Ref. Ares(2024)4685799 - 28/06/2024

Deliverable D3.1
Preparation of integrated demonstrator report on IAMS Vision, Validation & Architecture Report

Project acronym:	FP3 - IAM4RAIL
Starting date:	01/12/2022
Duration (in months):	48
Call (part) identifier:	HORIZON-ER-JU-2022-01
Grant agreement no:	101101966
Due date of deliverable:	Month 18
Actual submission date:	28-06-2024
Responsible/Author:	Marco Borinato (STS)
Dissemination level:	PU
Status:	Issued

Reviewed: yes

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101101966.

Document history		
Revision	*Date*	*Description*
0.1	23/06/2023	First issue with chapter structure.
0.2	19/09/2023	Finalization of architecture and setup of requirements
0.3	29/04/2024	Contribution to Chapters 5-6-7-8
0.4	13/05/2024	Contribution to Chapter 3-4-8
0.5	31/05/2024	Integration of reviewers' feedback and finalization of content
1.0	28/06/2024	Final version approved by the TMT and SC and submitted to ERJU

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1. Executive Summary

The objective of this document is to describe the general architecture and the core requirements of an Intelligent Asset management System implemented in the context of a railway scenario.
D3.1 provides the necessary information to allow the design and implementation of a IAMS platform capable of collecting data from different sources and supporting both the maintenance and TMS operators in carrying out their task more effectively.
Additionally, the 2 use cases where this system will be implemented are described in detail, providing also information about the main objectives to achieve and how the whole system will be then tested and validated at the end of the project.
Specifically, the document is divided as follows:

- **Chapter 3** gives an overview of the background of the project and what are the previous initiatives that have led to the work of WP3.
- **Chapter 4** provides a description of the objectives of the documents and the impact that the work carried out in WP3-WP4 will have on the scenarios addressed.
- **Chapter 5** describes how the IAMS vision defined in this document is linked with and aims at achieving the objectives foreseen in the FP3-IAM4RAIL Grant Agreement.
- **Chapter 6** contains the design of the IAMS architecture and the description of the different components of the general platform. The proposed architecture is based on the work carried out in previous IN2SMART & IN2SMART2 project and more generally on the ISO 55000-55001-55002; the first one provides an overview of the subject of asset management and the standard terms, while the other two provides the requirements and guidelines for the implementation of such management systems.
- **Chapter 7** provides a list of the general requirements that a IAMS application should implement. Each requirement is clearly described and linked with the specific IAMS module that should implement it. Additionally, the requirements are associated with unique ID to allow the subsequent WP3 deliverables (D3.2 and D3.3) to reference them directly when they will define the specific requirements of their scenarios.
- **Chapter 8** goes into the details of the two use cases identified in the project: it is divided into two parts to describe separately the objective of each use case, the sub-problems addressed by the developments and how each demonstrator will be validated at the end of the project, describing the initial list of KPI to be evaluated.
- **Chapter 9** summarises the content of the document and the expected impact of it to the scenarios in which WP3 is implemented. Additionally, it describes how the work carried out in the initial phase will enable the development of optimisation and decision support function that will improve the overall asset management process in the railway environment, while also supporting the TMS in the scheduling of rail traffic.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
ACCM	Central Computerized Multi-Station Apparatus (Apparato Centrale Computerizzato Multistazione in Italian)
AI	Artificial Intelligence
AMP	Asset Management Plan
API	Application Programming Interface
AR	Augmented Reality
ATO	Automatic Train Operation
BIM	Building Information Model
CDM	Common Data Model
CM	Corrective Maintenance
D&M	Diagnostic and Maintenance
DSS	Decision Support System
DT	Digital Twin
ER	Europe's Rail
ERP	Enterprise Resource Planner
ERTMS	European Rail Traffic Management System
FA	Flagship Area
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects, and Criticality Analysis
FP	Flagship Project
GA	Grant Agreement
HMI	Human-Machine Interface
HS	High-Speed
HW	Hardware
IAMP	Implementation of Asset Management Plan
IAMS	Intelligent Asset Management System
IL	Integration Layer
IM	Infrastructure Manager
ISO	International Organisation for Standardisation
IXL	Interlocking
KPI	Key Performance Indicator
LCC	Life-Cycle Costs
ML	Machine Learning
MS	Milestone
MTBF	Mean Time Between Failures
OB	On-Board
PC	Central Site (Posto Centrale in Italian)
PP	Peripheral Sites (Posti Periferici in Italian)
RAMS	Reliability, Availability, Maintainability and Safety

Abbreviation / Acronym	Description
RU	Railway Undertaking
SAMP	Strategic Asset Management Plan
SW	Software
SCCM	Multi-station Command and Control System (Sistema di Comando e Controllo Multistazione in Italian)
S&C	Switch and Crossing
TC	Track Circuit
TMS	Traffic Management System
TRL	Technology Readiness Leve
TS	Track-Side
UC	Use Case
WP	Work Package

3. Background

The present document constitutes the Deliverable D3.1 “Preparation of integrated demonstrator report on IAMS Vision, Validation & Architecture Report” in the framework of the Flagship Project 3 – IAM4RAIL (GA 101101966) as described in the EU-RAIL MAWP.

The Objective of WP3 is to design the generic architecture and to implement field installations for the setup of an Intelligent Asset Management System (IAMS) paving the way for the development of analytics and the integration with the TMS that WP4 will carry out.
The activities foreseen for WP3 are:

- To define use case vision and system requirements.
- To design, plan and implement all necessary field installations.
- To securely collect and store/archive data related to wayside assets (Mobile & Fixed diagnostic) plus on-board & wayside signalling equipment and to provide this data to WP4 and other WPs (e.g. WP13) for the development of the analytics.
- To integrate exogenous data sources (e.g., weather information or performed maintenance work orders).
- To start the design of the analytics methodologies.

All the activities will be implemented at 2 different physical locations validating the entire IAMS process: data acquisition from signalling equipment and sensors, data collection & storage and data analysis for Operation & Maintenance and TMS needs. To support TMS-related developments in FA1, WP3 will focus in particular on the assets responsible for the majority of rail traffic disruptions.

The 2 locations will allow testing data acquisition and analytics methodologies on different lines (i.e. High Speed, Conventional, Regional), under different environmental conditions, and combining both legacy and new generation systems.

WP3 is based on results from IN2RAIL (H2020, GA 635900), IN2SMART (H2020, GA 730569), IN2SMART2 (H2020, GA 881574), LINX4RAIL (H2020, GA 881826), X2RAIL-1(H2020, GA 730640) and X2RAIL-4 (H2020, GA 881806).

4. Objective/Aim

Deliverable D3.1 “Preparation of integrated demonstrator report on IAMS Vision, Validation & Architecture Report” has the objective of designing the general architecture and requirement of a complete IAMS platform tailored for the need of a railway environment.
The goal is to provide a high-level description of what are the essentials building blocks of a generic IAMS application, based on the existing standards (e.g. ISO 55000) and the work carried out within the context of previous Shift2Rail Projects, such as IN2SMART and IN2SMART2.

As stated in the FP3-IAM4RAL GA, the development and implementation of such a platform will have a significant impact on the capabilities of the railway environment in which it is operating:

- on the one hand, it shall support the Maintenance operator, by providing insight and predictive capabilities to enable the switch from a fixed, preventive asset management to a more flexible and cost-effective predictive approach;
- on the other hand, it shall help the TMS and the traffic operator to optimise the scheduling of trains taking into account the real operative conditions of the signalling and infrastructural assets on the line.

This deliverable will also introduce the two use cases that will implement the IAMS application in an operative railway environment, describing in detail their objectives and the validation methodologies to be implemented in order to evaluate their achievement at the end of the project.

In this context, D3.1 will support the future activities of WP3 and 4 in two ways:

- Firstly, it will provide the benchmark for the definition of the use cases’ specific architecture and requirements, that will be detailed in D3.2 and D3.3.
- Additionally, it will pave the way for the design and development of data analytics and machine learning pipelines that will be core enablers for supporting the operators in the optimisation of the planning of both maintenance and traffic.

The following chapters will delve deeper into the proposed system architecture and define the specific functional and technical requirements needed to achieve these ambitious goals.

5. IAMS Vision (linked with GA)

FP3-IAM4RAIL seeks to address the existing challenges within the railway industry by introducing innovative solutions for the management and maintenance of wayside assets.
Historically, railway asset management has been hindered by reactive or periodic maintenance practices, leading to service interruptions and increased operational costs. This approach often entails addressing issues only after they arise, rather than proactively preventing them. As a consequence, critical components such as level crossings and switches suffer from inadequate monitoring and maintenance.

