Deliverable D 1.5
D1.5 Technical/Impact KPIs Report (initial)

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0.1	13/05/2024	First issue
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1.0	19/06/2024	Final version approved by the TMT and SC and submitted to ERJU
2.0	12/05/2025	Second issue with the following recommendation addressed: • UCs should have a mix of PI and KPI with target. KPI and PI should be measured the same way. • Please clarify KPI / PI definition. • Please align UC definition in D1.5 with the updated list in D2.7 • Please update the matrix per UC with the PI/KPI.

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1. Executive Summary

This document, "Technical/Impact KPIs Report (initial)", explains how FP3-IAM4RAIL is addressing the Key Performance Indicators (KPIs) stated in the Multi-Annual Work Programme (MAWP) of the EU-Rail JU, the Performance Indicators (PIs) to be fulfilled specifically within the project lifetime and finally the positive impact the technical developments of FP3-IAM4RAIL will hopefully have on a variety of topics of the railway sector.

The Key Performance Indicators (KPIs) represent the overarching goals of the EU-Rail JU work programme and are to be reached by 2031 as stated in the programme, while Performance indicators (PIs) are specific targets to be met by the end of 2026.

FP3-IAM4RAIL project has established a baseline using data from 2022, where available, and has defined a clear methodology to ensure that results are comparable and repeatable. The project employs various approaches to measure progress towards KPIs, including demonstrations, simulations, and expert judgment, based on data availability and the overall timeline of demonstrations as stated in the MAWP.

The successful implementation of demonstrators and use cases within FP3-IAM4RAIL is expected to have measurable impacts on society and the economy.

The project plans to quantitatively assess these impacts whenever possible, while other impacts (e.g., societal) will be qualitatively assessed. Given the complexity of the developments and the numerous interdependencies within the rail system and the real world, the project results can only be evaluated holistically and taken as estimations.

This document will provide the baseline of all future work concerning KPIs within FP3 and also will be kept as a reference for Flagship Area 3 framework.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
AM	Additive Manufacturing
BIM	Building Information Model
CAPEX	Capital Expenditure
CBM	Condition Based Maintenance
ERJU	Europe's Rail Joint Undertaking
FA	Flagship Area
FP	Flagship Project
GA	Grant Agreement
HVAC	Heating, Ventilation and Air Conditioning
IAMS	Intelligent Asset Management Systems
KPI	Key Performance Indicator
LCC	Life Cycle Costing
MAWP	Multi Annual Work Programme
ML	Machine Learning
OPEX	Operational Expenditure
PI	Performance Indicator
PM	Preventive Maintenance
S&C	Switches & Crossings
TMS	Train Management System
TMT	Technical Management Team
TRL	Technology Readiness Level
TSR	Temporary Speed Restrictions
UC	Use Case
WP	Work Package

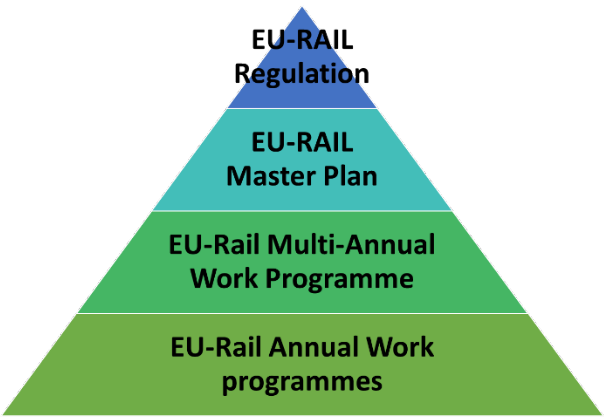
3. Background

The present document constitutes the Deliverable D1.5 "Technical/Impact KPIs report (initial)" There will be an update at the very end of the project by Month 48, named as Deliverable D1.4 "Technical/Impact KPIs report" in the framework of FP3- IAM4RAIL project (GA 101101966).

The project was co-funded by Europe's Rail Joint Undertaking (ERJU); the ERJU has several key strategic documents that guide its activities and objectives. These documents include the Master Plan, the Multi-Annual Work Programme (MAWP), and the Annual Work Plan (AWP).

The Master Plan is the overarching strategic document that outlines the long-term vision and objectives for the European rail sector. It aims to support the green and digital transition of Europe's railways by focusing on innovation, sustainability, and competitiveness. The Master Plan provides a systemic, long-term, and result-oriented delivery strategy for research and innovation in the railway sector.
The Multi-Annual Work Programme (MAWP) translates the strategic objectives of the Master Plan into specific, actionable goals over a multi-year period. It details the research and innovation activities, including flagship projects and other initiatives, that will be undertaken to achieve the objectives set out in the Master Plan. The MAWP provides a roadmap for the implementation of these activities, ensuring a coordinated and coherent approach.

The Annual Work Plan (AWP) is a more detailed document that outlines the specific activities, projects, and funding allocations for each year. It is derived from the MAWP and provides a yearly breakdown of the tasks and milestones that need to be achieved to stay on track with the multi-annual goals. The AWP is reviewed and updated annually to reflect any changes in priorities or new developments.



FP3-IAM4RAIL Grant Agreement identified impact areas from the EU-Rail JU Master Plan and expected contributions, reflected in the expected contribution al FA3 level, and derived from there two types of KPIs:

- Short-term KPIs (PIs) are going to be further analysed and developed, as well as their means of verification in order to ensure that during the Integrated demonstrations can be correctly measured.
- Long-term (impact KPIs) are going to be further analysed and developed, as well as their means of verification to ensure that and the end of the project the contribution of those KPIs is aligned with Europe's Rail JU Multiannual Work Plan.

Along the Grant Agreement of FP3-IAM4RAIL there are other documents related to the definition and assessment of Indicators.

In the framework of the Flagship Project 3 - IAM4RAIL and the EU-RAIL MAWP [3] the KPIs listed in the MAWP, as well as Performance Indicators (PIs) specific for each Use Case are taken into account to create this document. Furthermore, it is the first version of a number of KPI documents prepared within the project and will provide input to the next Deliverables.

4. Objective/Aim

This document aims to provide a comprehensive overview of the metrics and methodology used for the assessment of achievements and impacts in our research project deliverable.

The FP3-IAM4RAIL project is a highly complex and ambitious initiative; the complexity of the project is reflected in the extensive array of Indicators/Impacts.

The calculation and assessment of these indicators require a robust methodology, involving the establishment of baselines, precise measurement techniques, and continuous verification processes. The project's success depends on accurately tracking these indicators across various demonstrators and use cases, each contributing to the overarching objectives outlined in the Master Plan, Multi-Annual Work Programme (MAWP), and Annual Work Plan (AWP).

4.1. KPIs

The MAWP KPI definition process to measure the impacts and contributions from FP3-IAM4RAIL is a critical step in our research project as it enables us to establish clear and measurable objectives for performance evaluation and to ensure that our project is on track to achieve its goals. By defining KPIs, we can establish a baseline for performance measurement and track progress over time. The definition of metrics to measure these indicators is equally important as it ensures that our performance evaluation is objective and quantifiable, allowing us to make data-driven decisions that will ultimately improve our project's outcomes. Through this process, we can identify areas for improvement and optimise our resources, ultimately leading to more efficient and effective project outcomes.

FP3-IAM4RAIL will develop 7 different demonstrators. This was well known since the Grant Agreement phase so that KPIs were defined having in mind the demonstrators' ideas. 14 different MAWP KPIs have been identified:

1.Asset Management & TMS

- KPI 1 (I in GA) - Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50% in specific use cases.

2. Asset Management & Rolling Stock

- KPI 2.1 (II in GA) - Reduction of maintenance cost (Up to 10% in specific uses cases)
- KPI 2.2 (III in GA) - Reduction of service failures (25% reduction)
- KPI 2.3 (IV in GA) - Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use cases)

3. Long Term Asset Management

- KPI 3.1 (V in GA) - Tools which provide at least 3 possible strategies of long term management (with an accuracy (as defined by ISO) improvement of 10%)

4. Asset Management & Infraestructure

- KPI 4.1 (VI in GA) - Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use cases)
- KPI 4.2 (VII in GA) - Infrastructure Operation: Reduction of service failures (25% reduction)

5. Asset Management & Digital Twins

- KPI 5.1 (VIII in GA) - Number of assets managed and monitored by Digital Twin (Increase by 25 %)

6. Design & Manufacturing

- KPI 6.1 (IX in GA) - For repair: Extension of remaining life (25%)
- KPI 6.2 (X in GA) - Time reduction (from design to manufacturing) (20%)
- KPI 6.3 (XI in GA) - Design and Manufacturing: Cost reduction (20%)

7. Robotics & Interventions

- KPI 7.1 (XII in GA) - Increased accuracy of inspections with respect to conventional interventions (25%)
- KPI 7.2 (XIII in GA) - Reproducibility of inspections with respect to conventional interventions (25%)
- KPI 7.3 (XIV in GA) - Cost reductions of the interventions (by at least 10%)

Figure 1. Demonstrators and related KPIs

FP3-IAM4RAIL has defined also a Societal KPI to measure the Societal Impact (see figure 2):

8. Societal Impact

- KPI 8.1 - Support to rail workers - exoskeletons are used to perform sterenuous tasks, such as safely moving heavy loads

Figure 2. New KPI Societal Impact

The link of the UCs with the IAM4RAIL and the MAWP has been identified and reported in Table 1.

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.1 Qualitative and prompt integration of information, including reducing time to transfer asset condition stats to TMS *(Reducing time to transfer asset condition status to TMS by 50 % in specific us*	3.2.1 Rolling Stock Operation: Reduction of maintenance cost *(Up to 10% in specific use cas*	3.2.2 Rolling Stock Operation: Reduction of service failures *(25% reduction)*	3.2.3 Increasing rolling stock availability respective reducing workshop downtime *(Targeting 10% in specific use cas*	3.3 Tools which provide at least 3 possible strategies of long term management *(with an accuracy (as defined by ISO) improvement of 10*	3.4.1 Infrastructure Operation: Reduction of maintenance costs *(Targeting 10% in specific use case)*	3.4.2 Infrastructure Operation: Reduction of service failures *(25% reduction)*	3.5 Number of assets managed and monitored by Digital Twin *(Increase by 25%)*	3.6.1 For repair: Extension of remaining life *(25%)*	3.6.2 Time reduction (from design to manufacturing) *(20%)*	3.6.3 Design and Manufacturing: Cost reduction *(20%)*	3.7.1 Increased accuracy of inspections with respect to conventional interventions *(25%)*	3.7.2 Reproducibility of inspections with respect to conventional interventions *(25%)*	3.7.3 Cost reductions of the interventions *(by at least 10%)*	**Societal impact**: Support to rail workers - Exoskeletons are used to perform sterenuous tasks, such as safel moving heav
	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 4	Enabler 1, 2, 4, 5	Enabler 1, 2, 4, 5	Enabler 5	Enabler 6, 7	Enabler 6, 7	Enabler 6, 7	Enabler 2, 7	Enabler 2, 7	Enabler 2, 7	Enabler 2, 3, 7
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation															
UC3.2 Wayside monitoring in conventional and high-speed lines															
UC 5.1 Bogie Monitoring System (on-board) Alstom															
UC 5.2 Health Monitoring & Analytics of HVAC & Brake systems (ES, Talgo fleet)															
UC 5.3 Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)															
UC 5.4 Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, &															
UC 5.5 Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)															
UC 6.1 Development of next generation Traction Control Unit Hardware and Gate Drive															
UC 6.2 Traction component health monitoring & predictive															
UC 6.3 Set up of adaptative wireless telecom network between train elements - SNCF															
UC 6.4 Adhesion estimation for management - PRORAIL															
UC 6.5 Wayside Signalling Equipment Monitoring System - TALGO															
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in															
UC 6.7 Digital twin for energy - CAF															
UC 6.8 Smart maintenance scheduling tool - CAF															
UC7.1 Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)															
UC7.2 Pantograph Monitoring System (wayside – video and 2D-3D images)															
UC7.3 General physical anomaly detection Monitoring System (wayside – video and 2D-3D images)															
UC7.4 Data path diagram use case															
UC7.5 CBM algorithms use case															
UC8.1 Long term asset management and LCC															
UC8.2 Holistic long term asset management															
UC 9.1 - Sensing railway superstructure system components															
UC 9.2 - Railway infrastructure monitoring using optic fiber															
UC 9.3 - Track Geometry and S&C condition monitoring															
UC 9.4 - Infrastructure monitoring solutions															
UC 11.1 - Linking (new) monitoring technologies to asset management issues															
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis															
UC 12.1 - Multiscale monitoring of civil assets															
UC 12.2 - Bridges and earthworks assets management aided by geotechnics															
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel															
UC 12.4 - Data Analysis for condition monitoring															
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UC 15.3 - Track Condition data fusion in Point Clouds															
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UC 18.2 Automated installation of ERTMS balises and axle counters															
UC 18.3 - Disinfection of trains and small stations															
UC 18.4 - Train underbody inspection of difficult to reach or see areas															
UC 18.5 - Automated crossing repair															
UC 19.1 Upper-body exoskeleton for worker's support in railway industry															
UC 19.2 Augmented Reality tools to help and guide railway workers in maintenance operations															

Table 1. KPIs impact on Use Cases

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT	NO IMPACT

For each KPI a baseline and a formula has been identified, and it is reported in Chapter 6.

