Monitoring and inspection of all relevant track geometry parameters provides an almost continuous overview of the condition of the track. This results in the ability to respond to an early growing defect before speed reduction or track closure becomes necessary. Additionally, monitoring supports better forecasting and, thus, medium-term maintenance planning. The prediction itself is part of Use Case 9.4 Infrastructure monitoring solutions. Characterization of anomalies and root cause analysis provides 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 important building blocks for prescriptive maintenance.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
-	-	No interface reported

Demonstration Method:	Location:	Facilities:	Date:
Report of the approaches and validation results	Selected freight corridor Other locations for particular field tests in Germany, The Netherlands and Sweden.	Measurement trains Available monitoring data set Numerical evaluations	Demonstrator: M37 (Dec 2025) Deliverable: M48 (Nov 2026)

	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:	10.1
			Int. Demo	
			Leading Partner	STRUKTON POWER BV (SR Power)

		Image / Diagram
UC Name:	**Linking (new) monitoring technologies to asset management issues**	TBC
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.	

Description:	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.
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:
To be updated later	To be updates later	Data will be shared with the use case

Demonstration Method:	Location	Facilities:	Date:
On site and using Leonardo platform for train bound systems	Sites in Spain and the Netherlands	On location	M18 – 24: late 2024

	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:	10.2
			Int. Demo	
			Leading Partner	STRUKTON POWER BV (SR Power)

		Image / Diagram
UC Name:	**Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis**	TBC
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.	

Description:	a) Developing monitoring systems that utilize multi-sensor and multi-vehicle modular architectures for data acquisition, this includes collecting data and matching asset, location, 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:
To be updated later	To be updates later	Data will be shared with a use case for federated data spaces

Demonstration Method:	Location	Facilities:	Date:
On screen through dashboard	Sites in Spain and the Netherlands	On location	First results M18 – 24: late 2024, to be continued in WP11

	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**	Image / Diagram
Type:	Monitoring	Include here a photo of the Us  e Case
Problem Statement:	One of the latest target of the FS Group consists on 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. In order to move toward an holistic approach to control and management of the railway infrastructure, information from various data sources (from different technologies) has to 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.	

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 service for the automatic detection of defects and for the estimation of the residual lifetime of the civil infrastructures. The platform will become a new tool to support decisions pertaining bridge maintenance. Design and development of a Railway Monitoring Platform, integrating different data sources (satellite, drones, in-situ) to provide actionable insight on the whole railway network condition and its surrounding. The platform will represent a one-stop-shop for information related to hydrogeological risks, vegetation growth and third parties interference, and will provide support to 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 for identification of critical areas and bridge monitoring	HSL Milan -Turin, Italy	Milano-Greggio section	M36 (November 2025)

	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 reach the end of their useful life. Earthworks assets management. The study of a specific slope movement that has a long history of problems associated with instabilities even before the construction of the railway line in 1870. This is aggravated by the presence of a reservoir, causing damage to the tunnel lining and levelling defects on the track. A project to implement corrective measures to stabilize the hillside is currently being drafted.

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 to identify the optimal moment of replacement of the POT bearings before the failure or the blockage of them occurs. LVDT sensors, accelerometers, DAS technology, satellite images, among others will be deployed to follow this pathology. 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 and estimate the effectiveness of corrective stabilization measures.

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	Bridge: Viaduct over Arroyo de las Huertas de Mateo, located on line 040 HSL Madrid – Levante, Spain. Eartworks: Entrance slope to tunnel 40, CL 800 Palencia-La Coruña, Spain.	Bridge: Kilometric point 285+486. Its topology is representative of a large number of viaducts in the Spanish High Speed Rail network; a multispan continuous girder bridge made of post-tensioned concrete and 43- 45m spans. Track gauge: 1.435 mm Earthworks: kilometric points 277+100 to 277+457 of the line 800. Instabilities since before the construction of the railway line. Track gauge: 1.668 mm	M36 (November 2025)

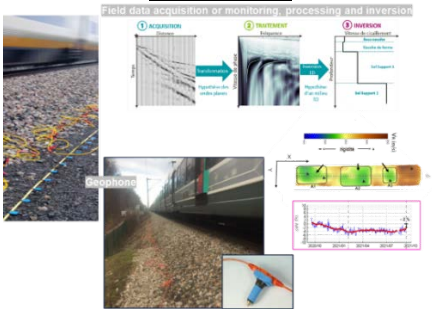
	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:							X	

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:	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 monitoring and checking the convergence. Today, for mechanical characterization of sub-ballast layer and sub-soil and to diagnosis the soil support for the risk of subsidence, we use classical geotechnical and geophysical method 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, but these methods do not allow their automation, which is one of the main objectives of these actions. Aims of project: -To decrease the maintenance operations and guarantee the traffic safety -To better constrain input data for optimizing works design, thus maintenance and regeneration cost We aim this approach to reach a predictive maintenance.