Moreover, the lack of comprehensive diagnostic capabilities and interoperability among different asset management systems has compounded these challenges. The fragmented nature of existing infrastructure, with separate systems controlling various assets, further impedes effective data sharing and limits diagnostic capabilities, contributing to inefficiencies in asset management. For example, critical components as level crossings and switches require meticulous monitoring. The current methods rely on basic inspections and corrective measures only upon detecting malfunctions, proving costly, inefficient, and prone to service interruptions.
For infrastructure managers, the need for meticulous monitoring of critical components increasingly important.
However, current methods often rely on basic inspections, leaving significant gaps in asset management practices. This reactive approach not only proves costly and inefficient but also increases the likelihood of service interruptions, impacting both operational efficiency and passenger satisfaction.

Within Cluster B of the Project, an Intelligent Asset Management System (IAMS) for wayside assets that harnesses advanced technologies will be developed. By securely collecting, storing, and analysing data from wayside assets, IAMS enables predictive maintenance, optimizes scheduling, and enhances overall railway management. Key objectives of IAMS include enhancing asset availability, minimizing service disruptions, and extending asset lifespan through proactive maintenance practices. Additionally, the project emphasizes the integration of IAMS with the Traffic Management System (TMS) to optimize traffic regulation, improve punctuality, and enhance overall efficiency.

Previous Shift2Rail projects, notably IN2SMART2, have laid the groundwork for addressing these challenges by emphasizing predictive maintenance, intelligent systems integration, and data-driven decision support.
FP3-IAM4RAIL is building upon the results achieved in IN2SMART2 on the topic of IAMS by improving the platform's capabilities for data collection, processing, and correlation. Crucially, the objective of the project will be to interact with the TMS, sharing analytics results and predictions to improve the management of train operations. One example of such interaction is that IAMS suggests to the TMS an alternative route inside a train station for the scheduling of heavy freight trains in order to reduce the stress on old or anomalous switches and limit the possibility of failures.

The demonstration seeks to showcase the practical implementation of information sharing between IAMS and TMS, a crucial step towards optimizing decision-making processes within the railway ecosystem. By achieving a Technology Readiness Level 6 (TRL6) by 2025, this demonstration will validate the efficacy of the integration in two use cases in Italy and Spain.

Starting with the definition of functionalities aligned with the Infrastructure Manager's objectives, IAMS application have been defined to address the following technical objectives:

TO1: Information Sharing between IAMS and TMS
Efforts are directed towards establishing robust mechanisms for sharing relevant data between IAMS and TMS. Information on the diagnostic status of signalling devices, track, and infrastructure can be fed back into the TMS to improve and optimize 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 decisions in the management of the service.

TO2: Inspection Systems
Advanced inspection systems, both unmanned and non-invasive, will be deployed to collect data from wayside assets. Leveraging AI solutions and ML algorithms, these systems analyse and integrate information from various inspection sources, ensuring thorough asset evaluation and proactive maintenance practices. Level crossing intersections present inherent hazards, necessitating robust obstacle detection systems to mitigate risks to both rolling stock and human safety. To address these challenges, the project focuses on developing a level crossing obstacle detector that combines Lidar and Radar sensors. By harnessing different wavelengths and algorithms, this dual detection mechanism enhances accuracy and reliability. Traditionally, obstacle detection in the railway domain relies on either Lidar or Radar technologies individually. However, this project pioneers the simultaneous use of both technologies, leveraging their complementary strengths. The independent processing chains associated with Lidar and Radar sensors ensure reliable detection, with the merged processing chains facilitating swift passage clearance upon detection of obstacles. Moreover, the hardware design enables standalone operation and simultaneous use of Lidar and Radar sensors, offering flexibility and versatility in obstacle detection scenarios. This innovative approach not only enhances railway safety but also contributes to the advancement of inspection systems within the industry.

TO4: Prescriptive Analytics for Decision Support
Prescriptive analytics capabilities are integrated into the decision-making process to enhance the effectiveness of asset management strategies. The Infrastructure Manager (IM) participates in identifying and describing major operational issues. Utilizing this information along with data collected from previous subsystems, the project will develop and apply specific machine learning models to address the highlighted issues effectively. For instance, in monitoring Track Circuits, the aim is to minimize false occupation instances, which can cause service disruptions and render lines unavailable. Validation of predictions against the actual asset state involves cross-referencing maintenance interventions to provide operators with a health index, criticality information, and remaining useful life data. This information is subsequently relayed to the Decision Support System

(DSS) for maintenance scheduling or to the Traffic Management System (TMS) for operational optimization. The DSS will suggest 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.

TO8: Preparation for Future Demonstrators

Preparation work is essential to ensure the scalability and adaptability of the integrated system for future demonstrations. This involves the development of a scalable information platform, implementation of edge computing solutions, and integration of AI-based decision support systems to support future deployments.

The solution under development aims to reduce costs, improve operational efficiency, and enhance passenger safety and satisfaction. Through collaborative efforts with railway operators, infrastructure managers, and research partners, the project endeavours to drive innovation and foster sustainable advancements in the railway industry. This focus on IAMS and proactive asset management represents a significant shift towards more efficient and effective railway operations, ensuring smoother service delivery and better outcomes for all stakeholders involved.

6. IAMS Architecture

The starting point when talking about the application of Intelligent Asset Management Systems in the railway environment is the IAMS Decision and Activity Flowchart described in IN2SMART Deliverable D3.1 "*System Requirements and Functional, Form Fit and Interfaces Specifications*" and reported here in **Error! Not a valid bookmark self-reference.**.

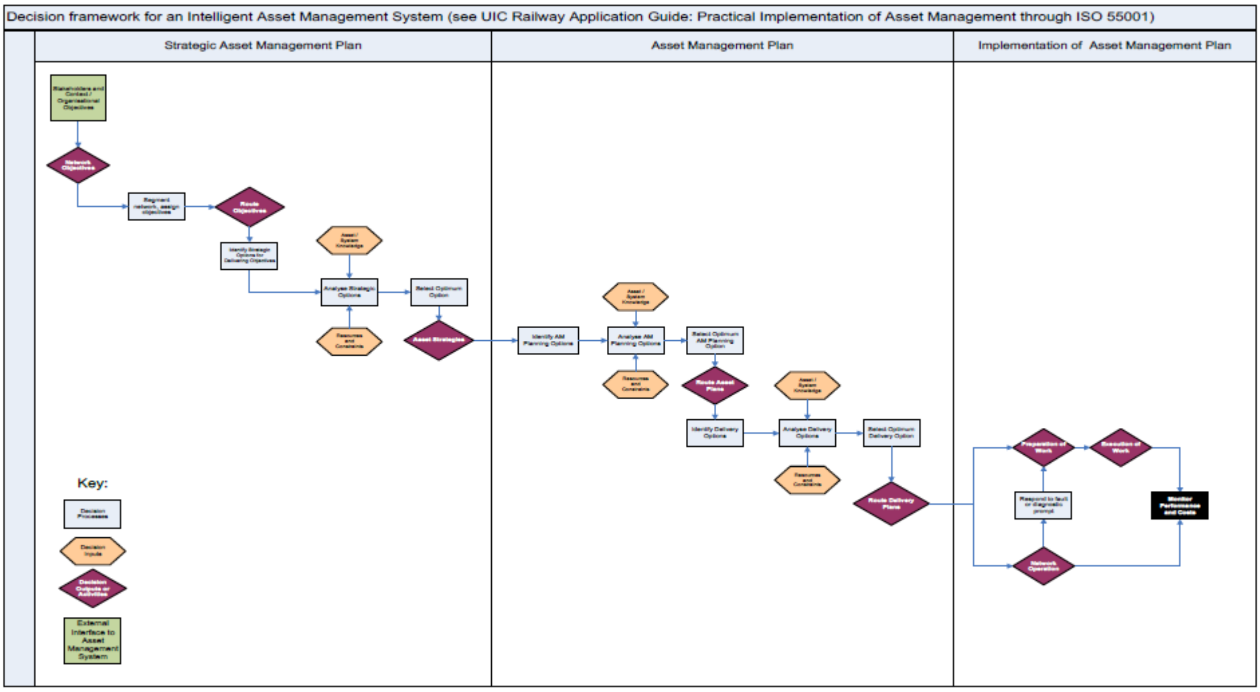

Figure 1: Level 1 IAMS Decision and Activity Flowchart linked to ISO 55001

The proposed architecture, visualised in **Error! Reference source not found.**, is described using the ArchiMate standard[1] from "The Open Group": a standard visual language for communicating and managing change and complexity through architecture description development.
The language is based on the following layers:

- The **Business Layer** (IAMS Level 1, in yellow) depicts business services offered to users/customers, which are realised in the organization by business processes performed by business actors.
- The **Application Layer** (IAMS level 2, in light blue) depicts application services that support the business services, and the applications that realise them.
- The **Technology Layer** (IAMS Level 3, in green) depicts technology services such as processing, storage, and communication services needed to run the applications, and the computer and communication hardware and system software that realise those services.

[1] https://pubs.opengroup.org/architecture/archimate32-doc/

Physical elements are added for modelling physical equipment, materials, and distribution networks to this layer.