4.2. Performance Indicators (PIs) at Use Case Level

Deliverable 2.6 "Use Case definition" identified specific indicators per Use Case, the so called "technical indicators". These PIs have been updated in the second issue of the deliverable i.e. D2.7.

The PIs are designed to be specific, measurable with a specific target as well as a baseline, allowing for precise tracking and evaluation.

Performance Indicators (PIs) are metrics used to evaluate the effectiveness and efficiency of each FP3-IAM4RAIL Use case, to ensure that each aspect of the project is monitored and assessed accurately. Each use case within the FP3-IAM4RAIL project has its own set of PIs tailored to its specific objectives and activities.

Chapter 7 reports for each UC the PI's.

Deliverable D2.6 "Use cases definition" identified first specific indicators per Use Case, while Deliverable D2.7, consolidated them into the so-called PIs ("performance indicators") to be met around 2026 (see Figure 3). Also, other table (see Table 2) was prepared in FP3-IAM4RAIL in view to contemplate the credible pathways to societal KPIs regarding KPIs foreseen in the Europe's Rail JU Multi Annual Work Programme MAWP, FP3-IAM4RAIL Technical Enablers and precise level of societal/technical impacts (no impact, low or high) and finally a complete mapping of all impacts and use cases with the impact for each KPI (see Table 3).

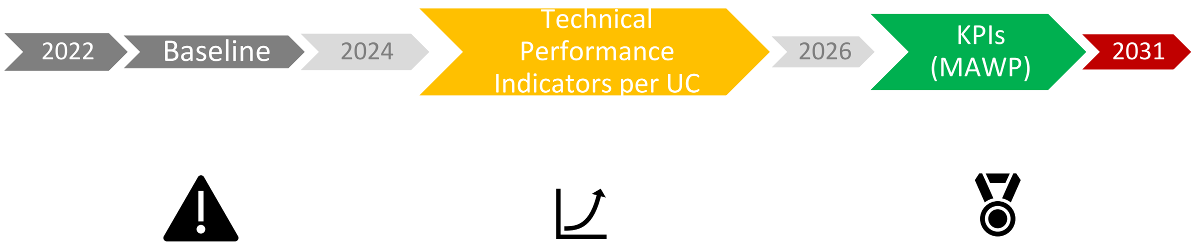

Figure 3. KPIs and PI´s timeline

4.3. Societal KPIs

The Europe's Rail Work Programme introduced also societal KPIs a to measure the broader societal impact of the programme. These societal KPIs are linked to the most relevant PIs, providing a comprehensive assessment of the programme's impact on society. This dual-layer approach ensures a detailed evaluation of both technological applications and their societal benefits, highlighting the significant role of research and innovation in driving progress, economic growth, and improving quality of life. **Table 2** reports the link between Societal KPI and FA3 KPIs reported in the MAWP according to the following criteria:

no impact
little/ indirect impact
high/ direct impact

PIs/ Impacts/ Enablers	3.1 Qualitative and prompt integration of information, including reducing time to transfer asset condition stats to TMS *(Reducing time to transfer asset condition status to TMS by 50 %, in specific use cases)*	3.2.1 Rolling Stock Operation: Reduction of maintenance cost *(Up to 10% in specific use case)*	3.2.2 Rolling Stock Operation: Reduction of service failures *(25% reduction)*	3.2.3 Increasing rolling stock availability respective reducing workshop downtime *(Targeting 10% in specific use case)*	3.3 Tools which provide at least 3 possible strategies of long-term management *(with an accuracy (as defined by ISO) improvement of 10%)*	3.4.1 Infrastructure Operation: Reduction of maintenance costs *(Targeting 10% in specific use case)*	3.4.2 Infrastructure Operation: Reduction of service failures *(25% reduction)*	3.5 Number of assets managed and monitored by Digital Twin *(Increase by 25 %)*	3.6.1 For repair: Extension of remaining life *(25%)*	3.6.2 Time reduction (from design to manufacturing) *(20%)*	3.6.3 Design and Manufacturing: Cost reduction *(20%)*	3.7.1 Increased accuracy of inspections with respect to conventional interventions *(25%)*	3.7.2 Reproducibility of inspections with respect to conventional interventions *(25%)*	3.7.3 Cost reductions of the interventions *(by at least 10%)*	**Societal impact:** Support to rail workers - Exoskeletons are used to perform strenuous tasks, such as safely moving heavy loads...
	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 1, 2, 4	Enabler 4	Enabler 1, 2, 4, 5	Enabler 1, 2, 4, 5	Enabler 5	Enabler 6, 7	Enabler 6, 7	Enabler 6, 7	Enabler 2, 7	Enabler 2, 7	Enabler 2, 7	Enabler 2, 3,, 7
Energy Savings in Transport															
GHG Emission Savings in Transport															
Congestion Savings in Transport															
Rail Affordability															
Rail Connectivity															
EU Rail Sector Competitiveness															
Occupational Safety in Rail															
Passenger Safety in Transport															
Circular Economy															

Table 2. PIs & Impacts & Enablers

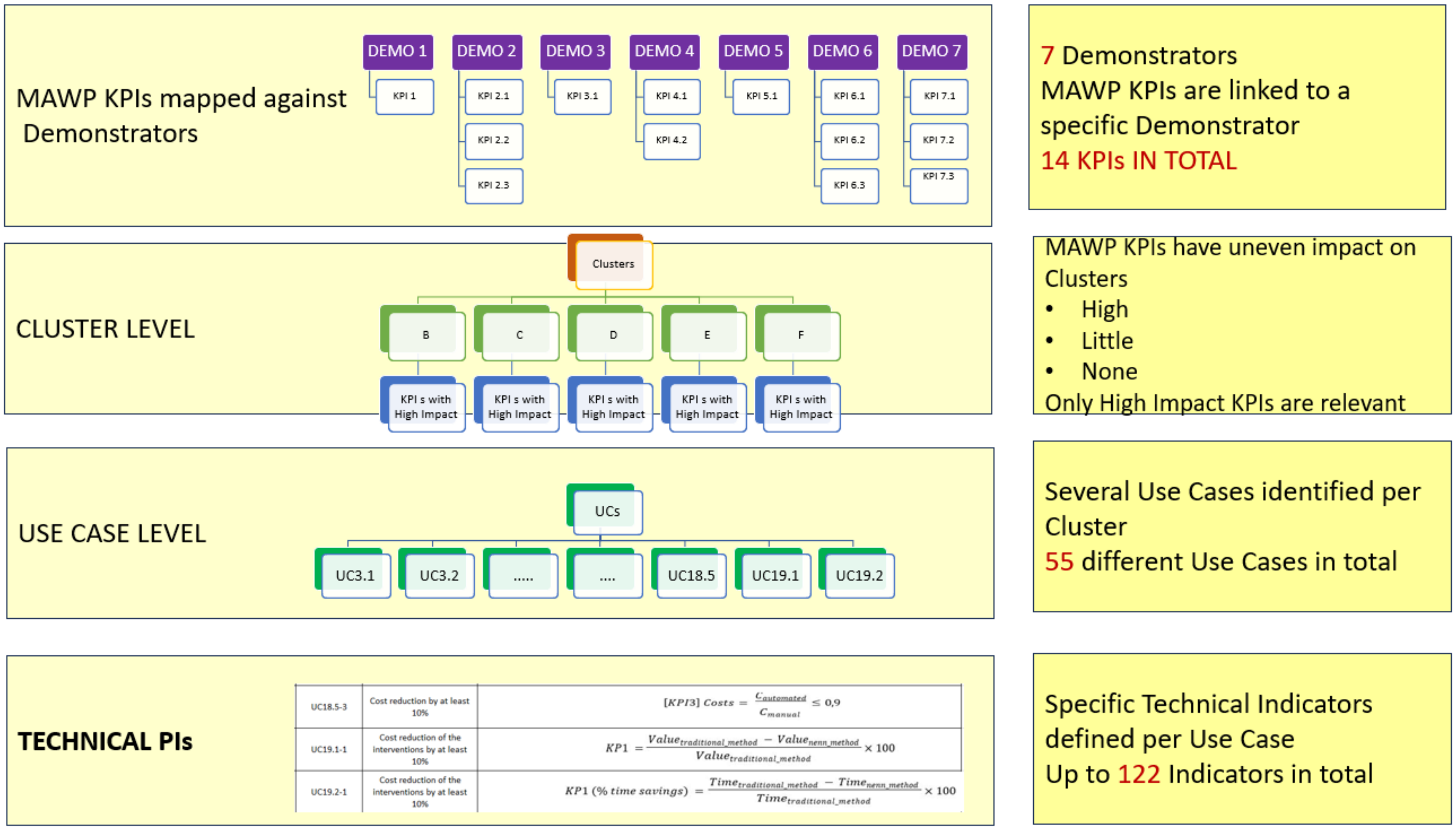

Figure 4. KPIs and PI´s relationship

5. Credible qualitative pathway to expected impact

FP3-IAM4RAIL will contribute in 5 out of 7 Impact Areas set out in the Master Plan, this chapter reports the credible qualitative pathway to each expected impact.

Customer Requirements

Technology is a key element in railway transport, and its use has become increasingly common to improve customer experience. FP3-IAM4RAIL developments will contribute to improve the overall performance of the railway system contributing to reduce the unavailability.

The project results will contribute to increase in operational reliability by fewer service disruptions and decrease incidents through continuous and precise condition monitoring of key components predicting failures in advance and scheduling preventive maintenance actions.

This will be reached with the reduction of unavailability for improved maintenance approach addressing wayside and on-board rolling stock monitoring as well as mounted over or embedded on infrastructure assets, including on-board diagnostics from vehicles.
The application of condition monitoring to railway sector provides a possibility to get information on the health condition of different train components under real operating conditions. Such information can facilitate the implementation of CBM (Condition-Based Monitoring) for railway vehicles. Compared to Preventive Maintenance (PM), it is believed that CBM will bring not only higher reliability but also more cost-efficient maintenance to the rail sector.

With diagnostic information of the assets, it is possible to improve railway management in terms of punctuality and regularity, reducing service interruptions, line unavailability and related management costs, improving the use of assets themselves.

Customer benefit from the project's focus on improved asset management, as it leads to more reliable and efficient rail services. By minimizing in-service failures, disruptions, and maintenance-related delays, passengers can enjoy a smoother and more predictable travel experience. Reduced downtimes and optimized maintenance practices result in fewer service interruptions and improved punctuality.

Improved Capacity

Capacity optimisation is achieved through optimisation of maintenance procedures with predictive capabilities and reduction of assets downtime, included in the developments focus on actions for Wayside Monitoring and TMS Link as well as for the rolling stock and infrastructure asset management.