Image / Diagram

SUB-BALLAST LAYER & SHALLOW SUBSURFACE



TUNNEL

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; - the convergence of tunnels with high-definition. Specifically, what will be developed: <u>Sub-structure characterisation</u> 1. Collection of seismic surface wave measurement on 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. <u>Tunnel Monitoring</u> 1. Start investigation with photogrammetry, lasergrammetry and infrared thermography on certain tunnels. 2. Apply AI on an internal database describing tunnel behaviour and to predict 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. <u>Sinkhole hazard monitoring</u> 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 in the data's interpretation
How Does Solution Address Problem Statement:	The project has to permit to reach an approach predictive maintenance for the platform and the infrastructures. For answer it we would to: - 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	WP13	Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels-> Task 13.3

Demonstration Method:	Location:	Facilities:	Date:
Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels (France and Spain)	On the French rail network	Site with a sinkhole hazard Site with problems's plateform (sub-ballast layer) Site in a tunnel IMA and CEDEX laboratories	M36 (November 2025)

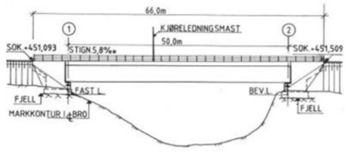
	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X						
Anticipated FP3-IAM4RAIL TRL:				(X)			X	

(X): For the development of a passive contactless magnetic microwire sensor arrays for high-definition tunnel convergence monitoring systems in tunnels.

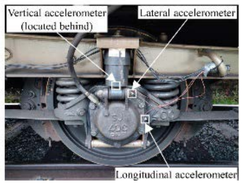
Work package:	WP12-13 Task:	Sub-task:	UC detail	
WP12&13	12.3 13.4 13.5	12.3.4 13.4.2 13.4.3 13.5.5	UC ID:	12.4
			Int. Demo	
			Leading Partner	PRORAIL BV (PRORAIL)

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, we analyse the capabilities of onboard monitoring together with historical data to determine and study locations with excessive deformation. The goal is to determine the complementary of the data to obtain better estimations of the embankment stability. Tentative railway lines: Dordrecht – Lage Zwalage and Delft-Schiedam.

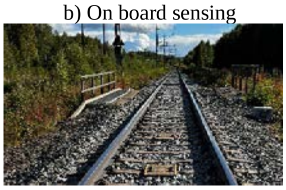
Image / Diagram



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, we will develop methods and models for monitoring and structural assessment and use them for potential structural upgrades for concrete bridges. In this use case, we are users of existing technologies with high TRL levels (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-danger areas with a focus on bridges and embarkments in this project. 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 bridge designs by extending the service life of large concrete structures instead of demolishing and building new ones.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
To be defined	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	Søsterbekk bridges, Ofoten line, Norway	Bridge structure and transition zone	2024-2025
Correlation measurements	Dordrecht- Lage Zwalage Delft-Schiedam, The Netherlands	CTO Train TUDelft – BBMS data base ProRail	2023-2025

	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 organization, all specified in individual organization structure. The implementation of this Use Case will be provided as modular and expandable instance of data driven decision support using among the 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 organizational 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 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:**
To be updated later	14.1.2	• introduction of Digital Twin and BIM data into data lake • Providing information from DSS into digital twin

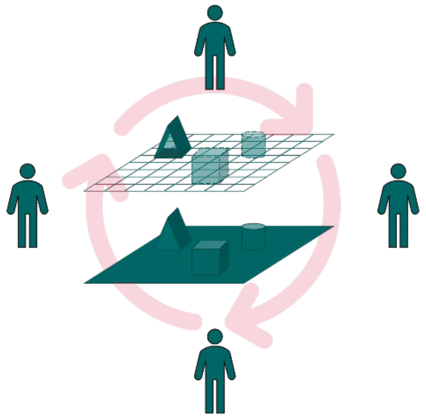
Demonstration Method:	Location:	Facilities:	Date:
Implementation of prototype	Poland – Łódź Kaliska Station, Łódź	Regional	~M40 (2026)