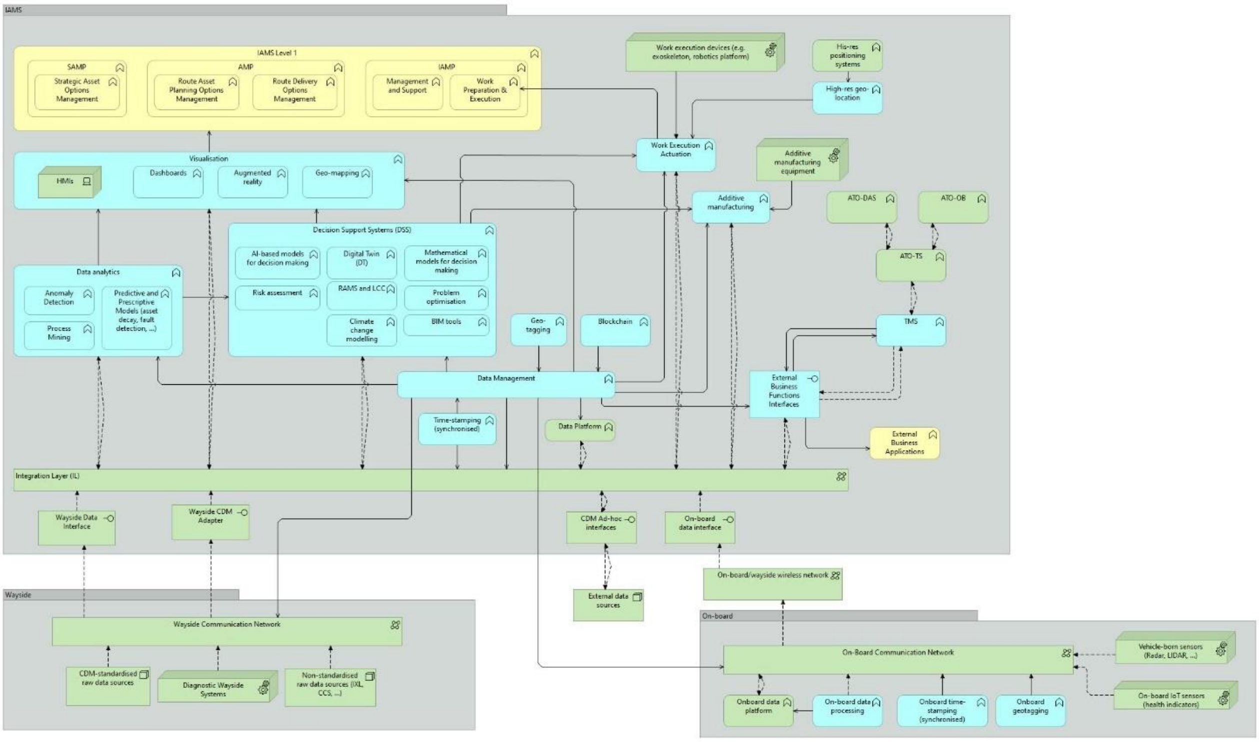

Figure 2: Improvement of the General IAMS Architecture coming from SHIFT2RAIL

It is necessary to have some familiarity with the adopted standard to properly understand layers and connection. The links are as follows:

- Dashed lines represent data flows.
- Plain lines represent logical links to be read as follows: A→B means that function A serves function B.

The proposed IAMS architecture has been drawn starting from the results of Shift2Rail activities and improved with new blocks keeping in mind the requirements and functionalities implemented by all the different WPs of FP3-IAM4RAIL. The goal is to present to the whole consortium a general functional architecture of a IAMS application to be used as reference in the development of each WP, in line with the objectives of MS02 of FP3-IAM4RAIL.

From that, WP3 partners have derived a second architecture that is more focused on the topics and objectives of WP3 and the subsequent WP4. This new version, shown in Figure 2, includes a subset of the modules and layers of the more general Architecture that are relevant to the technical objectives of a IAMS application that is focused on the collection of data from signalling and monitoring systems and has the goal of supporting both the IM and the TMS Operator in the management and improvement of their work. This, in a nutshell, is the goal of WP3 and WP4.

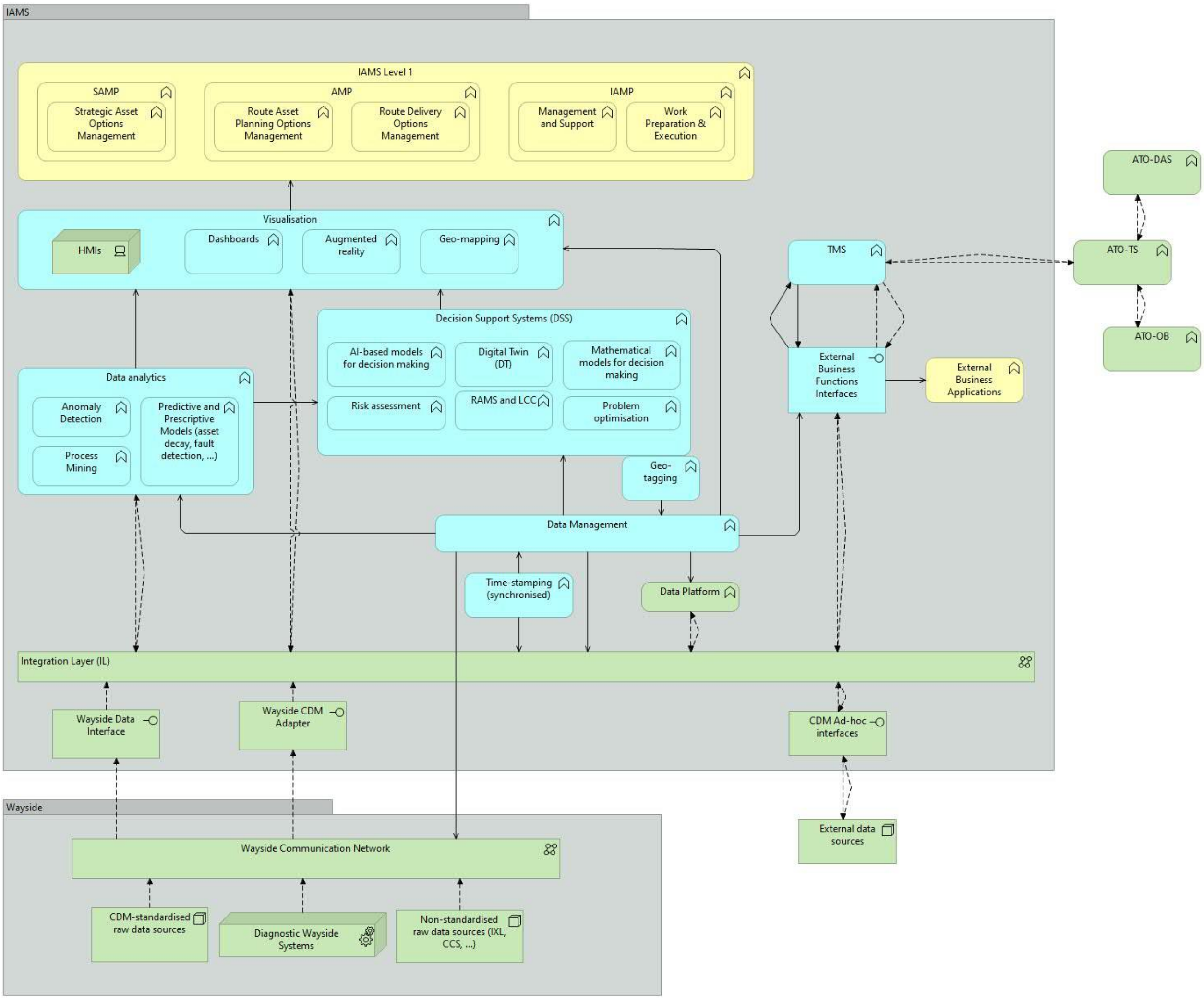

Figure 3: WP3 & WP4 specific IAMS Architecture

The next chapters will describe in detail all the layers and the related building blocks.

6.1. IAMS Level 1: Business Level

6.1.1. SAMP: Strategic Asset Management Plan

6.1.1.1. Strategic Asset Option Management

As reported in UIC Railway Application Guide: Practical implementation of Asset Management through ISO 55001 “the primary objective of the asset strategy (or asset strategies) is to optimise decisions on designing, procuring, constructing, inspecting, maintaining, disposing of, renewing and enhancing the infrastructure such that the route outputs are delivered at the minimum whole life cost. The asset strategies should provide demonstrable evidence that asset intervention decisions deliver the Route Objectives for the lowest whole life cost".

6.1.2. AMP: Asset Management Plan

6.1.2.1. Route Asset Planning Options Management

Route Asset Plans specify the asset intervention activities, including inspection, maintenance, refurbishment, replacement, new assets, rationalisation and disposal. The specific asset interventions are usually specified as the tactical component of the plans, in which the longer–term elements are typically derived from modelling tools. The plans should provide a specification for the delivery function. They should also provide assurance to senior management and external stakeholders, such as regulators and governments, that the costs are justified and that infrastructure outputs will be delivered in a sustainable way.