The project will develop and deploy innovative monitoring and inspection systems; the data collected on asset health will be used to perform data analysis and to develop predictive algorithms to support decision and planning of interventions. FP3-IAM4RAIL developments will contribute to optimize maintenance schedules, reduce downtime, and improve the reliability of station equipment.

The development will cover all assets type and the project will contribute to develop different decision support tools based on unsupervised, supervised, and reinforcement learning approaches to aid maintenance decision-making.

Reduced costs

Economic viability and reduction of costs are at the core of FP3-IAM4RAIL activities and already controlled by PIs for relevant use cases, ensuring long term competitiveness of IAMS and generating innovation-based growth, employment creation with leverage for R&I investments.

One of the primary goals of FP3-IAM4RAIL is to enhance maintenance planning by leveraging predictive failure methods, leading to a more comprehensive and precise maintenance schedule. This approach aims to reduce maintenance costs significantly (target at least 10% in specific use cases) while simultaneously improving train service reliability. By implementing accurate preventive planning based on predictive insights, the project seeks to minimise service interruptions and maximize equipment uptime, ultimately reducing expensive unplanned downtime.

Concerning Life Cycle Costs activities have already begun for the development of 3 guidelines for the design of low-maintenance and maintenance free-systems to reduce cost through efficient and effective maintenance, coming from Cluster C, Cluster D and Cluster F. IA-based solutions and digital solutions for railway maintenance through different use cases and reduction on the need of human intervention are included in these actions, monitored in progress referred to the current baseline.

Moreover, one of the objectives of FP3-IAM4RAIL is to implement railway Digital Twins in diverse use cases to optimize processes, maintenance planning, and logistics related to the design, maintenance, upgrade, and renewal of railway assets. This technology will contribute to reduce costs of maintenance of railway stations with cost effective asset management supported by digital (diagnosis) technologies and data analytics, reducing the need for human intervention. One example is the virtual certification tasks that can be conducted in laboratory.

Sustainable and resilient transport

FP3-IAM4RAIL solutions will not only bolster the resilience of the railway system through streamlined asset management and smarter monitoring practices but also contribute significantly to the sustainability of the railway sector. By minimising reliance on physical components and adopting more precise asset management techniques, the project will not only improve rail network availability but also reduce environmental impact and resource consumption. This shift towards sustainability will not only benefit railway staff with improved working conditions but also contribute to the long-term viability of the railway industry.

Through the integration of digital twins, AI, and data analytics into rail asset management, the project aligns with the EU's efforts to promote digital transformation, fostering sustainability and efficiency across various industries. Prioritizing asset management optimisation and resource utilization, the project aims to enhance infrastructure efficiency and bolster overall transport system performance. By prolonging overall asset lifespan, residual life expectancy and maximizing resources utilization, FP3-IAM4RAIL actively contributes to the development of a more efficient and sustainable transportation system in Europe.

Environmental impact is mostly addressed at Cluster F, specifically at WP16 for sustainable and cost-efficient eco-design for railway assets finishing already the report of ongoing and planned demonstrators, including background, description of solution, approach and selected research methods.

Also in Cluster F, environmentally friendly asset production processes are being established, marking a significant departure from traditional manufacturing techniques. By leveraging new design principles, fabrication & on-site repair techniques, and materials, the project aims to reduce the environmental impact of asset production while ensuring high-quality and durable results. The activities included defining use cases, user needs, specifications, and requirements, as well as initiating technical activities across different work packages. Main guidelines, common tools, and methodologies for ecosystem development were defined to establish orientations for subsequent innovations.

Improved EU rail supply industry competitiveness

FP3-IAM4RAIL aims to reinforce the industry's global technological leadership by blending innovation and technical standards (including interoperable technical specifications) thereby shaping cutting-edge and harmonised maintenance decision-making frameworks.

FP3-IAM4RAIL integrated solutions have the potential to revolutionise the railway sector by optimising asset lifecycle management and enhancing reliability, availability, maintainability and capacity. By achieving TRL 6/7 for its solutions, the project aims to pave the way for widespread adoption and commercialisation.

The only quantitative calculation will be performed for Impact areas #3 and 6.

#	Impact areas	Key Performance Indicator	Objective	Linked FAs	Target at the end of HE
3	Reduced Costs	Maintenance costs, including thanks to the use of digital twins, €	Direct link to lower costs	FP3, FP4	-10%[4]
		Design and manufacturing costs, €	Leading to reduced investment cost	FP3	-20%
6	Reinforced role for rail	Maintenance costs, including thanks to the use of digital twins, €	The combination of the indicators from Impact Areas 1 and 3 contribute to more effective and cost-efficient rail transport, thereby improving attractiveness of rail compared with other transport modes	FP3, FP4	-10%[4]
		Design and manufacturing costs, €		FP3	-20%

Table 3. FP3-IAM4RAIL quantitative contribution to Impact Areas

This will be demonstrated with the calculations of the following MAWP KPIs:

- KPI 2.1 (II in GA) - Reduction of maintenance cost (Up to 10% in specific uses cases)
- KPI 4.2 (VII in GA) - Infrastructure Operation: Reduction of service failures (25% reduction)
- KPI 6.3 (XI in GA) - Design and Manufacturing: Cost reduction (20%)
- KPI 7.3 (XIV in GA) - Cost reductions of the interventions (by at least 10%)

Additional details on these KPIs (including formulas and baselines) are reported in Chapter 6.

6. MAWP KPIs and their Impact on Use Cases.

The Key Performance Indicators established in EU-RAIL JU MAWP have been fine-tuned as part of D1.5 activities. The project has further detailed formula parameters and added some considerations.

The project has identified which Use Cases in particular have a high / direct impact in the Programme KPIs, so those with little / indirect impact will not be included in the table below. The assessment on the degree of impact has been accomplished by Cluster leaders taking into consideration their expert judgement.

As explained before, FP3-IAM4RAIL structure focuses on outputs of their demonstrators in the rather instead of those coming from Work Streams or Work Packages. In this way, the KPI refer to those demonstrators.

DEMOSTRATOR NAME	1. Asset Management & TMS
PI 1.1	Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS (Reducing time to transfer asset condition status to TMS by 50 %, in specific use cases)
FORMULA	KPI 1.1= $(\frac{T_{baseline} - T_{target}}{T_{baseline}}) \times 100$
GENERAL THRESHOLD	Up to 50%
BASELINE	The Use Cases involved will test specific scenarios, i.e. events involving the monitored assets and the responses of the TMS operator or the time to make the information available to the interface. The baseline response time will be evaluated experimentally or from the standard operating procedures.
BASELINE COMMENTS	Where: • $T_{baseline}$ is evaluated time to transfer assets condition status to TMS before the improvement provided by FP3-IAM4RAIL project, in the specific scenario of application. • T_{target} is the computed time to transfer assets condition status to TMS after the improvement provided by FP3-IAM4RAIL project, in the specific scenario of application.
Level of KPI Impact on Clusters	• Cluster B: High/direct Impact • Cluster C: Little/indirect Impact
UCs with High Impact on this KPI	• UC 3.1 - Wayside and Infrastructure IAMS for TMS optimisation • UC 3.2 - Wayside monitoring in conventional and high-speed lines for TMS optimisation

Table 4. KPIs for Asset Management & TMS. KPI 1.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.1 Qualitative and prompt integration of information, including reducing time to transfer asset condition stats to TMS *(Reducing time to transfer asset condition status to TMS by 50 %, in specific use cases)*
	Enabler 1, 2, 4
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	HIGH / DIRECT IMPACT
UC3.2 Wayside monitoring in conventional and high-speed lines	HIGH / DIRECT IMPACT
UC 6.1 Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link	LITTLE / INDIRECT IMPACT
UC 6.3 Set up of adaptative wireless telecom network between train elements - SNCF	LITTLE / INDIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 5. KPI 1.1. Impact level on relevant Use Cases

DEMOSTRATOR NAME	2. Asset Management & Rolling Stock
PI 2.1	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)
FORMULA	$\text{KPI 2.1} = \left(\frac{Maintenance\ Cost_{baseline} - Maintenance\ Cost_{I4R}}{Maintenance\ Cost_{baseline}}\right) \times 100$
GENERAL THRESHOLD	Up to 10%
BASELINE	The use cases will estimate reductions in maintenance cost across different subsystems, such as pantographs and bogie equipment. The baseline will be based on the respective maintainers and operator's data on historical maintenance, measured field data, experimentally extracted data as well as estimated maintenance cost for each of the subsystems and its components. The baseline values are in most cases confidential, and the method of calculation, assumptions and means of improvement will be provided including the estimation of reduction as a %.
BASELINE COMMENTS	Where: • $Maintenance\ Cost_{baseline}$ [€] represents the total maintenance cost before implementing any cost-saving measures. • $Maintenance\ Cost_{I4R}$ [€] represents the total maintenance cost after implementing the cost-saving measures. Note that for competitive purposes, cost savings might only be reported as a % savings, including an explanation of methodology and assumptions, without detailing absolute maintenance costs.
Level of KPI Impact on Clusters	• Clusters C and F: High/direct impact
UCs with High Impact on this KPI	• UC 5.1 - Bogie Monitoring System (on-board) • UC 5.2 - Health Monitoring & Analytics of HVAC & Brake systems (ES) • UC 5.3 - Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL) • UC 5.4 - Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes (ES) • UC 5.5 - Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL) • UC 6.3 - Set up of adaptative wireless telecom network between train elements

DEMOSTRATOR NAME	2. Asset Management & Rolling Stock
PI 2.1	Rolling Stock Operation: Reduction of maintenance cost (Up to 10% in specific use case)
	• UC 6.6 - On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany • UC 6.8 - Smart maintenance scheduling tool • UC 7.1 - Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID) • UC 7.2 - Pantograph Monitoring System (wayside – video and 2D-3D images) • UC 7.3 - General physical anomaly detection Monitoring System (wayside – video and 2D-3D images) • UC 7.5 - CBM algorithms use case • UC 18.4 - Train underbody inspection of difficult to reach or see areas

Table 6. KPIs for Asset Management & Rolling Stock. KPI 2.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers Use Cases	3.2.1 Rolling Stock Operation: Reduction of maintenance cost *(Up to 10% in specific use case)*
	Enabler 1, 2, 4
UC 5.1 Bogie Monitoring System (on-board) Alstom	HIGH / DIRECT IMPACT
UC 5.2 Health Monitoring & Analytics of HVAC & Brake systems (ES, Talgo fleet)	HIGH / DIRECT IMPACT
UC 5.3 Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)	HIGH / DIRECT IMPACT
UC 5.4 Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes (ES, CAF Fleet)	HIGH / DIRECT IMPACT
UC 5.5 Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)	HIGH / DIRECT IMPACT
UC 6.1 Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link	LITTLE / INDIRECT IMPACT
UC 6.2 Traction component health monitoring & predictive	LITTLE / INDIRECT IMPACT
UC 6.3 Set up of adaptative wireless telecom network between train elements - SNCF	HIGH / DIRECT IMPACT
UC 6.4 Adhesion estimation for management - PRORAIL	LITTLE / INDIRECT IMPACT
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany - SIEMENS	HIGH / DIRECT IMPACT
UC 6.8 Smart maintenance scheduling tool - CAF	HIGH / DIRECT IMPACT
UC7.1 Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)	HIGH / DIRECT IMPACT
UC7.2 Pantograph Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.3 General physical anomaly detection Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.4 Data path diagram use case	LITTLE / INDIRECT IMPACT
UC7.5 CBM algorithms use case	HIGH / DIRECT IMPACT
UC 17.2. AM repair machine for wheels	LITTLE / INDIRECT IMPACT
UC 18.3 - Disinfection of trains and small stations	LITTLE / INDIRECT IMPACT
UC 18.4 - Train underbody inspection of difficult to reach or see areas	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 7. KPI 2.1. Impact level on relevant Use Cases