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			x					
AnticipatedFP3-IAM4RAIL TRL:						x		

Work package:	WP3 Task:	Sub-task:	UC detail:	
WP14-15	15.4	15.4.2	UC ID:	15.2
			Int. Demo	
			Leading Partner	FERROVIE DELLO STATO ITALIANE SPA (FS)

UC Name:	**Virtual Certification Framework**
Type:	Virtual Certification & Digital Twin
Problem Statement:	The Use Case proves the use of Digital Twin improving different critical asset management processes: • **Asset data collection, organization and sharing:** 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. • **Reliability of conformity verification:** For asset subject to physical or scheduling constraints at validation, or validated against requirements on emergent properties, Validators may need to accept a limited degree of confidence. This may expose the IM to the risk of partial conformity, undetected non-conformity. • **Efficiency of asset inspection**: Multiple systems for retrieving asset information; the outputs of surveying mapping as well as the mechanised diagnostic systems remain separated in SILOs without being fully integrated. Infrastructure managers must use different systems and tools to access this information which is time-consuming and cost demanding. • **Efficient Maintenance planning**: for track, understanding how the substructure of the track behaves under different loading conditions and speeds and how substructure condition correlates to track geometry defects requires development of the substructure physical model whose outputs will be visually linked to the actual conditions of the track.

Image / Diagram



Description:	The implementation of this use case will execute a complete instance of the virtual certification process for specific asset, to include track. The use case is based on the synergic use of: • advanced asset survey techniques and data processing; • Digital Twin for data sharing; • asset simulation to support conformity assurance; • blockchain for process tracing and certification handling.
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; • Provide a unique environment to access all information related to the digitalised assets, explore asset locations inside the point cloud and display the track conditions in synchronisation; • Model the behaviour of the asset to fine tune maintenance planning • Model the behaviour of the asset to improve asset validation and conformity verification

System Integration:

"Label":	Interfacing sub-task:	Interface:
CDM, CDE	FP1/TT	Conceptual Data Model specification and Digital Twin toolchain including Common Data environment -> Task14, 15
Track data	WP3-4	Track data from Archimede diagnostic train -> Task14.2.2, 14.2.3, 15.1.1
Station BIM model	FP4	BIM model of a real station -> Task14.1
VCF	FP2 WP34-35	Virtual Certification Framework (benchmark) -> Task14.4

Demonstration Method:	Location:	Facilities:	Date:
• Stage a full instance of the Virtual Certification Framework following the lifecycle of asset certification	To be compiled	To be compiled	M48 (November 2026)

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			X	X				
AnticipatedFP3-IAM4RAIL TRL:						X	X	

Work package:	WP3 Task:	Sub-task:	UC detail	
WP14-15	15.4	15.4.3	UC ID:	15.3
			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 are 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 signaling 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 generalized data model for signaling 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 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:
To be updated later	FP3: Sub-task 15.4.2	• detection of defects triggers start of the maintenance and re-certification • collected data fed into model of certifiable assets agreed by subtasks

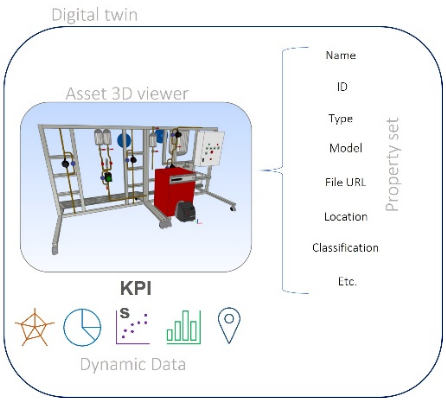
Demonstration Method:	Location		Facilities:	Date:
Visual and point cloud data collection along AŽD test tracks in Czechia	• Most – Lovosice branch line • Dolní Bousov – Kopidlno branch line		Local	M36 (November 2025)

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:			x					
AnticipatedFP3-IAM4RAIL TRL:						x		

Work package:	WP3 Task:	Sub-task:	UC detail	
WP14-15	14.1	14.1.2	UC ID:	15.4
			Int. Demo	
			Leading Partner	GTS DEUTSCHLAND GMBH (GTSD)

UC Name:	**BIM model as support to communicate and populate the Station's Asset Management System**
Type:	Digital Twin
Problem Statement:	• Sorting, organizing 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 case encountered in transportation. • Most solution 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 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 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 to the maintenance and operation. -Unique identification for 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's 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	THALES	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	16.1.1-2	UC ID:	16.1
			Int. Demo	
			Leading Partner	TRAFIKVERKET - TRV (TRV)

UC Name:	**Green tracks and turnouts**
Type:	Statistical approach
Problem Statement:	Railway transportation is the most environmental friendly form of transportation but has high emission of CO2 during production and operation. Optimization 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.