6.1.2.2. Route Delivery Options Management

Route Delivery Plans translate the work specified in the Route Asset Plans into a detailed plan for execution. The Delivery Plans should:

- Optimize the delivery of asset interventions, grouping work spatially, by skills, by access arrangements and combining work to be delivered at the same time.
- Provide a detailed design for construction and renewal projects.
- Confirm the availability and source of funding.
- Agree the delivery programme with customers and stakeholders (including national transport authorities and ministries).
- Align the delivery programme with the local track access regime and the delivery capability of suppliers.

6.1.3. IAMP: Implementation of Asset Management Plan

6.1.3.1. Work Preparation & Execution

Execution of Work is the final element in the asset, which is the delivery of work. This should include the following:

- Mobilisation of the project team, the scheduling of resources and booking of possessions.
- The provision of tools, facilities and equipment.
- Construction, renewal, testing and commissioning.
- Hand back of work.
- Updates to asset registers and cost management systems as a result of changes to the infrastructure.

6.1.3.2. Management and Support

This business function covers all ancillary activities necessary to implement Work Preparation & Execution, including for example spare parts management and unplanned events management.

6.1.4. External Business Applications

Any business application any IAMS needs to interface with. External business applications can either belong to the railway ecosystem (e.g., the on-board / track-side energy management or the Traffic Management System) or be external independent applications (e.g., the weather forecasts or a logistic operator's applications).

6.2. IAMS Level 2: Application Layer

6.2.1. Visualisation

6.2.1.1. Dashboards

Any application (dashboard and, more in general, user interface) that provides at-a-glance views of Key Performance Indicators (KPIs) and asset status information relevant to a particular business process possibly driven by the context.
Dashboards should also allow the examination of data or content (descriptive analytics) to answer questions like "What has happened?" (data discovery), "What is happening?" (condition-based approach), "What will happen?" (predictive approach), "What could be done?" or "What are the best options?" (prescriptive approach), through visualisations such as pie charts, bar charts, line graphs, tables, or generated narratives.

6.2.1.2. Augmented reality

Any application/technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view

6.2.1.3. Geo-mapping

Any application that allows to display, query and, more in general, manage geo-referenced/geo-located data (e.g., GIS applications and schematics).

6.2.2. Data analytics

6.2.2.1. Anomaly Detection

Any data analytics application that is able to implement anomaly detection, i.e., the process of identifying unexpected items or events in data sets, which differ from the norm.

6.2.2.2. Process Mining

Any data analytics application that is able to implement process mining, i.e., a methodology for discovering, monitoring, and improving real processes by extracting knowledge from process data (e.g., event logs).

6.2.2.3. Predictive and Prescriptive Models (asset decay, fault detection, ...)

Any data analytics application (model) that is able to predict the status of an asset in the future (i.e., able to answer the question "What will happen?") and/or to prescribe maintenance actions (i.e., able to answer the questions "What could be done?" or "What are the best options?"). Here the future is strictly depending on individual use cases and can range from few minutes (nowcasting) to days or months or even years (forecasting).

6.2.3. Decision Support Systems (DSS)

6.2.3.1. AI-based models for decision-making

Any application (model) based on Artificial Intelligence (AI) - ranging from rule-based systems to machine learning - that supports the decision-making process during asset management.

6.2.3.2. Digital Twin (DT)

Digital Twin has various definitions, like for example:

- Gartner: "A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organization, person or other abstraction. Data from multiple digital twins can be aggregated for a composite view across a number of real-world entities, such as a power plant or a city, and their related processes".
- Barricelli et al. [2]: "Digital Twins can be defined as (physical and/or virtual) machines or computer based models that are simulating, emulating, mirroring, or "twinning" the life of a physical entity, which may be an object, a process, a human, or a human-related feature".
- SNCF4: "a digital twin is the virtual reproduction of a system as it really exists and not as it would be in an ideal world. A digital twin is a 3D model (or Building Information Modelling [BIM] system) that enables users such as SNCF Réseau to project how infrastructure will perform in the future by predicting incidents, wear and tear or the effects of particular phenomena on the whole or a particular part of the system".

Any application that fits one of the above definitions (or similar) is part of this layer. This module can include also similar solutions, like the BIM-based Virtual Mock-up, a digital representation of a design or proposal where any aspect to be analysed through 3D illustrations and simulations can be presented and simulated based on the information collected in the model.

6.2.3.3. RAMS and LCC

Any application able to implement/support RAMS (Reliability, Availability, Maintainability and Safety) and LCC (Life-Cycle Costs) analysis. This includes for example tools to implement Failure Mode and Effects Analysis (FMEA) and Failure Mode, Effects, and Criticality Analysis (FMECA).

6.2.3.4. Problem optimisation

Any application aimed at optimisation of resources or processes.

6.2.3.5. Mathematical models for decision-making

Any mathematical/stochastic (data driven) application (model) that supports the decision-making process during asset management.

6.2.3.6. Risk Assessment

Any application that allows to assess risks and possibly suggest risk mitigation actions involved in the decision-making process during asset management.

6.2.4. Data Management

All IAMS functions need to access data through the Data Management function only (i.e., direct access to the data sources or Data Platform is not allowed) that guarantees (and keep track of) the access to all data. This can also be seen as a set of services with specific datasets serving specific functions to prevent direct access to databases: these services include, for example, the Integration Layer (IL) APIs.

6.2.5. Geo-tagging

Any application able to geographically tag data, including conversion from different reference systems (e.g., from geographical coordinates to linear referencing).

6.2.6. Time-stamping (synchronised)

Any application that allows to timestamp data generated within IAMS or to synchronise data collected data outside the IAMS system. Generally, the same clock is used to allow synchronisation of data within IAMS.

6.2.7. External Business Function Interfaces

Any interface serving/managing the connection with external business applications.

6.2.8. Traffic management System (TMS)

Any interface serving/managing the connection with application that provides permanent control across the railway network, automatically sets routes for trains and logs train movements as well as detects and solves potential conflicts.

6.3. IAMS Level 3: Technology Layer

6.3.1. Data Platform

The Data Platform is the only place where data are stored inside the IAMS architecture. The Data Platform is used to store data generated within the IAMS system and those data needed more than once for the processing to avoid creating yet another asset register. Data stored in the Data Platform can be compliant with CDM. Temporary storage at the functions' level is allowed but not explicitly shown in the diagram.

6.3.2. Integration Layer (IL)

All communications within the functional modules inside IAMS are managed by an Integration Layer (IL). All data that is published on the IL to be shared with the different IAMS modules, should be compliant with a Conceptual Data Model (CDM), however it is possible to share data also in a "non-standardised" format.

6.3.3. Human Machine Interfaces (HMIs)

Any Human Machine Interface (HMI) device ranging from simple monitors to video-walls.

6.3.4. Wayside Communication Network

Any network infrastructure that allows the exchange of data from the different wayside systems to the IAMS Interfaces.

6.3.5. Diagnostic Wayside Systems

Any system composed of HW and SW modules that implements a monitoring function for a specific (or a set of) wayside devices and/or field elements.

6.3.6. CDM-standardised raw data sources

Any data source that produces data compliant with the CDM format.

6.3.7. Non-standardised raw data sources

Any source of data part of asset management systems but not CDM-compliant.

6.3.8. External data sources

Any source of data not part of a signalling or wayside diagnostic systems.

6.3.9. Wayside Data Interface

Any application (normally SW) that implements the exchange or retrieval of data from Wayside system.

6.3.10. Wayside CDM Adapter

Any adapter (normally SW) to convert data coming from the Wayside into CDM format.

6.3.11. CDM Ad-hoc interfaces

Any ad-hoc interface (normally HW + SW) to convert data coming from external systems into CDM format.

6.3.12. ATO

Automatic Train Operation (ATO) - A method of operation in which different train operation tasks are automated, according to the Grade of Automation (GoA) level present, up to GoA 4 level, where the train is automatically controlled without the presence of staff on board.

6.3.13. ATO-OB

On-Board Automatic Train Operation (ATO-OB) The sub-system and set of automated non-safety-related driver functions, depending on the grade of automation.

6.3.14. ATO-TS

Track-Side Automatic Train Operation (ATO-TS) A set of functions that interfaces with the necessary trackside systems which contain the operational data and infrastructure data that is required by the ATO on-board.

7. Requirement Specification

This section defines the IAMS general requirements for the WP3&WP4 scenario that are applicable for both Use Cases. This approach is derived from the work done in the Shift2Rail IN2SMART and IN2SMART2 project, specifically from the IAMS Architecture Requirement table present in D3.1 of WP3.

The goal is to define a number of high-level requirements that are common, both in literature and in the vision of the partners involved, for the application of a IAMS in the railway environment. These requirements are collected and described in the table present in Section 7.2 and will serve as a baseline for the definition of UC specific requirements that are going to be described in D3.2 and D3.3. Additionally, the table provided links each requirement to the architectural module(s) described in Chapter 6.