DEMOSTRATOR NAME	2. Asset Management & Rolling Stock
PI 2.2	Rolling Stock Operation: Reduction of service failures (25% reduction)
FORMULA	$\text{KPI 2.2} = \left(\frac{ServiceFailure_{baseline} - ServiceFailure_{I4R}}{Service\ Failure_{baseline}}\right) \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	The use cases will estimate reductions in service failures across different subsystems, such as pantographs and bogie equipment. The baseline will be based on the respective maintainers and operator's data on historical, measured and estimated in service failures for each of the subsystems and its components. In addition, analysis of potential failure modes and the current monitoring strategy can be used as a means of estimating service failures where data is not sufficient. The baseline values are in most cases confidential, and the method of calculation, assumptions and means of improvement will be provided including the estimation of reduction as a %. As a service failure, a failure that halts the functions of the specific monitored subsystem or component is considered.
BASELINE COMMENTS	Where: • $ServiceFailure_{baseline}$ *[Number of failure per M train – km]:* The total number of service failures in the previous measurement period. • $ServiceFailure_{I4R}$ *[Number of failure per M train – km]*: The number of service failures in the current measurement period after implementing changes or improvements.
Level of KPI Impact on Clusters	• Cluster C: High/direct impact • Cluster F: Little/indirect impact
UCs with High Impact on this KPI	• UC 5.1 - Bogie Monitoring System (on-board) • UC 5.2 - Health Monitoring & Analytics of HVAC & Brake systems (ES) • UC 5.3 - Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL) • UC 5.4 - Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes (ES) • UC 5.5 - Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL) • UC 6.1 - Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link • UC 6.2 - Traction component health monitoring & predictive • UC 6.5 - Wayside Signalling Equipment Monitoring System • UC 7.1 - Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID) • UC 7.2 - Pantograph Monitoring System (wayside – video and 2D-3D images) • UC 7.3 - General physical anomaly detection Monitoring System (wayside – video and 2D-3D images) • UC7.5 - CBM algorithms use case

Table 8. KPIs for Asset Management & Rolling Stock. KPI 2.2

IAM4RAIL Technical KPIs/ Impacts/ Enablers Use Cases	3.2.2 Rolling Stock Operation: Reduction of service failures *(25% reduction)*
	Enabler 1, 2, 4
UC 5.1 Bogie Monitoring System (on-board) Alstom	HIGH / DIRECT IMPACT
UC 5.2 Health Monitoring & Analytics of HVAC & Brake systems (ES, Talgo fleet)	HIGH / DIRECT IMPACT
UC 5.3 Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)	HIGH / DIRECT IMPACT
UC 5.4 Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes (ES, CAF Fleet)	HIGH / DIRECT IMPACT
UC 5.5 Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)	HIGH / DIRECT IMPACT
UC 6.1 Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link	HIGH / DIRECT IMPACT
UC 6.2 Traction component health monitoring & predictive	HIGH / DIRECT IMPACT
UC 6.3 Set up of adaptative wireless telecom network between train elements - SNCF	LITTLE / INDIRECT IMPACT
UC 6.4 Adhesion estimation for management - PRORAIL	LITTLE / INDIRECT IMPACT
UC 6.5 Wayside Signalling Equipment Monitoring System - TALGO	HIGH / DIRECT IMPACT
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany - SIEMENS	LITTLE / INDIRECT IMPACT
UC 6.8 Smart maintenance scheduling tool - CAF	LITTLE / INDIRECT IMPACT
UC7.1 Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)	HIGH / DIRECT IMPACT
UC7.2 Pantograph Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.3 General physical anomaly detection Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.4 Data path diagram use case	LITTLE / INDIRECT IMPACT
UC7.5 CBM algorithms use case	HIGH / DIRECT IMPACT
UC 18.4 - Train underbody inspection of difficult to reach or see areas	LITTLE / INDIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 9. KPI 2.2. Impact level on relevant Use Cases

DEMOSTRATOR NAME	2. Asset Management & Rolling Stock
PI 2.3	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)
FORMULA	$KPI\ 2.3 = \left(\frac{TrainDownTime_{baseline} - TrainDownTime_{I4R}}{TrainDownTime_{baseline}}\right) \times 100$
GENERAL THRESHOLD	Up to 10%
BASELINE	The use cases will estimate reductions in time down on the availability of train operation by monitoring subsystems and its components. The baseline will be based on the current maintenance procedures, maintainers and operator's data on historical maintenance, measured field data, experimentally extracted data as well as the estimated time in the detection of failures for each of the subsystems and its components. The baseline values are in most cases confidential, and the method of calculation, assumptions and means of improvement will be provided including the estimation of reduction as a %.
BASELINE COMMENTS	Where: • $TrainDownTime_{baseline}$ *[Downtime of system per operating period]:* Total train downtime per period caused by an (unpredicted) component failure causing downtime or operation not at 100% of its capacity • $TrainDownTime_{I4R}$ *[Downtime of system per operating period]:* Total train downtime per period caused by an (unpredicted) component failure causing downtime or operation not at 100% of its capacity, after implementation of improvements within FP3-IAM4RAIL.

DEMOSTRATOR NAME	2. Asset Management & Rolling Stock
PI 2.3	Increasing rolling stock availability respective reducing workshop downtime (Targeting 10% in specific use case)
Level of KPI Impact on Clusters	• Cluster C high/direct impact • Cluster F little/indirect impact
UCs with High Impact on this KPI	• UC 6.1 - Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link • UC 6.2 - Traction component health monitoring & predictive • UC 6.6 - On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany • UC 6.8 - Smart maintenance scheduling tool • UC 7.1 - Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID) • UC 7.2 - Pantograph Monitoring System (wayside – video and 2D-3D images) • UC 7.3 - General physical anomaly detection Monitoring System (wayside – video and 2D-3D images) • UC 7.5 - CBM algorithms use case

Table 10. KPIs for Asset Management & Rolling Stock. KPI 2.3

IAM4RAIL Technical KPIs/ Impacts/ Enablers / **Use Cases**	3.2.3 Increasing rolling stock availability respective reducing workshop downtime *(Targeting 10% in specific use case)*
	Enabler 1, 2, 4
UC 5.1 Bogie Monitoring System (on-board) Alstom	LITTLE / INDIRECT IMPACT
UC 6.1 Development of next generation Traction Control Unit Hardware and Gate Drive Communication Link	HIGH / DIRECT IMPACT
UC 6.2 Traction component health monitoring & predictive	HIGH / DIRECT IMPACT
UC 6.3 Set up of adaptative wireless telecom network between train elements - SNCF	LITTLE / INDIRECT IMPACT
UC 6.5 Wayside Signalling Equipment Monitoring System - TALGO	LITTLE / INDIRECT IMPACT
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany - SIEMENS	HIGH / DIRECT IMPACT
UC 6.8 Smart maintenance scheduling tool - CAF	HIGH / DIRECT IMPACT
UC7.1 Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)	HIGH / DIRECT IMPACT
UC7.2 Pantograph Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.3 General physical anomaly detection Monitoring System (wayside – video and 2D-3D images)	HIGH / DIRECT IMPACT
UC7.4 Data path diagram use case	LITTLE / INDIRECT IMPACT
UC7.5 CBM algorithms use case	HIGH / DIRECT IMPACT
UC 18.4 - Train underbody inspection of difficult to reach or see areas	LITTLE / INDIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 11. KPI 2.3. Impact level on relevant Use Cases

DEMOSTRATOR NAME	3. Long Term Asset Management
PI 3.1	Tools which provide at least 3 possible strategies of long term management (with an accuracy (as defined by ISO) improvement of 10%)
FORMULA	$\text{KPI } 3.1 = \left(\frac{Accuracy_{with\ Tool/Method} - Accuracy_{traditional}}{Accuracy_{traditional}}\right) \times 100$
GENERAL THRESHOLD	Up to 10%
BASELINE	Still under definition. It is under evaluation to use as baseline 2022 practices in order to measure the improvements using new tools and methods. With reference to 2022 practices is under identification relevant tools for comparison.
BASELINE COMMENTS	Where: • $Accuracy_{with\ Tool/Method}$: The accuracy level achieved by implementing a specific tool or method. • $Accuracy_{traditional}$: The accuracy level of selected asset management practices prior start of the project.
Level of KPI Impact on Clusters	• Clusters B and C: little/indirect impact • Cluster D: high/direct impact
UCs with High Impact on this KPI	UC 8.1 - Long term asset management and LCC UC 8.2 - Holistic long term asset management UC 16.6 - Diagn'eau

Table 12. Long Term Asset Management. KPI 3.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.3 Tools which provide at least 3 possible strategies of long term management *(with an accuracy (as defined by ISO) improvement of 10%)*
	Enabler 4
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	LITTLE / INDIRECT IMPACT
UC3.2 Wayside monitoring in conventional and high-speed lines	LITTLE / INDIRECT IMPACT
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany -	LITTLE / INDIRECT IMPACT
UC 6.8 Smart maintenance scheduling tool - CAF	LITTLE / INDIRECT IMPACT
UC8.1 Long term asset management and LCC	HIGH / DIRECT IMPACT
UC8.2 Holistic long term asset management	HIGH / DIRECT IMPACT
UC 16.6 - Diagn'eau	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 13. KPI 3.1 Impact level on relevant Use Cases

DEMOSTRATOR NAME	4. Asset Management & Infrastructure
PI 4.1	Infrastructure Operation: Reduction of maintenance costs (Targeting 10% in specific use cases)
FORMULA	$\text{KPI } 4.1 = \left(\frac{Cost_{baseline\ method} - Estimated\ Cost_{IR4\ method}}{Cost_{baseline\ method}} \right) \times 100$
GENERAL THRESHOLD	Up to 10%
BASELINE	For UC 12.1, 12.2, 12.3 and 12.4. It is necessary to compile information of the costs of implementing the inspection and maintenance plan for all assets, including bridges, tunnels, turnouts, and earthworks, currently present in the railway infrastructure. In addition, for UC10.1 and UC10.2. Inspection and maintenance cost for S&C per year both High speed lines and conventional lines traffic related.
BASELINE COMMENTS	Where: • The fraction's numerator describes the difference between the current maintenance process cost for a specific use case and the one associated with the new method. • The fraction's denominator defines the cost of the current maintenance process for that specific use case. • Due to the nature of the costs of the baseline (outsourced, confidentiality, complexity due to multiple tasks conducted per intervention, etc.), in some innovations the baseline costs will not be disclosed but a methodology will be explained (with the respective assumptions) to obtain the % of cost reduction.
Level of KPI Impact on Clusters	• Clusters B, D, E and F: high/direct impact
UCs with High Impact on this KPI	• UC 3.1 - Wayside and Infrastructure IAMS for TMS optimisation • UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 12.1 - Multiscale monitoring of civil assets • UC 12.2 - Bridges and earthworks assets management aided by geotechnics • UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel • UC 12.4 - Data Analysis for condition monitoring • UC 15.4 - Point Machine Digital Twin simulation • UC 15.5 - Automatic track visual inspection by drones • UC 16.5 - Platipus • UC 18.5 - Automated crossing repair