Image / Diagram

Description:	Key challenges targeted in the use case are ballast destruction for track and turnouts, squats in rail and understanding the real condition of rail material.
How Does Solution Address Problem Statement:	Tailor analysis methods for specific turnouts and tracks of the customer and optimize the bedding situation by introducing and install several enhanced components and solutions to enlarge the durability and availability of turnouts and tracks. Develop test methods and models for understanding realistic behaviour in rail material.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Green TO	N/A	No integration with other systems
TO heating system	N/A	No integration with other systems
Rail test	N/A	No integration with other systems

Demonstration Method:	Location:	Facilities:	Date:
Installation of turnout demonstrator and geothermal heating system in railway.	To be defined	To be defined	M36 (November 2025)

	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	16.2.1-4	UC ID:	16.2
			Int. Demo	
			Leading Partner	TRAFIKVERKET - TRV (TRV)

UC Name:	**Resilient and sustainable lines**
Type:	Statistical approach
Problem Statement:	Some bridges in rail infrastructure are likely to been built on over-conservative values based on models which does 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. Bridges and other sub-systems in the railway such as earthworks, tracks and signalling, are also at high risk of being exposed to natural hazards which could cause effects on safety and availability in the system. Due to climate change, these events are becoming more extreme and more frequent and the importance of maintaining safety, limit financial damage and ensure train operations during environmental impact is rising.

Image / Diagram

Description:	Tools will be developed to maintain infrastructure safety and operation considering climate change and environmental impact.
How Does Solution Address Problem Statement:	The project aims to use digitalisation to develop train-track-bridge interaction models for realistic estimates of dynamic effects on bridges and to increase the understanding of bridges with ballasted tracks under dynamic loading. In addition, tools will be developed to maintain infrastructure safety and operation considering climate change and environmental impact.

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).
Scour-Flood tool	N/A	No integration with other systems

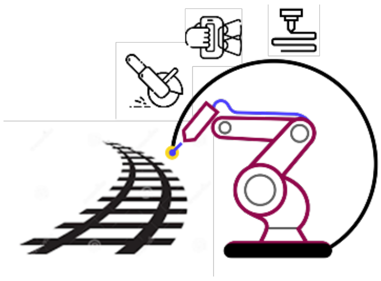
Demonstration Method:	Location:	Facilities:	Date:
Train-track-bridge interaction model based on long-term monitoring on selected bridges, available data of recorded track irregularities and possibly on-board train data.	Sweden	KTH	M36 (November 2025)
Train-track-bridge interaction model based on long-term monitoring on selected bridges, available data of recorded track irregularities and possibly on-board train data.	Sweden	KTH	M36 (November 2025)
Developed tools for maintenance of railway system considering climate change test	France	SNCF	M36 (November 2025)

	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 (iam4Rail FP3)	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 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 minimizes 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:	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.	CEIT (San Sebastián, Spain)	December 2025

	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 trying 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 characterization 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:	Facilities:	Date:
A repair of a wheel using two different AM methodologies, cold spray and laser DED. Characterization at different levels from test probe to representative test bench.	Test bench and laboratories	Dec-2026

	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. The minimal 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.

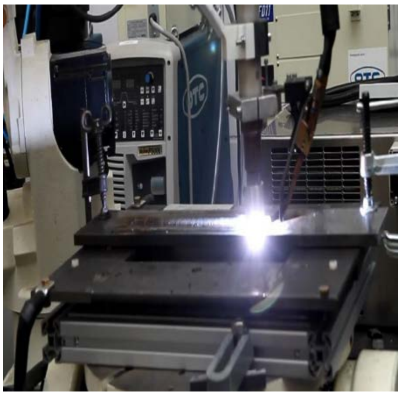
Demonstration Method:	Facilities:	Date:
Recovery of rails and switches using DED laser techniques, on tracks where the consortium has tenders for recovery on the European rail network, within the foreseen period. It is expected that at least 1-2 interventions can be carried out, which will take place 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.	Adif or Strukton facilities	December 2025