High-Level requirements of D3.1

Req_ID	Name	Description	Reference
Req_01	Data Collection	Collect maintenance and diagnostic data from maintenance data provider	Data Management
Req_02	Nowcast asset status	IAMS shall assess the current state of assets, detecting and highlighting anomalies, and providing assets status prediction.	Data Analytics, DSS
...			

UC-specific requirements from D3.2/D3.3

ID	REQUIREMENT	Category	Ref. ID
Gen_01	IAMS shall be able to forecast the insurgence of an anomaly related to the track circuits at least 5 days in advance.	Mandatory	Req_02

Figure 4: The link between high level KPI form D3.1 and the technical KPIs defined in the D3.2 and D3.3

This deliverable will define only general requirements that a textbook implementation of a IAMS application should have, linking each of them with the different blocks and modules presented on the architecture. Therefore, each requirement will have a sequential ID (e.g. Req_00, Req-01, …), while a categorization of the different families will be performed in the subsequent deliverables, namely D3.2 and D3.3.

7.1. Terms and Definitions

Before starting with the definition of the general requirements for the WP3-WP4 IAMS, it is important to give some context of the platform, services and the stakeholders involved.

This section contains a description of the main terms used in the requirements tables.

- **Anomalies:** Identification of rare events or observations, which differ significantly from the majority of the data. Typically, the anomalous observation will lead to some kind of problem in the monitored component.
- **Conceptual Data Model (CDM):** It aims at facilitating the integration of collaborating applications by designing an application-independent data model. The components may have different data representations internally, but whenever exporting or importing data to/from other components, they must translate this data to the canonical form.
- **Condition based maintenance:** Preventive maintenance, which includes a combination of condition monitoring and/or inspection and/or testing, analysis and the ensuing maintenance actions. The condition monitoring and/or inspection and/or testing may be scheduled, on request or continuous.
- **Constraint:** A constraint is an inequality or equality defining limitations on decisions. Constraints arise from a variety of sources such as limited resources, contractual obligations, or physical laws.
- **Corrective maintenance:** Maintenance carried out after a problem has occurred.
- **Criticality:** Numerical index of the severity of a failure or a fault combined with the probability or frequency of its occurrence.
- **Data Lake:** A data lake is a system or repository of data stored in its natural/raw format.
- **Failure:** Termination of the ability of an item to perform a required function. After failure, the item has a fault, which may be complete or partial. "Failure" is an event, as distinguished from "fault", which is a state. The concept as defined does not apply to items consisting of software only.
- **Fault:** State of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources. A fault usually results from a failure, but in some circumstances, it may be a pre-existing fault.
- **Forecasting:** Process of making predictions of the future based on past and present data and most commonly by identifying trends.
- **Gateway:** Tool used to monitor data sources, detect new data and copy it into the Data Lake.
- **Integration Layer:** A data processing module that manages the communication, data validation, sharing and analysis.
- **Key Performance Indicator (KPI):** In academic terms, a Key Performance Indicator (KPI) is a quantifiable metric that reflects progress towards a specific objective within a strategic plan. KPIs are carefully chosen to assess the effectiveness, efficiency, and alignment of actions with overall goals. They provide measurable benchmarks to track performance and facilitate data-driven decision-making.

- **Long-term planning:** Long-term planning is the DSS functionality aimed at generating the scheduling of maintenance interventions that require temporary line limitation and to provide solutions for impact mitigation, that is the activation of alternative services.
- **Nowcasting:** Process of exploiting past and present uncertain or incomplete data to make deductions about the present.
- **Preventive maintenance:** Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.
- **Predictive maintenance:** Condition-based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the significant parameters of the degradation of the item.
- **Processed Data:** Within data analytics applications, processed data refers to raw information that has undergone manipulation and refinement to enhance its quality and usability for analysis. This preparation often involves techniques for data cleaning, transformation, and feature engineering, resulting in a structured format optimized for subsequent statistical modelling or machine learning tasks.
- **Raw Data:** Raw data is unstructured and unformatted data that comes directly from a source. It can be in different formats, such as files, visual images, figures, database records or any other digital data. Raw data is unprocessed, not “trimmed”, unlike aggregated data, which is presented in a summarized format and limits your analytical capabilities.
- **Work order:** A task for the maintainer that can be scheduled or assigned to someone.

7.2. General Requirements

This section reports the IAMS general requirements for the WP3&WP4 scenarios: the main high-level features of the demonstrator are listed in the following table. As stated before, these requirements are going to be expanded and implemented at UC level and the more specific definition will be provided in D3.2 and D3.3. In order to show the link between the two categories, each requirement will have a unique "*Req_ID*" that must be referenced in the UC specific table. The "*Name*" and "*Description*" provide definition of the specific requirement and the context in which it will be implemented. Finally, the "*Reference*" column links the specific requirements with those identified in the architecture.

Req_ID	Name	Description	Reference
REQ_01	Manage system configuration	Receive, store and modify configuration of IAMS system applications.	IL, Data Management, CDM-standardised raw data sources
REQ_02	Export System configuration	Export configuration data (e.g., own system, maintenance data provider system, data decoding, pre-processing).	IL, Data Management, CDM-standardised raw data sources
REQ_03	Operational Data Collection	Collect and store operational data related to the sources monitored in raw format.	IL, Data Management, Data Platform
REQ_04	Diagnostic Data Collection	Collect and store diagnostic data related to the sources monitored in raw format.	IL, Data Management, Data Platform
REQ_05	Planned Maintenance Data Collection	IAMS shall collect and store information related to the scheduling and execution of planned (preventive) maintenance, including reports and operator's forms.	IL, Data Management, Data Platform
REQ_06	Corrective Maintenance Data Collection	IAMS shall collect and store information related to the scheduling and execution of corrective maintenance, including reports and operator's forms.	IL, Data Management, Data Platform

Req_ID	Name	Description	Reference
REQ_07	Self-diagnostic Data Collection	Collect and store diagnostic and operational data of IAMS system/applications performance.	IL, Data Management, Data Platform
REQ_08	Exogenous Data Collection	Collect and store exogenous data related to the sources monitored in raw format.	IL, Data Management, Data Platform
REQ_09	Railway System Interface	IAMS shall be able to interface with existing railway systems (such as TMS, IXL, ERTMS, etc) to implement the data collection processes.	IL, Wayside Data Interface, Wayside CDM Adapter, TMS
REQ_10	External Systems Interface	IAMS shall be able to interface with external systems (such as weather stations, ERPs, etc) to implement the data collection processes.	IL, CDM ad-hoc interfaces, External Business Functions Interfaces
REQ_11	Timestamping	IAMS shall be able to timestamp data generated within IAMS or to synchronise data collected data outside the IAMS system to a common "clock".	IL, Data Management, Time-stamping
REQ_12	Geo-tagging	IAMS shall be able to geographically tag data, including conversion from different reference systems (e.g., from geographical coordinates to linear referencing).	IL, Data Management, Geo-tagging
REQ_13	Raw Data Storage	IAMS shall store the raw data collected for a configurable amount of time and in any case for a period no longer than 2 years.	IL, Data Management, Data Platform
REQ_14	Processed Data Storage	IAMS shall store all processed data (KPIs, Analytics, Alarms, Events, etc) produced by the different applications for a configurable amount of time and in any case for a period no longer than 2 years.	IL, Data Management, Data Platform
REQ_15	Long-term Data Storage	IAMS shall provide the capability to move old data from the operational database to a "cold-storage" location.	IL, Data Management, Data Platform
REQ_16	Data pre-processing	Perform pre-processing procedures on collected data.	IL, Data Management, Data Analytics

Req_ID	Name	Description	Reference
REQ_17	Data processing	Perform processing procedures (cleaning, decoding, standardization, aggregation) on collected data.	IL, Data Management, Data Analytics
REQ_18	Data Correlation	Provide the capability to aggregate multiple data sources into a single dataset and extract additional information.	IL, Data Management, Data Analytics
REQ_19	Self-diagnostic data processing	Perform processing procedures (cleaning, decoding, standardization, aggregation) on collected self-diagnostic data (metrics and logs).	IL, Data Management, Data Analytics
REQ_20	Data analytics	Provide the capabilities to implement data analytics methodologies on the data collected, to extract knowledge and to compute relevant statistics.	IL, Data Management, Data Analytics
REQ_21	Machine Learning	Provide the capabilities to develop, test and subsequently deploy specific ML application for particular assets.	IL, Data Management, Data Analytics
REQ_22	Application Programming Interfaces (APIs)	Provide the capability for external services/applications to query processed data and export it in standardised data format. The IAMS APIs shall allow data exchange in a continuous way (subscription) or upon request.	IL, Data Management, Data Platform, External Business Functions Interfaces
REQ_23	KPI engine	Provide the capabilities to define, evaluate and manage Key Performance Indicators, in accordance with the IM/RU definition.	IL, Data Management, Data Analytics
REQ_24	Asset prioritisation	IAMS shall be able to prioritize the assets according to their status, given their criticality and relative position. This should be done based on risk analysis that would assess the consequence of the different asset failures on maintenance and operations.	IL, Data Management, Data Analytics, DSS
REQ_25	Anomaly detection	IAMS shall be able to identify specific anomalies related to the assets monitored, provided that the data collected is of quality and includes instances of the specific anomaly.	IL, Data Management, Data Analytics