Table 14. Asset Management & Infrastructure. KPI 4.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers Use Cases	3.4.1 Infrastructure Operation: Reduction of maintenance costs *(Targeting 10% in specific use case)*
	Enabler 1, 2, 4, 5
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	HIGH / DIRECT IMPACT
UC3.2 Wayside monitoring in conventional and high-speed lines	LITTLE / INDIRECT IMPACT
UC8.1 Long term asset management and LCC	LITTLE / INDIRECT IMPACT
UC8.2 Holistic long term asset management	LITTLE / INDIRECT IMPACT
UC 9.1 - Sensing railway superstructure system components	LITTLE / INDIRECT IMPACT
UC 9.2 - Railway infrastructure monitoring using optic fiber	LITTLE / INDIRECT IMPACT
UC 9.3 - Track Geometry and S&C condition monitoring	LITTLE / INDIRECT IMPACT
UC 9.4 - Infrastructure monitoring solutions	LITTLE / INDIRECT IMPACT
UC 11.1 - Linking (new) monitoring technologies to asset management issues	HIGH / DIRECT IMPACT
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	HIGH / DIRECT IMPACT
UC 12.1 - Multiscale monitoring of civil assets	HIGH / DIRECT IMPACT
UC 12.2 - Bridges and earthworks assets management aided by geotechnics	HIGH / DIRECT IMPACT
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	HIGH / DIRECT IMPACT
UC 12.4 - Data Analysis for condition monitoring	HIGH / DIRECT IMPACT
UC 15.1 - Decision support systems for railway station asset management	LITTLE / INDIRECT IMPACT
UC 15.2 - Blockchain for certification	LITTLE / INDIRECT IMPACT
UC 15.4 - Point Machine Digital Twin simulation	HIGH / DIRECT IMPACT
UC 15.5 - Automatic track visual inspection by drones	HIGH / DIRECT IMPACT
UC 15.6 - BIM model as support to communicate and populate the Station's Asset Management System	LITTLE / INDIRECT IMPACT
UC 16.1 - Green tracks and turnouts	LITTLE / INDIRECT IMPACT
UC 16.2 – Innovative Sleeper System	LITTLE / INDIRECT IMPACT
UC 16.3 – Maintenance Reducing Squat Resistant Rail	LITTLE / INDIRECT IMPACT
UC 16.5 - Platipus	HIGH / DIRECT IMPACT
UC 16.7 - Geogrids	LITTLE / INDIRECT IMPACT
UC 17.1. In-situ AM repair machine for rails, switches and crossings	LITTLE / INDIRECT IMPACT
UC 17.3. In situ repair of track metallic assets	LITTLE / INDIRECT IMPACT
UC 17.4. Stationary solution for AM repaired turnout crossings using WAAM technology	LITTLE / INDIRECT IMPACT
UC 18.1 - Light & Flexible on track inspection	LITTLE / INDIRECT IMPACT
UC 18.2 Automated installation of ERTMS balises and axle counters	LITTLE / INDIRECT IMPACT
UC 18.5 - Automated crossing repair	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 15. KPI 4.1 Impact level on relevant Use Cases

DEMOSTRATOR NAME	4. Asset Management & Infrastructure
PI 4.2	Infrastructure Operation: Reduction of service failures (25% reduction)
FORMULA	$\text{KPI 4.2} = \left(\frac{N^\circ\ of\ Failures_{IR4}}{N^\circ\ of\ Failures_{baseline}}\right) \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	For UC 10.1 and 10.2 for which it is necessary to compile information of the costs of service failures (TSRs (Temporary Speed Restrictions), delays, accidents ....) generated by unforeseen anomalies in the railway assets currently present on the infrastructure.
BASELINE COMMENTS	Where: • The fraction's numerator describes the computed number of failures for a specific use case after the monitoring/repairing solution is implemented. • The fraction's denominator defines the current estimated number of failures for a specific use case. • Note that the number of failures of the baseline is to be estimated based on the specific use case. This number will include the best estimation possible for the total number of failures. This correction is needed, for instance, when an I4R technology detects more failures than the state-of-the-art technology. • Note that actual failures are not common in various of the Use Cases. For specific cases, we account for warnings or maintenance triggers (signals reaching or above the maintenance threshold). Note that those warnings, when no actions are conducted to mitigate them, can turn into actual failures in a certain time horizon. • Due to the nature of the concept of failures, in some innovations the number of failures will not be disclosed but a methodology will be explained (with the respective assumptions) to obtain the % of failure reduction.
Level of KPI Impact on Clusters	• Cluster B and D: high/direct impact • Cluster C, E and F: little/indirect impact
UCs with High Impact on this KPI	• UC 3.1 - Wayside and Infrastructure IAMS for TMS optimisation • UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 12.1 - Multiscale monitoring of civil assets • UC 12.2 - Bridges and earthworks assets management aided by geotechnics • UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel • UC 12.4 - Data Analysis for condition monitoring • UC 15.4 - Point Machine Digital Twin simulation

Table 16. Asset Management & Infrastructure. KPI 4.2

IAM4RAIL Technical KPIs/ Impacts/ Enablers Use Cases	3.4.2 Infrastructure Operation: Reduction of service failures *(25% reduction)*
	Enabler 1, 2, 4, 5
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	
UC3.2 Wayside monitoring in conventional and high-speed lines	
UC7.1 Bogie Monitoring System (wayside – acoustic, 2D images, video, laser and RFID)	
UC7.2 Pantograph Monitoring System (wayside – video and 2D-3D images)	
UC7.3 General physical anomaly detection Monitoring System (wayside – video and 2D-3D images)	
UC7.5 CBM algorithms use case	
UC 9.1 - Sensing railway superstructure system components	
UC 9.2 - Railway infrastructure monitoring using optic fiber	
UC 9.3 - Track Geometry and S&C condition monitoring	
UC 9.4 - Infrastructure monitoring solutions	
UC 11.1 - Linking (new) monitoring technologies to asset management issues	
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	
UC 12.1 - Multiscale monitoring of civil assets	
UC 12.2 - Bridges and earthworks assets management aided by geotechnics	
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	
UC 12.4 - Data Analysis for condition monitoring	
UC 15.1 - Decision support systems for railway station asset management	
UC 15.2 - Blockchain for certification	
UC 15.3 - Track Condition data fusion in Point Clouds	
UC 15.4 - Point Machine Digital Twin simulation	
UC 15.5 - Automatic track visual inspection by drones	
UC 15.6 - BIM model as support to communicate and populate the Station's Asset Management System	
UC 16.1 - Green tracks and turnouts	
UC 16.2 – Innovative Sleeper System	
UC 16.3 – Maintenance Reducing Squat Resistant Rail	
UC 17.1. In-situ AM repair machine for rails, switches and crossings	
UC 17.3. In situ repair of track metallic assets	
UC 17.4. Stationary solution for AM repaired turnout crossings using WAAM technology	
UC 18.1 - Light & Flexible on track inspection	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 17. KPI 4.2 Impact level on relevant Use Cases

DEMOSTRATOR NAME	5. Asset Management & Digital Twins
PI 5.1	Number of assets managed and monitored by Digital Twin (Increase by 25 %)
FORMULA	$\text{KPI } 5.1 = \left(\frac{P_{ADem} - P_{AavDT}}{P_{AavDT}}\right) \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	For UC 6.7, 15.1,15.2, 15.3 and 15.4 by compiling information on the number of digitised railway assets, how they are being managed, where they are being stored, how they are being visualised and how they are being managed and the impact they have on the predictive maintenance of the assets.
BASELINE COMMENTS	• P_{ADem} - is the percentage of assets whose data of interest are managed through the Digital Twin technology, identified, and counted as for the purposes of the demonstrators. This value will be computed over relevant demonstrators weighting appropriate scales and importance. • P_{AavDT} – is the average percentage of assets whose data of interest are managed through the Digital Twin technology of some kind among operators in Europe. Asset averages will be weighted by asset class, its prevalence and operator scale of operation. This is a baseline value. • Baseline is not given by a data at the moment as this requires a qualitative study that will give the necessary percentage estimates. Study will be realized by creating appropriate questionaries for European Infrastructure Managers and aggregating data in the proper way. • In case the baseline percentage is 0, the KPI is maxed out at 100%.
Level of KPI Impact on Clusters	• Cluster C, D and E: high/ direct impact • Cluster B and F: little/ indirect impact
UCs with High Impact on this KPI	• UC 6.7 - Digital twin for energy - CAF • UC 9.4 - Prescriptive Maintenance for Railway Infrastructure • UC 12.2 - Bridges and earthworks assets management aided by geotechnics • UC 15.1 - Decision support systems for railway station asset management • UC 15.2 - Blockchain for certification • UC 15.3 - Track Condition data fusion in Point Clouds • UC 15.4 - Point Machine Digital Twin simulation • UC 15.5 - Automatic track visual inspection by drones • UC 15.6 - BIM model as support to communicate and populate the Station's Asset Management System

Table 18. Asset Management & Digital Twins. KPI 5.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers Use Cases	3.5 Number of assets managed and monitored by Digital Twin *(Increase by 25 %)*
	Enabler 5
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	
UC3.2 Wayside monitoring in conventional and high-speed lines	
UC 6.4 Adhesion estimation for management - PRORAIL	
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany - SIEMENS	
UC 6.7 Digital twin for energy - CAF	
UC 9.1 - Sensing railway superstructure system components	
UC 9.2 - Railway infrastructure monitoring using optic fiber	
UC 9.3 - Track Geometry and S&C condition monitoring	
UC 9.4 - Infrastructure monitoring solutions	
UC 11.1 - Linking (new) monitoring technologies to asset management issues	
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	
UC 12.1 - Multiscale monitoring of civil assets	
UC 12.2 - Bridges and earthworks assets management aided by geotechnics	
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	
UC 12.4 - Data Analysis for condition monitoring	
UC 15.1 - Decision support systems for railway station asset management	
UC 15.2 - Blockchain for certification	
UC 15.3 - Track Condition data fusion in Point Clouds	
UC 15.4 - Point Machine Digital Twin simulation	
UC 15.5 - Automatic track visual inspection by drones	
UC 15.6 - BIM model as support to communicate and populate the Station's Asset Management System	
UC 18.1 - Light & Flexible on track inspection	
UC 18.2 Automated installation of ERTMS balises and axle counters	
UC 18.5 - Automated crossing repair	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 19. KPI 5.1 Impact level on relevant Use Cases

DEMOSTRATOR NAME	6. Design & Manufacturing
PI 6.1	For repair: Extension of remaining life (25%)
FORMULA	$\text{KPI } 6.1 = \left(\frac{Lifetime_{I4R\ solution} - Lifetime_{Baseline\ solution}}{Lifetime_{Baseline\ solution}} \right) \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	For use cases UC 17.1, 17.2, 17.3 and 17.4., it is necessary to know the useful life according to specifications, as well as the possible failures that lead to shorten the number of effective hours of use and finally know the number of hours of effective life of the assets once they have been repaired.
BASELINE COMMENTS	Where: • $Lifetime_{I4R\ solution}$: lifetime of a railway component after the AM repairing solution is implemented. • $Lifetime_{Baseline\ solution}$: lifetime of a railway component after the traditional repairing build-up welding process.
Level of KPI Impact on Clusters	• Cluster D and F: high/direct impact • Cluster E: little/indirect impact

DEMOSTRATOR NAME	6. Design & Manufacturing
PI 6.1	For repair: Extension of remaining life (25%)
UCs with High Impact on this KPI	• UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 17.1 - In-situ AM repair machine for rails, switches and crossings • UC 17.2 - AM repair machine for wheels • UC 17.3 - In situ repair of track metallic assets • UC 17.4 - Stationary solution for AM repaired turnout crossings using WAAM technology

Table 20. Design & Manufacturing. KPI 6.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.6.1 For repair: Extension of remaining life *(25%)*
	Enabler 6, 7
UC 9.1 - Sensing railway superstructure system components	
UC 9.2 - Railway infrastructure monitoring using optic fiber	
UC 9.3 - Track Geometry and S&C condition monitoring	
UC 9.4 - Infrastructure monitoring solutions	
UC 11.1 - Linking (new) monitoring technologies to asset management issues	
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	
UC 12.1 - Multiscale monitoring of civil assets	
UC 12.2 - Bridges and earthworks assets management aided by geotechnics	
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	
UC 12.4 - Data Analysis for condition monitoring	
UC 15.4 - Point Machine Digital Twin simulation	
UC 16.1 - Green tracks and turnouts	
UC 16.2 – Innovative Sleeper System	
UC 16.3 – Maintenance Reducing Squat Resistant Rail	
UC 16.5 - Platipus	
UC 17.1. In-situ AM repair machine for rails, switches and crossings	
UC 17.2. AM repair machine for wheels	
UC 17.3. In situ repair of track metallic assets	
UC 17.4. Stationary solution for AM repaired turnout crossings using WAAM technology	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 21. KPI 6.1 Impact level on relevant Use Cases