	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 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

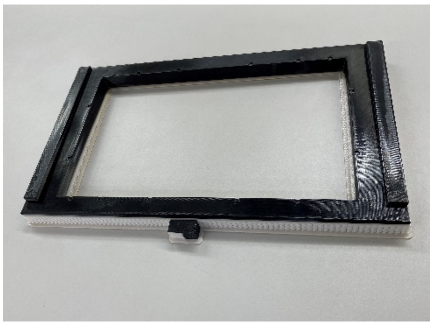
Demonstration Method:	Facilities:	Date:
Demonstration in the laboratory: The development of a functional WAAM repair welding process for crossings and the use of specific material concepts will be demonstrated in laboratory.	RWTH Aachen – ISF (Aachen, Germany)	November 2025

	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)

UC Name:	**Additive Manufacturing of large interior flame-retardant polymer spare part**
Type:	Additive Manufacturing
Problem Statement:	RU maintain 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 part are limited by the capacities of printers. The capability of large printers needs to be demonstrated and compared to railway specification and standards.

Image / Diagram



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:	Facilities:	Date:
To reach TRL 6, the material will be characterized and validated for R1-HL2 level and environment conditions. The process will be also characterized to ensure the feasibility of large components. Finally, the component will be tested on a bench.	To be define later	Dec 2025

	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 identify 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

I

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 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:	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 deep analysis of a few AM Use-Cases included in a digital warehouse.	Digital	December 2025

	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 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 measurements systems or due to the difficulties to transport them at the right location) the traditional means of inspection (measuring trains...) cannot be mobilized or not in such a flexible way as required to carry out particular surveillances. IM 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 prioritize 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 inspection availability. If achieved, the IM or RU would be able to identify potential hazards or issues quickly, allowing for prioritization 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: 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 it by 2040. In addition, the associated track work is typically harsh 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 want to find a solution to lower 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 one the system can even be more efficient without engaging additional human workforces. In addition, robots are powerful and able to manoeuvre and position themselves. Therefore, robot can do heavy repetitive work for the installation. The use case is 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

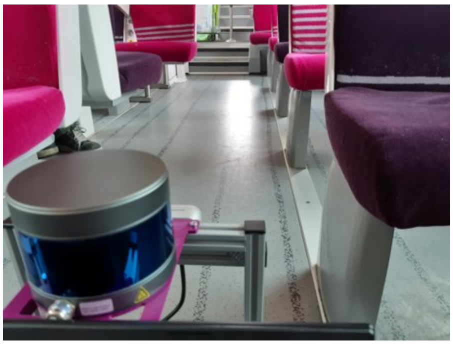
Demonstration Method:	Location:	Facilities:	Date:
Field test and report	In the Netherlands (located in one of the 8 tranches where ERTMS installation will be deployed)	ERTMS compact eurobalise on concrete sleepers common un dutch network axle counter Thales on 54E1 rail, most common rail in dutch network 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 sanitizing 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 one time out of five. 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 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 sanitized; • **Low disinfection time** in 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	Z50 000 train in a SNCF factory near Paris, in France FSI facilities in Italy (OMC Osmannoro and Maintenance plants sited in Rome) In Poland (to be defined where exactly)	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	18.4.4	UC ID:	18.4
			Int. Demo	
			Leading Partner	FERROVIE DELLO STATO ITALIANE SPA (FS)

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 type of traffic flow. In addition, gate provide limited views of certain organs, for instance in the case of the train underbody. The RU need complementary inspection solutions.

Image / Diagram

Description:	ARGO (**A**utonomous inspection of **R**ollin**G** st**O**ck) will help 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 summarized 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 disk; 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	FSI facilities in Italia (OMC Osmannoro and Maintenance plants sited in Rome) DB facilities in Germany NS facilities in the Netherlands	No additional facilities 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	18.4.5	**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 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 done fully autonomic 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.