Req_ID	Name	Description	Reference
REQ_26	Nowcast Asset Status	IAMS Shall be able to assess, within a reasonable interval of confidence or accuracy, the current operational status of an asset.	IL, Data Management, Data Analytics
REQ_27	Forecasting Asset Status	IAMS Shall be able to assess, within a reasonable interval of confidence or accuracy, the future operational status of an asset.	IL, Data Management, Data Analytics
REQ_28	Alternative Maintenance Planning	IAMS shall be able to propose to the operator an alternative maintenance plan. This new plan shall improve the former one based on the optimisation of a set of factors (e.g. reduction of costs, improvements of resources, asset's criticality, etc).	IL, Data Management, Data Analytics, DSS
REQ_29	Data Visualization: HMI	IAMS shall present to the final operator with a functional and easy-to-use HMI for the visualization of the data collected and produced. This HMI can be accessible with different methodologies (e.g. web application, client application, etc).	Data Management, HMI
REQ_30	Data Visualization: log-in	IAMS shall allow the possibility to access the HMI protected by log-in credentials, if asked by the final operator.	Data Management, HMI
REQ_31	Data Visualization: roles	IAMS shall allow the creation of different roles inside the HMI, in order to allow or restrict access to specific interfaces depending on the user role.	Data Management, HMI
REQ_32	Data Visualization: dashboards	IAMS shall implement interfaces to provides at-a-glance views of Key Performance Indicators (KPIs) and asset status information relevant to a particular business process possibly driven by the context.	Data Management, HMI, Dashboard
REQ_33	Data Visualization: geo-mapping	IAMS shall implement interfaces that allows to display, query and, more in general, manage geo-referenced/geo-located	Data Management, HMI, Geo-mapping

Req_ID	Name	Description	Reference
		data (e.g., GIS applications and schematics).	
REQ_34	Data visualization: Integration	IAMS shall allow the possibility to switch among the different application and interfaces within the context of the HMI and without the need to open external applications or providing new credentials.	Data Management, HMI, Visualisation
REQ_35	SAMP: Strategic Options	The proposed IAMS shall allow the selection a broad range of strategic options because the selection has a significant impact on the subsequent asset performance and maintainability.	IAMS Level 1 (SAMP), Decision Support Systems (DSS), Visualisation
REQ_36	SAMP: Asset / System Knowledge	The proposed IAMS shall support the analysis of the strategic options by providing access to the current status of assets and also how they are likely to perform in the future.	IAMS Level 1 (SAMP), Decision Support Systems (DSS), Visualisation
REQ_37	SAMP: Analyse Strategic Options	IAMS shall allow users to define scenarios, import assets / system knowledge (asset status, work already in plan, asset relationships).	IAMS Level 1 (SAMP), Decision Support Systems (DSS), Visualisation
REQ_38	SAMP: Asset Strategies	IAMS shall be able to produce Asset Strategies in the form of intervention rules to be used in the Asset Plans.	IAMS Level 1 (SAMP), Decision Support Systems (DSS), Visualisation
REQ_39	AMP: Asset / System Knowledge	IAMS shall support the analysis of the planning options by providing access to the current status of assets. It shall support the prioritization of the assets over the route based on a risk analysis carried out to assess the whole consequences of each asset failure, for nowcasting and forecasting usage and the assessment of Operational and Ageing behaviour of each asset, based on past observations / measurements and failures (Reliability and Maintenance inputs).	IAMS Level 1 (AMP), RAMS and LCC, Decision Support Systems (DSS), Visualisation

Req_ID	Name	Description	Reference
REQ_40	AMP: Resources and Constraints	IAMS shall list the available resources that are needed to perform maintenance covering the material and machinery resources, as well as the IT ones, and the human resources.	IAMS Level 1 (AMP), Decision Support Systems (DSS), Visualisation
REQ_41	AMP: Identify and Analyse AM Planning Options	IAMS shall present different scenarios of supervision, maintenance, and replacement of the assets considered, all constituting a possible Asset Management Plan, and allow the possibility to consider various options, particularly the opportunity of grouping operations.	IAMS Level 1 (AMP), Decision Support Systems (DSS), Visualisation
REQ_42	AMP Output	IAMS shall produce as output a plan in terms of inspection and supervision activities, providing, for each asset type or group of assets, a list of inspections to be performed, their frequency and expected costs.	IAMS Level 1 (AMP), RAMS and LCC, Decision Support Systems (DSS), Visualisation
REQ_43	IAMP: Input for scheduled maintenance operations	The proposed IAMS shall take as input of the IAMP phase the Route Delivery Plan integrated with additional information, based on local knowledge (assets, operational context and available resources), in order to mitigate operational risks and to adapt, if necessary, the consistency and/or organisation of operations to be performed.	IAMS Level 1 (IAMP), Decision Support Systems (DSS), Visualisation
REQ_44	IAMP: Asset/System Knowledge	The proposed IAMS shall provide access to: 1) Geographical, topographical and functional description of the assets and their surrounding; 2) past and current status of the assets, and their Maintenance history; 3) characteristics of the asset components to be maintained.	IAMS Level 1 (IAMP), Decision Support Systems (DSS), Visualisation
REQ_45	IAMP: Resources and Constraints	The proposed IAMS shall be able to introduce in the decision-making process resources (operational human forces at local level and logistics management and current logistical support) and constraints (engineering access, track	IAMS Level 1 (IAMP), Decision Support Systems (DSS), Visualisation

Req_ID	Name	Description	Reference
		access, current operational maintenance condition, legal, standards).	
REQ_46	IAMP: Preparation of Work	To mitigate the risks associated to each Maintenance intervention and to maximize their effectiveness, the proposed IAMS shall allow to prepare the work on site by performing the following activities: mobilisation of works delivery team and resources, scheduling of resources, Provision of tools, plant, facilities, spare parts, and equipment; Booking possessions; Setting-up safety at worksite; Risk assessment and establishing mitigation plan (e.g. possession overrun).	IAMS Level 1 (IAMP), Decision Support Systems (DSS), Visualisation, Work Preparation and Execution
REQ_47	IAMP: Execution of Work	The proposed IAMS shall be able to update databases after the maintenance intervention has been performed, reporting technical work, costs, and asset status.	IAMS Level 1 (IAMP), Decision Support Systems (DSS), Data Management

8. Use Cases Description and Validation process.

As defined in the GA description, the technical objectives of WP3 and WP4 have been divided into 2 demonstrators, corresponding with Task 3.2 and Task 3.3.
Specifically, they are:

- UC1: Wayside and Infrastructure IAMS for TMS optimisation.
- UC2: Wayside monitoring in conventional and high-speed lines for TMS optimization.

While the 2 UCs follow similar principles in terms of architecture definition and general objectives, as detailed in the previous chapters, they differ quite significantly with regard to the operational environment and the asset monitored.
The first major difference is that UC2 focuses solely on the monitoring of wayside signalling assets, while UC1 also takes into consideration infrastructural elements; the kind of rail line and traffic monitored is also different, with UC1 focusing only on conventional (meaning regional passengers trains) and freight and UC2 on conventional and High-Speed. Additionally, UC2 will develop specific monitoring sensors and systems to collect data from the signalling assets, while UC1 will exploit the existing IXL system to collect operational data of track circuits and switches.
The table below should serve as a reference to highlight these differences:

TOPICS		UC1	UC2
OPERATIONAL CONDITION	High-Speed		X
	Conventional	X	X
	Freight	X	
ELEMENTS MONITORED	Switch&Crossings	X	X
	Level crossings	X	X
	Track Circuits	X	
	Bridges	X	
	Track geometry	X	
TECHNOLOGIES/ENABLERS	Radar/Lidar	X	
	Video inspection	X	
	Edge Computing	X	X
	Sensors		X

The following paragraphs will detail the general context and objectives of the 2 use cases, giving also a description of the problem addressed by each demonstrator. Additionally, the definition of the UC-specific KPIs is provided, including also the formula to evaluate the indicator. This definition will serve as the base for the validation process that will be carried out in WP4 and that will be detailed inside D4.1 “Data analytics framework design, development and validation report”.

8.1. UC1: Wayside and Infrastructure IAMS for TMS optimisation

8.1.1. Use Case Description

The management of routes is currently carried out through the latest generation apparatus, called Central Computerized Multi-Station 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 is managed by the SCCM (Multi-station 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 limited (with the exception of new systems that provide a dedicated diagnostic channel) and often elaborated independently, instead merging them together to extract added value.
Within the context of improving the infrastructure maintenance process, the need to introduce predictive maintenance (which uses data analysis and modeling 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.