DEMOSTRATOR NAME	6. Design & Manufacturing
PI 6.2	Time reduction (from design to manufacturing) (20%)
FORMULA	$\text{KPI 6.2} = \left(\frac{Time_{I4R\ method} - Time_{Baseline\ method}}{Time_{Baseline\ method}}\right) \times 100$
GENERAL THRESHOLD	Up to 20%
BASELINE	For UC 17.5 It is necessary to know the number and types of parts to be repaired or replaced, as well as the time taken for design and manufacture using currently employed techniques.
BASELINE COMMENTS	Where: • $Time_{I4R\ method}$: effective time to deliver the demonstrator including the design modifications time. • $Time_{Baseline\ method}$: time given by the supplier to deliver the demonstration part produced by conventional process based on new or existing offers. A positive KPI indicates that the estimated time for the new method is less than the time required for traditional methods.
Level of KPI Impact on Clusters	• Cluster F: high/direct impact • Cluster D: and E little/indirect impact
UCs with High Impact on this KPI	• UC 16.1 - Green tracks and turnouts • UC 16.2 - Innovative Sleeper System • UC 16.3 - Maintenance Reducing Squat Resistant Rail • UC 17.5 - Additive Manufacturing of large interior flame-retardant polymer spare part • UC 17.6 - Digital warehouse

Table 22. Design & Manufacturing. KPI 6.2

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.6.2 Time reduction (from design to manufacturing) *(20%)*
	Enabler 6, 7
UC 9.1 - Sensing railway superstructure system components	
UC 16.1 - Green tracks and turnouts	
UC 16.2 – Innovative Sleeper System	
UC 16.3 – Maintenance Reducing Squat Resistant Rail	
UC 16.4 - Bridge dynamics	
UC 16.7 - Geogrids	
UC 17.5. Additive Manufacturing of large interior flame retardant polymer spare part	
UC 17.6. Digital warehouse	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 23. KPI 6.2 Impact level on relevant Use Cases

DEMOSTRATOR NAME	6. Design & Manufacturing
PI 6.3	Design and Manufacturing: Cost reduction (20%)
FORMULA	KPI 6.3 = $\frac{Cost_{baseline\_method} - Cost_{I4R\_method}}{Cost_{baseline\_method}} \times 100$
GENERAL THRESHOLD	Up to 20%
BASELINE	For UC 17.6 It is necessary to know currently, the number and type of parts, as well as the cost of designing and implementing spare parts.
BASELINE COMMENTS	Where: • $Cost_{I4R\_method}$: cost of a railway component manufactured using additive manufacturing (AM) techniques. • $Cost_{baseline\_method}$: cost of a railway component manufactured using traditional methods.
Level of KPI Impact on Clusters	• Cluster F: high/direct impact
UCs with High Impact on this KPI	• UC 16.4 - Bridge dynamics • UC 16.7 - Geogrids • UC 17.5 - Additive Manufacturing of large interior flame-retardant polymer spare part • UC 17.6 - Digital warehouse

Table 24. Design & Manufacturing. KPI 6.3

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.6.3 Design and Manufacturing: Cost reduction *(20%)*
	Enabler 6, 7
UC 16.1 - Green tracks and turnouts	LITTLE / INDIRECT IMPACT
UC 16.2 – Innovative Sleeper System	LITTLE / INDIRECT IMPACT
UC 16.3 – Maintenance Reducing Squat Resistant Rail	LITTLE / INDIRECT IMPACT
UC 16.4 - Bridge dynamics	HIGH / DIRECT IMPACT
UC 16.7 - Geogrids	HIGH / DIRECT IMPACT
UC 17.5. Additive Manufacturing of large interior flame retardant polymer spare part	HIGH / DIRECT IMPACT
UC 17.6. Digital warehouse	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 25. KPI 6.3 Impact level on relevant Use Cases

DEMOSTRATOR NAME	7. Robotics & Interventions
PI 7.1	Increased accuracy of inspections with respect to conventional interventions (25%)
FORMULA	$\text{KPI } 7.1 = \left(\frac{N^{o}\ of\ AnomaliesDetected_{new} - N^{o}\ of\ AnomaliesDetected_{conventional}}{N^{o}\ of\ AnomaliesDetected_{in\ ground\ truth\ data}}\right) \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	N/A

DEMOSTRATOR NAME	7. Robotics & Interventions
PI 7.1	Increased accuracy of inspections with respect to conventional interventions (25%)
BASELINE COMMENTS	N/A
Level of KPI Impact on Clusters	• Cluster C, D and F high/ direct impact • Cluster E little/ indirect impact
UCs with High Impact on this KPI	• UC 6.4 - Adhesion estimation for management - PRORAIL • UC 9.1 - Sensing railway superstructure system components • UC 9.2 - Railway infrastructure monitoring using fibre optics • UC 9.4 - Prescriptive Maintenance for Railway Infrastructure • UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel UC 18.1 - Light & Flexible on track inspection • UC 18.1 - Light & Flexible on track inspection • UC 18.2 - Automated installation of ERTMS balises and axle counters • UC 18.4 - Train underbody inspection of difficult to reach or see areas

Table 26. Robotics & Interventions. KPI 7.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers / **Use Cases**	3.7.1 Increased accuracy of inspections with respect to conventional interventions *(25%)*
	Enabler 2, 7
UC 6.4 Adhesion estimation for management - PRORAIL	
UC 6.6 On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany - SIEMENS	
UC 6.8 Smart maintenance scheduling tool - CAF	
UC 9.1 - Sensing railway superstructure system components	
UC 9.2 - Railway infrastructure monitoring using optic fiber	
UC 9.3 - Track Geometry and S&C condition monitoring	
UC 9.4 - Infrastructure monitoring solutions	
UC 11.1 - Linking (new) monitoring technologies to asset management issues	
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	
UC 12.4 - Data Analysis for condition monitoring	
UC 15.5 - Automatic track visual inspection by drones	
UC 18.1 - Light & Flexible on track inspection	
UC 18.2 Automated installation of ERTMS balises and axle counters	
UC 18.4 - Train underbody inspection of difficult to reach or see areas	
UC 19.2 Augmented Reality tools to help and guide railway workers in maintenance operations	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 27. KPI 7.1 Impact level on relevant Use Cases

DEMOSTRATOR NAME	7. Robotics & Interventions
PI 7.2	Reproducibility of inspections with respect to conventional interventions (25%)
FORMULA	KPI 7.2 = $\frac{Reproducibility_{New\_method} - Reproducibility_{Conventional\_method}}{Reproducibility_{Conventional\_method}} \times 100$
GENERAL THRESHOLD	Up to 25%
BASELINE	Where: • $Reproducibility_{New\_method}$ is the reproducibility of the new inspection method. • $Reproducibility_{Conventional\_method}$ is the reproducibility of the conventional inspection method. This formula expresses the percentage increase in reproducibility of the new method over the conventional method. If KPI 7.2 is 25%, it means the reproducibility of the new method is 25% higher than that of the conventional method. The reproducibility of a method (conventional or new), is measured as follows: Metric: Measurement Consistency Ratio (MCR) assesses the reproducibility of a measurement method by gauging the consistency of results when the same tool is employed repeatedly under identical conditions. Reproducibility, in this context, is synonymous with repeatability and reliability. The MCR reflects the reliability of the measurement method. MCR = $\frac{N^{o}\ of\ Consistent\ Measurements}{Total\ N^{o}\ of\ Measurements} \times 100$ Where: • $N^{o}\ of\ Consistent\ Measurements$is the count of measurements that produced the same result when the tool was used repeatedly under the same circumstances. • $Total\ N^{o}\ of\ Measurements$ is the overall count of measurements taken during the assessment period. This formula yields a percentage, representing the Measurement Consistency Ratio, indicating the proportion of measurements that exhibit consistency or reproducibility. This is the input for the above mentioned KPI.
BASELINE COMMENTS	N/A
Level of KPI Impact on Clusters	• Cluster D and F: high/direct impact • Cluster C and E: little/indirect impact
UCs with High Impact on this KPI	• UC 9.3 - Track Geometry and S&C condition monitoring • UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 18.1 - Light & Flexible on track inspection • UC 18.4 - Train underbody inspection of difficult to reach or see areas

Table 28. Robotics & Interventions. KPI 7.2

IAM4RAIL Technical KPIs/ Impacts/ Enablers — Use Cases	3.7.2 Reproducibility of inspections with respect to conventional interventions *(25%)*
	Enabler 2, 7
UC 6.8 Smart maintenance scheduling tool - CAF	
UC 9.1 - Sensing railway superstructure system components	
UC 9.2 - Railway infrastructure monitoring using optic fiber	
UC 9.3 - Track Geometry and S&C condition monitoring	
UC 9.4 - Infrastructure monitoring solutions	
UC 11.1 - Linking (new) monitoring technologies to asset management issues	
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	
UC 12.1 - Multiscale monitoring of civil assets	
UC 12.4 - Data Analysis for condition monitoring	
UC 15.5 - Automatic track visual inspection by drones	
UC 18.1 - Light & Flexible on track inspection	
UC 18.4 - Train underbody inspection of difficult to reach or see areas	

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 29. KPI 7.2 Impact level on relevant Use Cases

DEMOSTRATOR NAME	7. Robotics & Interventions
PI 7.3	Cost reductions of the interventions (by at least 10%)
FORMULA	KPI 7.3 = $\frac{C_{I4R}}{C_{baseline}} \leq 0{,}9$
GENERAL THRESHOLD	Under 90%
BASELINE	Where: C_{I4R}: Total costs of I4R process $C_{baseline}$: Total costs of baseline
BASELINE COMMENTS	N/A
Level of KPI Impact on Clusters	• Cluster D and F: high/direct impact • Cluster B, C and E: little/indirect impact
UCs with High Impact on this KPI	• UC 9.1 - Sensing railway superstructure system components • UC 9.3 - Track Geometry and S&C condition monitoring • UC 9.4 - Prescriptive Maintenance for Railway Infrastructure • UC 11.1 - Linking (new) monitoring technologies to asset management issues • UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis • UC 12.1 - Multiscale monitoring of civil assets • UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel • UC 18.1 - Light & Flexible on track inspection • UC 18.3 - Disinfection of trains and small stations • UC 18.4 - Train underbody inspection of difficult to reach or see areas • UC 19.2 - Augmented Reality tools to help and guide railway workers in maintenance operations

Table 30. Robotics & Interventions. KPI 7.3

Use Cases \ IAM4RAIL Technical KPIs/ Impacts/ Enablers	3.7.3 Cost reductions of the interventions *(by at least 10%)*
	Enabler 2, 7
UC3.1 Wayside and Infrastructure IAMS for TMS optimisation	LITTLE / INDIRECT IMPACT
UC3.2 Wayside monitoring in conventional and high-speed lines	LITTLE / INDIRECT IMPACT
UC 6.8 Smart maintenance scheduling tool - CAF	LITTLE / INDIRECT IMPACT
UC 9.1 - Sensing railway superstructure system components	HIGH / DIRECT IMPACT
UC 9.2 - Railway infrastructure monitoring using optic fiber	LITTLE / INDIRECT IMPACT
UC 9.3 - Track Geometry and S&C condition monitoring	HIGH / DIRECT IMPACT
UC 9.4 - Infrastructure monitoring solutions	HIGH / DIRECT IMPACT
UC 11.1 - Linking (new) monitoring technologies to asset management issues	HIGH / DIRECT IMPACT
UC 11.2 - Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis	HIGH / DIRECT IMPACT
UC 12.1 - Multiscale monitoring of civil assets	HIGH / DIRECT IMPACT
UC 12.2 - Bridges and earthworks assets management aided by geotechnics	LITTLE / INDIRECT IMPACT
UC 12.3 - Characterization of sub-ballast, sub-soil and tunnel	HIGH / DIRECT IMPACT
UC 12.4 - Data Analysis for condition monitoring	LITTLE / INDIRECT IMPACT
UC 15.5 - Automatic track visual inspection by drones	LITTLE / INDIRECT IMPACT
UC 18.1 - Light & Flexible on track inspection	HIGH / DIRECT IMPACT
UC 18.3 - Disinfection of trains and small stations	HIGH / DIRECT IMPACT
UC 18.4 - Train underbody inspection of difficult to reach or see areas	HIGH / DIRECT IMPACT
UC 18.5 - Automated crossing repair	LITTLE / INDIRECT IMPACT
UC 19.1 Upper-body exoskeleton for worker's support in railway industry	LITTLE / INDIRECT IMPACT
UC 19.2 Augmented Reality tools to help and guide railway workers in maintenance operations	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 31. KPI 7.3 Impact level on relevant Use Cases

DEMOSTRATOR NAME	8. Transversal. SOCIETAL IMPACT
PI 8.1	EXOSKELETONS ARE USED TO PERFORM STERENUOUS TASKS, SUCH AS SAFELY MOVING HEAVY LOADS
FORMULA	$\text{KPI } 8.1 = \frac{Value_{new-method} - Value_{traditional-method}}{Value_{traditional-method}} \times 100$
GENERAL THRESHOLD	Subjective assessment by questionnaires. Likert-type scales for quantitative measures.
BASELINE	User Satisfaction without exoskeleton.