System Integration:		
"Label":	**Interfacing sub-task:**	**Interface:**
Robotics		This use-case does not share information outside of this WP

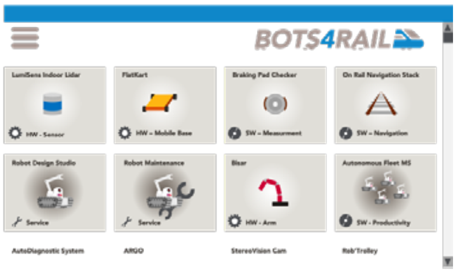
Demonstration Method:	Location:	Facilities:	Date:
Demonstrator in laboratory	Joanneum Research (Niklasdorf, Austria)	Dedicated welding installations and associated monitoring equipment	M36 (November 2025)

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:		X	X					
Anticipated FP3-IAM4RAIL TRL:			X	X				

Work package:	WP18 Task:	Sub-task:	UC detail	
WP18	18.1	18.1.1 to 18.1.3	UC ID:	18.6
			Int. Demo	
			Leading Partner	SOCIETE NATIONALE SNCF (SNCF)

UC Name:	Purchasing Railway maintenance robots
Type:	high-tech automated solutions for inspection and interventions
Problem Statement:	Today, there is no real offer of railway maintenance robotics. The proposed products only cover a small part of the needs. However, the possible uses of robotics in the railway world and more precisely for asset management are very varied. But so are the robots that can meet these needs. It is therefore to special machine developers that the railway sector must turn today. Nevertheless, a significant number of hardware or software components can be shared between these robots. If IM/ROs do not take advantage of this, the development of the robots they need (as special machines) will be time-consuming but above all extremely expensive. This is a major risk for the expansion of robotics. Modularity, which is the technical tool allowing the reuse of components, does not organize itself. It is through a platform policy that the modularity can be used for the benefit of all actors. If the driving forces of the railway sector do not organize it, either we will remain on a status-quo (and the robotization of the sector will remain marginal) or one or two large players will organize it to their profit, strongly restricting competition and the dynamics of innovation.

Image / Diagram



Description:	The first step is the selection of a common middleware. This is what first allows a high degree of reusability of components between the different railway robots of tomorrow. The objective is to select in common the middleware that meets our needs whether they are of a technical or non-technical nature. It is then a software overlay to the middleware which must allow a fast integration of the components with powerful system engineering tools. Our goal is to define the modularity principles we want to take advantage of and prioritize them. We will then develop the tools supporting the essential functionalities. Finally, it is thanks to a marketplace that the components and associated services can be easily distributed. Our goal is to develop a prototype of the marketplace.
How Does Solution Address Problem Statement:	It is thanks to the marketplace that end-users or the integrators they have commissioned will be able to purchase the robot components needed to develop a new maintenance tool. As the marketplace is focused on railway applications, the potential for component reuse will be natively high: a component successfully used by a IM in Spain is likely to be used with the same success by another IM in Belgium or Greece. By segmenting functionality into different components, economic actors of all sizes (from start-ups to major groups) can be able to offer products. This is a guarantee of dynamism, openness of the offer and good quality/price ratio for the railway players.

System Integration:		
"Label":	Interfacing sub-task:	Interface:
Robotics		This use-case does not share information outside of this WP

Demonstration Method:	Location:	Facilities:	Date:
Creation of a software prototype to help create a marketplace of specfic maintenance robots components and associated services	No location needed	no facility needed	M37

	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	19.4.2	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.
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 worker support during on track operations, that can reduce gravity load of tools, relieve arm and shoulder physical load and be compatible with other protective outfit, so overall reducing the risk of onset of Work-related Musculoskeletal Disorders (WMSDs).

System Integration:		
"Label":	Interfacing sub-task:	Interface:
"Exoskeleton"		

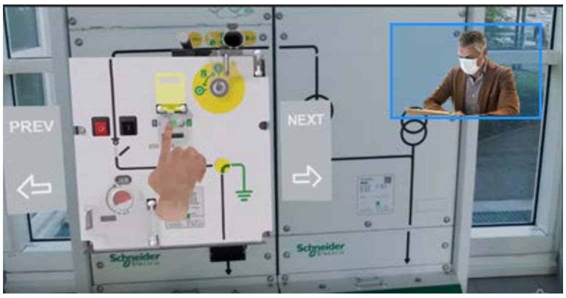
Demonstration Method:	Location	Facilities:	Date:
Validation of the new exoskeleton system in 4 testing scenarios and KPI measurement compared with current manual process.	Netherlands (Strukton) Italy (Mermec) Italy (FSI) Poland (PKP)	Strukton working site Mermec working site Test Circuit of Bologna S. Donato Green Modular Station	M37 (December 2025)

	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 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 Augmented Reality 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 to 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	M37 (December 2025)

	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8/9
Current TRL:				X				
Anticipated FP3-IAM4RAIL TRL:						X		