Additionally, it is foreseen to study the application of prescriptive algorithms for maintenance: this would mean building upon the prediction and insights provided by the analytics in order to provide suggestions about the actions to perform to solve the unexpected problems. The implementation of such methodologies would ensure the correct functioning of components and systems over time, providing also useful information to the maintainer to optimize their workflow.

Therefore, the Infrastructure Manager intends to pursue this ambitious objective by collecting operational, diagnostic and maintenance data from both the wayside systems (Signals, S&C, Balise, Track Circuits, etc.) and the infrastructural elements (bridges, level crossings) along the line. Specifically on this last point, it is envisioned to use available data provided by diagnostic vehicles, 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 support the asset maintenance process. Additionally, IAMS will support the TMS (Train Management System) by providing diagnostic information of the assets in order to improve railway management in terms of punctuality and regularity, reducing service interruptions, line unavailability and related management costs.

As already mentioned in the previous paragraph, currently the SCCM system (Multi-station Command and Control System) that is physically located in 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 the 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 optimize 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, analyze and locate the situations of failure that may occur in the system, obtained through the integration of the following basic functions:

- Online 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 planning and the report of the activities performed are stored on a proprietary ERP system called “INRETE2000", which uses the information on the systems collected by the diagnostic functions to provide operators with operational support for the management of maintenance interventions. In general, the maintenance functions managed by INRETE2000 can be classified as follows:

- Corrective (or extraordinary) maintenance: aimed at restoring the fully 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 MTBF of the individual components through the programming of maintenance interventions.
- On condition: where the scheduling of the activity is defined based on the operating conditions of the asset.

In addition to the above, Supplementary protection systems are put in place to monitor Level Crossings passage’s clearance. This Obstacle Detection System will be developed jointly by Mermec and FS within the course of the project and tested in laboratory. 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 infrastructure, the rolling stock and harming people.

Therefore, due to the above considerations, final and consolidated choice of the line section for

the acquisition of signalling (from ACC and SCC-Scada) and infrastructural maintenance data (Track geometry and civil works -bridges) is based on section of railway lines under the jurisdiction of the Qadrivio Turro (ACCM) near Milano Greco (PC), geographically located in northern Italy - see first two pictures below.
Regarding the monitoring solution for level crossing (prototype developed at Mermec facilities), it will be tested in representative environment, geographically located in southern Italy, near Mola di Bari (rendering in last picture below).

Figure 5: Location and some photos of the UC1 site (qv Turro in Milan)

8.1.2. Subproblems Addressed by the Use Case

8.1.2.1. 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 UCs by providing access to the functional parameters, alarms and logs related to the different assets monitored.

Within the context of WP3 it is envisioned to develop a monitoring system that would allow to collect 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.

8.1.2.2. Infrastructure Monitoring System

Information related to the geometry of the track and structural health conditions of the bridges, exposure of the surrounding environment to hydrogeological risks and vegetation encroachment is essential to obtain a more holistic view of the network status. The continuous update of this information defines a Real Time Monitoring system that allows managers setting appropriate thresholds 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 satellites and to develop efficient procedures for data pruning and threshold definition to automate and make more efficient the selection of information to be transmitted to the TMS.

8.1.2.3. 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, road vehicles or sensibly sized objects falling from them could be located between barriers. The usage of obstacle detectors in proximity of level crossing is therefore pivotal to prevent damage to the rolling stock and protect 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. Generally, these two technologies are not exploited simultaneously.

Some functions related to 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.

8.1.2.4. 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, a number of specific machine learning models will be developed and applied in order to solve the issues highlighted. For example, in the case of the monitoring of the Track Circuits, the objective will be to reduce false occupations instances, which can lead to service disruptions and line unavailability.
The goal will be to validate this prediction against the actual state of the assets monitored, by cross-checking the number of maintenance interventions performed, in order to provide the operator with a health index of the asset and additional information on its criticality and remaining useful life.
This information will be then provided to the DSS module for the scheduling of maintenance procedures or to the TMS for the optimization of operations.

8.1.2.5. Decision Support System for Automatic and Optimised Maintenance Scheduling

The DSS is aimed at suggesting possible alternative maintenance plans 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, increase the quality of the service and guarantee regular and seamless connections.
More in detail 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.

8.1.2.6. 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 input 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.

8.1.3. KPIs Definition and Validation Method

The objectives that this Use Case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #1: Asset Management and TMS and the related KPIs.
Specifically, The FP3-IAM4RAIL Grant Agreement connects the Demonstration Objective 1 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 conditions.
- 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.

8.1.3.1. KPI 1. Reduction of speed restrictions on trains due to deteriorating asset conditions

Short description

Predictive maintenance can significantly influence the reduction of speed restrictions 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 from the railway assets and store it into the Integrated Asset Management System (IAMS).
By analysing this information, the predictive models to be developed will be able to detect patterns and anomalies that indicate potential problems before they become critical failures. This allows them to schedule maintenance before it is needed, helping to reduce unplanned downtime and improve the reliability and availability of rail infrastructure.
In short, predictive maintenance can help improve the reliability and availability of rail infrastructure, which can reduce the need for speed restrictions 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 conditions will be quantified with the current corrective / preventive maintenance approach compared to the future predictive maintenance approach in which maintenance activities can be scheduled without affecting circulation. The time period will be determined based on the available data.

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

Where:

- *LTVn* is the number of total speed restrictions on the railway line due to deteriorating asset conditions with new maintenance strategy.
- *LTVt* is the number of total speed restrictions on the railway line due to deteriorating asset conditions with current maintenance strategy.

8.1.3.2. KPI 2. – Reduction of 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, 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 an optimal preventive maintenance that, by knowing the state of health of the infrastructure in a faster time, allows infrastructure managers to detect any critical area along the infrastructure take appropriate actions if necessary, including high resolution data gathering, detection of threshold values for activation of emergency procedure and 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, 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, that indicates that the estimated time for the new method is less than the time required for the traditional method.

However, if KP2 is negative, that indicates that the estimated time for the new method is greater than the time required for the traditional method.

Within the context of maintenance activities implementation, the time saved in the implementation of a particular intervention is strongly related to the cost associated to that activity, Therefore, the KPI formula presented before can be changed to focus more on this new aspect, as 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, that indicates that the estimated cost for the new method is less than the cost required for the traditional method.

However, if KP2 is negative, that indicates that the estimated cost for the new method is greater than the cost required for the traditional method.

8.1.3.3. 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 with respect to 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 kinds 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 not only on the asset monitored (so in this case, putting obstacles on the line) but also on the monitoring technology (radar / lidar), checking the capability of the system to work with just one technology. This will demonstrate the higher availability of the combined solution.

Calculation of this KPI is trivial. In fact, comparing 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).

8.1.3.4. KPI 4. Corrective maintenance prediction

Short description

This KPI refers to the algorithm’s 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:

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

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

8.1.3.5. 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 KPI is dependent on the availability of maintenance intervention planned and implemented to be used as 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.

8.1.3.6. 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. To different data sources corresponds to different data processing techniques, so each data source is considered separately for the computation of the KPI and finally the average is calculated.

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

8.2. UC2: Wayside monitoring in conventional and high-speed lines for TMS optimization

8.2.1. Use Case Description.

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 for 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. In the event that 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 at early stages and at level crossings. The implementation of predictive maintenance would lead to advantages such as:

- Improving maintenance planning.
- 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 that said information will be able to be sent to the signalling assets in order to be more agile when it comes to managing rail traffic.

At ADIF, as previously mentioned, we assume that asset reviews are not carried out predictively, anticipating the possibility of asset failure, but rather preventive maintenance (periodic inspections), as well as corrective maintenance, if the asset has already failed.

Achieving predictive maintenance is very important because it would allow the scheduling of activities only for those assets that need to be maintained, with a significant cost reduction with respect to the current process. 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.

The general use case described above will be divided into three use cases that are presented in the following points:

High-Speed Switch Point Machine monitoring (INDRA)
The main motivation for implementing predictive maintenance stems from past incidents where fractures have been documented in engine rails, attributed to vibrations induced by passing trains. These vibrations propagate to the internal components of the engine, potentially leading to structural failure. To address this issue comprehensively, the main objective is to incorporate sensor technology into the inspection of railway switch engines and associated components. This initiative aims to meticulously analyse the root causes of damage or breakage, thus facilitating predictive maintenance interventions.
A set of sensors will be installed in the railway switch system to enable predictive maintenance. This monitoring system will be implemented at Santa Cruz de la Zarza (Toledo, Spain), where one of the point machines (A1-11) has been experiencing recurrent problems with its rails. The focus will be on two engines, monitoring two engines helps to compare the data from one machine, which has recorded a high number of incidents, with another machine belonging to the same group, which has not recorded as many breakages (A1-12).