DEMOSTRATOR NAME	8. Transversal. SOCIETAL IMPACT
PI 8.1	EXOSKELETONS ARE USED TO PERFORM STERENUOUS TASKS, SUCH AS SAFELY MOVING HEAVY LOADS
BASELINE COMMENTS	We will carry out real maintenance task with and without the exoskeleton. A minimum of 2 workers in 4 different working scenarios will participate in the validation phase (8 workers in total). A subjective evaluation by the workers that will test and validate the exoskeleton will be carried out in order to evaluate their satisfaction when using the exoskeleton mainly regarding physical effort reduction, safety, ergonomics and usability. Questionnaires will be developed, and Liker-type scales will be used for quantitative measures. Only one scenario will be considered for initial demonstration, while all scenarios will be deployed by the end of the project. KPIs will also be measured in these two phases. If KPI is positive: Indicates that the new method is more satisfactory for the operator than the traditional method. Therefore, we can deduce that workers are willing to use the exoskeletons and thus we will get the targeted societal impacts, and indirectly the associated cost reductions. If KPi is negative: Indicates that the traditional method is more satisfactory for the operator than the new method, and the impacts are not obtained.
Level of KPI Impact on Clusters	• Cluster E: little/indirect impact • Cluster F high/direct impact
UCs with High Impact on this KPI	• UC 18.2 - Automated installation of ERTMS balises and axle counters • UC 19.1 - Upper body exoskeleton for workers support in railway industry

Table 32. Transversal KPI. Societal Impact. KPI 8.1

IAM4RAIL Technical KPIs/ Impacts/ Enablers / Use Cases	**Societal impact**: Support to rail workers - Exoskeletons are used to perform sterenuous tasks, such as safely moving heavy loads...
	Enabler 2, 3, 7
UC 15.5 - Automatic track visual inspection by drones	LITTLE / INDIRECT IMPACT
UC 18.1 - Light & Flexible on track inspection	LITTLE / INDIRECT IMPACT
UC 18.2 Automated installation of ERTMS balises and axle counters	HIGH / DIRECT IMPACT
UC 18.3 - Disinfection of trains and small stations	LITTLE / INDIRECT IMPACT
UC 18.4 - Train underbody inspection of difficult to reach or see areas	LITTLE / INDIRECT IMPACT
UC 18.5 - Automated crossing repair	LITTLE / INDIRECT IMPACT
UC 19.1 Upper-body exoskeleton for worker's support in railway industry	HIGH / DIRECT IMPACT

HIGH / DIRECT IMPACT	LITTLE / INDIRECT IMPACT

Table 33. KPI 8.1 Impact level on relevant Use Cases

7. Technical Performance Indicators per USE CASE

As mentioned before D2.6 “Use Cases Definition” and later on, D2.7 has identified the performance indicators applicable to each Use Case. It is a living document and has already undergone various reviews. At the time of drafting this document the third review is available, and new changes cannot be ruled out. Below a list of those indicators applicable at this stage.

UC3.1	Wayside and Infrastructure IAMS for TMS optimisation
LEADING PARTNER	HITACHI RAIL-STS
PI reference	PI title
3.1-1	Reduction of speed restrictions on trains due to deteriorating asset condition
3.1-2	Reduction of on infrastructural data management time, useful for TMS connection
3.1-3	Providing alarms to TMS, via ixl, in case of obstacles on the level crossing area
3.1-4	Corrective maintenance prediction
3.1-5	Reduction of service disruption
3.1-6	Data processing time

Table 34. UC3.1 PIs

UC3.2	Wayside monitoring in conventional and high-speed lines for TMS optimisation
LEADING PARTNER	HITACHI RAIL-STS
PI reference	PI title
3.2.-1	Reduction of delayed trains due to asset condition
3.2.-2	Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown
3.2.-3	Reduction of normalisation time in case of the monitoring of the point machine slack in the “locks” to closure

Table 35. UC3.2 PIs

UC5.1	Bogie Monitoring System (on-board)
LEADING PARTNER	ALSTOM TRANSPORT SA (ATSA)
PI reference	PI title
5.1-1	Number of components / assets that could be monitored with each sensor
5.1-2	Average accuracy of detecting faulty components
5.1-3	Reduction of in-service failures

Table 36. UC5.1 Pis

UC5.2	Health Monitoring & Analytics of HVAC & Brakes systems (ES)
LEADING PARTNER	KNORR-BREMSE SYSTEME FUR SCHIENENFAHRZEUGE GMBH (KB)
PI reference	PI title
5.2-1	Reduction of maintenance costs
5.2-2	Reduction of in-service failures

Table 37. UC5.2 PIs

UC5.3	Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)
LEADING PARTNER	KNORR-BREMSE SYSTEME FUR SCHIENENFAHRZEUGE GMBH (KB)
PI reference	PI title
5.3-1	Reduction of maintenance costs
5.3-2	Reduction of in-service failures

Table 38. UC5.3 PIs

UC5.4	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes, Traction & Auxiliary systems (ES)
LEADING PARTNER	FAIVELEY TRANSPORT SAS (FT)
PI reference	PI title
5.4-1	Reduction of maintenance costs
5.4-2	reduction of in-service failures

Table 39. UC5.4 PIs

UC5.5	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)
LEADING PARTNER	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)
PI reference	PI title
5.5-1	Reduction of maintenance costs
5.5-2	Reduction of in-service failures

Table 40. UC5.5 PIs

UC6.1	Development of next generation Traction control unit hardware and gate drive communication link
LEADING PARTNER	ALSTOM TRANSPORT SA (ATSA)
PI reference	PI title
6.1-1	Increase the number of monitored subsystems

Table 41. UC6.1 Pis

UC6.2	Traction Component Health Monitoring & predictive Maintenance
LEADING PARTNER	ALSTOM TRANSPORT SA (ATSA)
PI reference	PI title
6.2-1	Maintenance costs reduction
6.2-2	Increase service availability
6.2-3	Increase the number of monitored subsystems

Table 42. UC6.2 PIs

UC6.3	Set up of adaptive wireless telecom network between train elements
LEADING PARTNER	SOCIETE NATIONALE SNCF (SNCF)
PI reference	PI title
6.3-1	Coupling Time & distance
6.3-2	Usual IP Metrics

Table 43. UC6.3 PIs

UC6.4	Adhesion estimation for management
LEADING PARTNER	PRORAIL BV (PRORAIL)
PI reference	PI title
6.4-1	Accuracy of COF estimation

Table 44. UC6.4 PIs

UC6.5	Wayside signalling equipment monitoring system
LEADING PARTNER	PATENTES TALGO SL (TALGO)
PI reference	PI title
6.5-1	Compliance with cybersecurity standards
6.5-2	Reduce the impact of top threats

Table 45. UC6.5 PIs

UC 6.6	On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany
LEADING PARTNER	SMO Siemens Mobility
PI reference	PI title
6.6-1	Application of SMO bogie diagnostic solution
6.6-2	Integration of results to maintenance process

Table 46. UC6.6 PIs

UC6.7	Digital twin for energy
LEADING PARTNER	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)
PI reference	PI title
6.7-1	Accuracy of the energy consumption model
6.7-2	Expected improvement in energy reduction

Table 47. UC6.7 PIs

UC6.8	Smart maintenance scheduling tool
LEADING PARTNER	Construcciones y Auxiliar de Ferrocarriles, S.A. (CAF)
PI reference	PI title
6.8-1	Savings in maintenance cost
6.8-2	Increase in fleet availability

Table 48. UC6.8 PIs

UC7.1	Bogie Monitoring System (Wayside – acoustic, 2D-3D images, video, and laser and RFID)
LEADING PARTNER	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)
PI reference	PI title
7.1-1	Wheel defects
7.1-2	Wheel profile defects
7.1-3	Degree of network utilization – all trains
7.1-4	Accuracy

Table 49. UC7.1 PIs

UC7.2	**Pantograph Monitoring System (Wayside – video and 2D-3D images)**
LEADING PARTNER	PATENTES TALGO SL (TALGO)
PI reference	PI title
7.2-1	Pantograph defects
7.2-2	Accuracy

Table 50. UC7.2 PIs

UC7.3	General physical anomaly detection Monitoring System (Wayside – video and 2D-3D images)
LEADING PARTNER	PATENTES TALGO SL (TALGO)
PI reference	PI title
7.3-1	Effort spent in visual inspections
7.3-2	Anomalies detected with new technologies

Table 51. UC7.3 PIs

UC7.4	Data path diagram use case
LEADING PARTNER	DEUTSCHE BAHN AG (DB)
PI reference	PI title
7.4-1	Reduction of the timespan

Table 52. UC7.4 PIs

UC7.5	CBM algorithms for freight
LEADING PARTNER	ASOCIACION CENTRO TECNOLOGICO CEIT (CEIT)
PI reference	PI title
7.5-1	Detection of anomalies
7.5-2	Diagnosis of anomalies

Table 53. UC7.5 PIs

UC8.1	Long term asset management and LCC
LEADING PARTNER	NORWEGIAN RAILWAY DIRECTORATE (NRD)
PI reference	PI title
8.1-1	Accuracy of estimated response to traffic loads based on the bridge modelling
8.1-2	Overall cost of operation (OPEX and CAPEX)

Table 54. UC8.1 PIs

UC8.2	Holistic long term asset management
LEADING PARTNER	TRAFIKVERKET - TRV (TRV)
PI reference	PI title
8.2-1	Availability
8.2-2	Total maintenance cost (resources used)

Table 55. UC8.2 PIs

UC9.1	Sensing railway superstructure system components
LEADING PARTNER	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)
PI reference	PI title
9.1-1	Reduction of the maintenance cost
9.1-2	Reduction of in-service failures

Table 56. UC9.1 PIs

UC 9.2	Railway infrastructure monitoring using fibre optics
LEADING PARTNER	SOCIETE NATIONALE SNCF (SNCF)
PI reference	PI title
9.2-1	Detection of infrastructure anomalies and assets monitoring
9.2-2	Detection of vehicle anomalies

Table 57. UC9.2 Pis

UC 9.3	Track Geometry and S&C condition monitoring
LEADING PARTNER	MER MEC ENGINEERING S.R.L. (MME)
PI reference	PI title
9.3-1	Optimisation of track work prioritisation
9.3-2	Optimisation of turnout work prioritisation
9.3-3	Performance of inspection solutions

Table 58. UC9.3 PIs

UC 9.4	Prescriptive maintenance for railway infrastructure
LEADING PARTNER	DEUTSCHE BAHN AG (DB)
PI reference	PI title
9.4-1	Completed campaigns
9.4-2	Detection of anomalies
9.4-3	Correlation between anomalies and track geometry deterioration
9.4-4	Validation of track geometry prediction