High-Speed and Conventional Switch Point Machine monitoring (THALES)
The demonstration, carried out on a high-speed line, consists of the installation of a set of switch monitoring sensors designed by THALES to be used as a predictive tool for monitoring and decision-making during maintenance work on electrohydraulic engines.
This system will be installed in electrohydraulic engine L826H nº 11 of point 115, located at PK 28.414 in Bif. Torrejón de Velasco (Madrid, Spain).
The aim is to validate the prototype monitoring system for THALES L826H point engine and to obtain data in an operating environment with high-speed traffic.
The demonstrator, which will be carried out on a conventional out-of-service track, will consist of the installation of an outdoor cabinet in which the following will be located:

- The intelligent object controller (SWOC)
- The 4G LTE wireless router equipment with outdoor antennas

The purpose of this installation is to be used as a predictive tool for monitoring and decision-making in the maintenance of electro-hydraulic engines. This system will be installed on the L826H electro-hydraulic engine of the A2 switch, located in front of the technical building of Olmedo Medina (Valladolid, Spain).
The aim is to validate the prototype monitoring system for THALES L826H switch engine and to

obtain data in a non-operational test environment.

<u>Level Crossing barrier monitoring (ENYSE)</u>

Level crossing barriers are protective elements that prevent vehicles, pedestrians or animals from crossing the railway lines when a train approaches, avoiding accidents and possible loss of human or animal life.

The failure or unavailability of a level crossing barrier causes the stoppage of trains and, therefore, delays in railway circulation.

With the aim of increasing the availability of the assets, ENYSE is going to install a new sensorized level crossing barrier system that will allow a large amount of data to be extracted. This data will be sent to the IAMS, which will provide predictions of possible asset failures. The predictions will allow us to anticipate possible failures and implement mitigations to avoid them, increasing the availability of the assets.

Additionally, IAMS will be able to integrate information from several sources such as TMS, external data sources or other assets, enriching its predictive capabilities.

The predictions may be consulted through the IAM system itself or sent to the TMS or through other means to be defined.

ENYSE, as part of the demonstrator, will install a sensorized level crossing barrier at the Lláscares Level Crossing (PK 35.090, Asturias), belonging to the RFIG (Red Ferroviaria de Interés General, General Interest Railway Network) of ADIF.

8.2.2. Subproblems Addressed by the Use Case

8.2.2.1. Signalling data Acquisition - Level crossing barrier 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 are working (vibrations, adverse weather conditions, vandalism, ...). In addition, it provokes the trains to stop, causing serious delays in train operation.

As indicated before, we assume that reviewing level-crossing barriers is not carried out predictively to anticipate the possibility of asset failures, but rather preventive maintenance (periodic inspections), as well as corrective maintenance, if the asset has already failed.

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

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, reduce maintenance costs and optimise the operation (TMS).

8.2.2.2. Unmanned System Data Acquisition - Switches monitoring system

The objective is 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.
Given the crucial role of railway switches, it is of outmost importance to early detect and predict defects and damages in the elements of the switch (structural, obstacles, etc) that would prevent the element from its normal operation.
Two of the point machine failures that can have a high impact on the HSL operation are the break of the lock bars of the point machines of the points due to the vibrations and the inability to reach the final position due to the slack in the "locks" to closure. The analysis of these two failures will be addressed. Also, the analysis of the existence of potential objects, obstacles or other impacts in the movement of the point that may affect to the switch availability will be analysed through the parameters of the movement of the point machine.
The relevant information for TMS is the availability of the switches due to the high impact in the train operation, as counterpart for the analysis of the condition it will be analysed if additional parameters provided by the TMS would be relevant.
The unmanned monitoring system has a direct influence on the more than 15.000 switches of the railway network in Spain, as sensitive components in the operation and destination of high investments for maintenance.
Such an innovative system allows 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.

8.2.2.3. Asset Status Forecasting System

Using AI technologies, the information acquired from the sensors and stored in the IAMS will be processed to detect anomalies in the operating patterns and make predictions of the asset's behaviors and possible problems. This will allow the planning of maintenance and changes in the operation to reduce the impact of the problem before it occurs.
Additionally in the switch point machine use case, 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.

8.2.2.4. Decision Support System for Optimised Maintenance Scheduling

The data produced by the different monitoring systems will be used to predict the operative status of the assets and therefore to improve the maintenance scheduling. The goal is to change the fixed scheduling paradigm, currently implemented in most cases, to a more flexible one that takes into consideration the current status of the assets.

Some of the objectives are related to:

- Focusing the attention on relevant information supporting the prioritisation of decisions to be taken.
- Providing holistic view (exo-data and ecosystem) related to specific events analysis to support decisions based on wider scope of information.
- Supporting the correlation of information and potential events to support decisions related to root cause analysis and impacts.

8.2.2.5. Integration of Analytics with TMS

With the data provided by the TMS and the sensor networks stored IAMS will perform an analysis and processing to infer the state of the elements and be able to extract relevant information that can help the decision support system for maintenance optimization and provide additional information of the status to the TMS to optimise the operation.

8.2.3. KPIs Definition and Validation Method

The objectives that this Use Case aims to achieve are in line with the description of the FP3-IAM4RAIL Demonstrator #1: Asset Management and TMS and the related KPIs.

Specifically, The FP3-IAM4RAIL Grant Agreement connects the Demonstration Objective 1 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 delayed trains due to asset condition.
- Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown.
- Reduction of normalisation time in case of the monitoring of the point machine slack in the "locks" to closure.

8.2.3.1. KPI 1: Reduction of delayed trains due to asset condition

Short description

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

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

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

How to compute KPI 1

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

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

Where:

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

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

Delay minutes will be measured at all available measuring points. Of those trains with a measured delay minutes that exceed a specific threshold, a delay event is counted. The threshold will vary depending on the line type and the category of the train involved: for example, in a High-Speed scenario, a train delay event is counted if the delay exceeds 5 minutes for passenger services and 15 minutes for freight services.

No train delay event is counted if these thresholds are not exceeded at any measuring point.

8.2.3.2. KPI 2: Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown

Short description

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

How to compute KPI 2

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

For the calculation of the KPI: The time required to diagnose a broken electric motor using the conventional diagnostic method shall be compared to the automated solution. The time shall be counted from the moment the problem occurs until the maintenance staff knows the reason for the problem. The KPI will be met when:

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

Where:

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

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

8.2.3.3. KPI 3: Reduction of normalisation time in case of the monitoring of the point machine slack in the “locks” to closure

Short description

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

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

How to compute KPI 3

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

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

For the calculation of the KPI: We sum up all reporting times of all faults related to turnout setting faults and divide by the total number of faults.
When comparing the values on the same point machine in the years before the demonstrator is set up (2021-2023) and after (2024-2026) the improvement will be the ratio between the average in previous 2 years and the average in the 2 years of demonstration.
When comparing the assessment of the slack in the “locks” to closure by visual Inspection (same point machine in previous years i.e. 2021-2024) with its automated counterpart operated by the IAMS (2024-2025), it is clear how adoption of the automated solution results in a reduction of time for communicating the status of the assets with the TMS. Equally, there would be a reduction of human intervention as regular visual inspection will be less demanded.
The improvement is computed as the ratio of the 2 normalization time =

$$\frac{ANTo-ANTn}{ANTo} x\ 100$$

Where:

- ANT_o is the average normalisation time per failure before the new monitoring approach.
- ANT_n is the average normalisation time per failure of the new monitoring approach.

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

9. Conclusions

The ever-growing complexity of railway infrastructure, coupled with increasing pressure to optimize operations and maintenance costs, necessitates a paradigm shift towards a data-driven approach to the management of railway assets and the decision-making processes. This document proposes the design and implementation of an Intelligent Asset Management System specifically tailored to two railway scenarios. The objective is not just to develop a data collection and storage platform, but to create a comprehensive system that leverages the power data analytics and machine learning to achieve the following results:

- **Enhanced decision-making:** By analysing real-time and historical data from various sources, including sensors embedded within tracks, IAMS aims to provide actionable insights for maintenance planning and resource allocation. This will enable informed decisions about preventive maintenance schedules, optimizing resource utilization and minimizing downtime.
- **Predictive maintenance:** The system will leverage machine learning algorithms to analyse sensor data and predict potential equipment failures before they occur. This proactive approach will significantly reduce the risk of unexpected breakdowns, improve operational safety, and minimize disruption to railway schedules.
- **Improved asset lifecycle management:** The IAM system will track and analyse the health and performance of railway assets throughout their lifecycle. This comprehensive data will facilitate informed decisions about asset replacement and upgrades, ensuring optimal utilization and extending asset lifespan.
- **Streamlined information flow:** By integrating with existing railway information systems, IAMS will create a centralized repository for asset-related data. This will streamline information flow, improve communication and collaboration among different stakeholders and systems within the railway environment, to enhance the overall operational efficiency.

The ultimate objective is to create platform that fosters a data-driven approach to railway asset management. This application will also contribute to a more reliable, efficient, and cost-effective railway network, supporting the operator in the planning of traffic.

10. References

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