Table 59. UC9.4 PIs

UC 11.1	Linking (new) monitoring technologies to asset management issues
LEADING PARTNER	STRUKTON POWER BV (SR Power)
PI reference	PI title
11.1-1	Detection of anomalies
11.1-2	Diagnosis of anomalies

Table 60. UC11.1 PIs

UC 11.2	Fusion of (onboard and wayside) monitoring data for an enhanced fault detection and diagnosis
LEADING PARTNER	STRUKTON POWER BV (SR Power)
PI reference	PI title
11.2-1	Detection of anomalies
11.2-2	Diagnosis of anomalies

Table 61. UC11.2 PIs

UC 12.1	Multiscale monitoring of civil assets
LEADING PARTNER	MER MEC ENGINEERING S.R.L. (MME)
PI reference	PI title
12.1-1	Bridge inspection -reduction of maintenance costs
12.1-2	Bridge inspection - reduction of traffic disruption caused by traditional bridge inspection in the railway infrastructure
12.1-3	Reduction of on track data collection time

Table 62. UC12.1 Pis

UC 12.2	Bridges and earthworks assets management aided by geotechnics
LEADING PARTNER	ADMINISTRADOR DE INFRAESTRUCTURAS FERROVIARIAS (ADIF)
PI reference	PI title
12.2-1	Failure mode predictability
12.2-2	Reduction of theoretical time per circulation by failures in the railway infrastructure
12.2-3	Cost reduction of instrumentation equipment for earthworks
12.2-4	Reduction of costs in the pot bearings replacement
12.2-5	Effectiveness of slope stabilization measures

Table 63. UC12.2 PIs

UC 12.3	Monitorization of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels
LEADING PARTNER	SOCIETE NATIONALE SNCF (SNCF)
PI reference	PI title
12.3-1	Reduction of maintenance times
12.3-2	Reduction of the maintenance cost

Table 64. UC12.3 PIs

UC 12.4	Data Analysis for condition monitoring
LEADING PARTNER	PRORAIL BV (PRORAIL)
PI reference	PI title
12.4-1	Track condition monitoring
12.4-2	Detectability of incipient known failures

Table 65. UC12.4 PIs

UC 15.1	Decision support systems for railway station asset management
LEADING PARTNER	POLSKIE KOLEJE PANSTWOWE SPOLKA AKCYJNA (PKP)
PI reference	PI title
15.1-1	Number of assets covered by predictive maintenance
15.1-2	Number of accessibility assets covered by predictive maintenance
15.1-3	Average time of cleanliness incident detection

Table 66. UC15.1 PIs

UC 15.2	Blockchain for certification management of railway infrastructure
LEADING PARTNER	FERROVIE DELLO STATO ITALIANE SPA (FS)
PI reference	PI title
15.2-1	System Response Time

Table 67. UC15.2 Pis

UC 15.3	Track Condition data fusion in Point Clouds
LEADING PARTNER	MERMEC
PI reference	PI title
15.3-1	The number of data anomalies found in asset digitalization

Table 68. UC15.3 PIs

UC 15.4	Digital Twin of Point Machine to enable Virtual Certification Framework
LEADING PARTNER	Hitachi Rail GTS Deutschland
PI reference	PI title
15.4-1	Number of tests enabled by Digital Twin

Table 69. UC15.4 PIs

UC 15.5	Demonstration of automatic track visual inspection by unmanned means (drones)
LEADING PARTNER	AZD PRAHA SRO (AZD)
PI reference	PI title
15.5-1	The number of assets managed and monitored by digital twins
15.5-2	Reduction of maintenance costs

Table 70. UC15.5 PIs

UC 15.6	BIM model as support to communicate and populate the Station's Asset Management System
LEADING PARTNER	HITACHI RAIL GTS France (GTSF)
PI reference	PI title
15.6-1	The number of assets managed and monitored by Digital Twins
15.6-2	Data quality treated in the digital twin
15.6-3	Time reduction to create a data base for asset management

Table 71. UC15.6 PIs

UC 16.1	Green turnout
LEADING PARTNER	VOESTALPINE (vaRS)
PI reference	PI title
16.1-1	Time reduction
16.1-2	Extension of remaining lifetime
16.1-3	Reduce maintenance cost

Table 72. UC16.1 PIs

UC 16.2	Innovative Sleeper System
LEADING PARTNER	VOESTALPINE (vaRS)
PI reference	PI title
16.2-1	Time reduction
16.2-2	Extension of remaining lifetime
16.2-3	Reduce maintenance cost

Table 73. UC16.2 PIs

UC 16.3	Maintenance Reducing Squat Resistant Rail
LEADING PARTNER	VOESTALPINE (vaRS)
PI reference	PI title
16.3-1	Time reduction
16.3-2	Extension of remaining lifetime
16.3-3	Reduce maintenance cost

Table 74. UC16.3 PIs

UC 16.4	Bridge dynamics
LEADING PARTNER	TRAFIKVERKET - TRV (TRV)
PI reference	PI title
16.4-1	Cost reduction

Table 75. UC16.4 PIs

UC 16.5	Platipus
LEADING PARTNER	SNCF
PI reference	PI title
16.5-1	Extension of remaining life
16.5-2	Reduction of maintenance cost

Table 76. UC16.5 PIs

UC 16.6	Diagn'eau
LEADING PARTNER	SNCF
PI reference	PI title
16.6-1	Infrastructure long-term Asset Management

Table 77. UC16.6 PIs

UC 16.7	Geogrids
LEADING PARTNER	SNCF
PI reference	PI title
16.7-1	Time reduction
16.7-2	Cost reduction at the track bed renewal scale
16.7-3	Cost reduction for maintenance

Table 78. UC16.7 Pis

UC 17.1	In-situ AM repair machine for rails, switches and crossings
LEADING PARTNER	ASOCIACION CENTRO TECNOLOGICO CEIT (CEIT)
PI reference	PI title
17.1-1	Extension of remaining life of the railway asset repair

Table 79. UC17.1 PIs

UC 17.2	AM repair machine for wheels
LEADING PARTNER	PATENTES TALGO SL (TALGO)
PI reference	PI title
17.2-2	Extension of remaining life of the repaired wheel

Table 80. UC17.2 PIs

UC 17.3	In situ repair of track metallic assets
LEADING PARTNER	FUNDACION TEKNIKER (TEKNIKER)
PI reference	PI title
17.3-1	Extension of remaining life of a railway asset repair

Table 81. UC17.3 PIs

UC 17.4	Stationary solution for AM repaired turnout crossings using WAAM technology
LEADING PARTNER	VOESTALPINE RAILWAY SYSTEMS GMBH (vaRS)
PI reference	PI title
17.4-1	Extension of remaining life

Table 82. UC17.4 PIs

UC 17.5	Additive Manufacturing of large & flame-retardant polymer spare part
LEADING PARTNER	SOCIETE NATIONALE SNCF (SNCF)
PI reference	PI title
17.5-1	Time reduction (from design to manufacturing since ordering)
17.5-2	Cost reduction in parts and assets

Table 83. UC17.5 PIs

UC 17.6	Digital warehouse
LEADING PARTNER	DEUTSCHE BAHN AG (DB)
PI reference	PI title
17.6-1	Time reduction (from design to manufacturing)
17.6-2	Cost reduction in parts and assets

Table 84. UC17.6 Pis

UC 18.1	Light & Flexible on-track inspection
LEADING PARTNER	NORWEGIAN RAILWAY DIRECTORATE (NRD)
PI reference	PI title
18.1-1	Cost per measured kilometre
18.1-2	Confusion

Table 85. UC18.1 PIs

UC 18.2	Automated installation of ERTMS balises and axle counters
LEADING PARTNER	STRUKTON RAIL NEDERLAND BV (SRNL)
PI reference	PI title
18.2-1	Use of robotised tools
18.2-2	Tender offer
18.2-3	Heavy repetitive work

Table 86. UC18.2 PIs

UC 18.3	Disinfection of trains and small stations
LEADING PARTNER	FERROVIE DELLO STATO ITALIANE SPA (FS)
PI reference	PI title
18.3-1	Disinfection Time (DT)
18.3-2	Disinfection Cost (DC)

Table 87. UC18.3 PIs

UC 18.4	Train underbody inspection
LEADING PARTNER	FERROVIE DELLO STATO ITALIANE SPA (FS)
PI reference	PI title
18.4-1	Maintenance Costs (MC)
18.4-2	Maintenance Time (MT)
18.4-3	Defects Index (DI)

Table 88. UC18.4 PIs

UC 18.5	Automated crossing repair
LEADING PARTNER	VOESTALPINE RAILWAY SYSTEMS GMBH (vaRS)
PI reference	PI title
18.5-1	Accuracy of inspections
18.5-2	Reproducibility of inspections
18.5-3	Cost reduction

Table 89. UC18.5 Pis

UC 19.1	Upper-body exoskeleton for worker’s support in railway industry
LEADING PARTNER	STRUKTON RAIL NEDERLAND BV (SRNL)
PI reference	PI title
19.1-1	Societal Impact

Table 90. UC19.1 PIs

UC 19.2	Augmented Reality tools to help and guide railway workers in maintenance operations
LEADING PARTNER	RETE FERROVIARIA ITALIANA (RFI)
PI reference	PI title
19.2-1	Cost reduction of the interventions

Table 91. UC19.2 PIs

8. Description of the plan to monitor and evaluate the high level KPIs and PIs during the course of the project

8.1. Overall FP3-IAM4RAIL Assessment Process

Table below provides a structured overview of the assessment process for monitoring and evaluating the FP3-IAM4RAIL project's performance. By detailing the types of assessments, methods, responsible parties, timing, and related documents, the table ensures that all aspects of the project's performance are systematically monitored and evaluated.

Type	How	Who	When	Documents
Impact areas	Qualitative estimation, except for Impact areas #3 and #6 that will be addressed by MAWP KPIs	Project Coordinator, Cluster Leaders and UC Leaders	At M48	D1.4 «Technical/Impact KPIs report»
Societal KPIs	Qualitative estimation	Project Coordinator, Cluster Leaders	At M48	D1.4 «Technical/Impact KPIs report»
MAWP KPIs	Quantitative estimation	Cluster Use Case leaders	At M48 final, Intermediate at least 1 per year	Use Cases related deliverables
PIs	Quantitative estimation	Use Case leaders	At M48	Use Cases related deliverables

Table 92. Assessment process for monitoring and evaluating the FP3-IAM4RAIL project's performance

Assessment process and data for MAWP KPIs and PIs are reported in the following chapter.

8.2. Introduction. Assessment Process and data of MAWP KPIs and PIs

This chapter addresses the following topics:

- Which Indicators need to be monitored and reported.
- Who is in charge of monitoring.
- When to measure.
- What validation methods and aids will be used.

- Who needs to be informed.
- What info needs to be recorded.
- How to cope with poor results, if any.

As a general rule, all KPIs and Technical PIs need to be measured and reported back to ERJU System Pillar. High level KPIs are mandatory since they derive directly from MAWP, and address highly important performance areas identified as key by ERJU. On the contrary, technical PIs offer flexibility and can be adjusted based on operational requirements, but also on technical specifications, safety parameters and economic aspects.

Use Cases' leaders oversee KPIs and PIs monitoring and reporting. They are tasked with collecting all relevant data obtained during the trials, specifically identifying the data required to derive the indicators. It is the responsibility of Use Case leaders to assess the statistical relevance of the data gathered and to request additional runs if the quality of data is inadequate, irrelevant, or inconclusive.

Use Case leaders are required to report to Cluster leaders and System Experts every 6 months. TMT meetings serve as the appropriate forum to present partial results and discuss any issues encountered during use cases trials.

Baseline data is crucial as it serves as the foundation for measuring the actual improvement delivered by FP3-IAM4RAIL new concepts. Therefore, Use Case leaders should carefully outline the baseline data used with any underlying assumptions.

As previously mentioned, TMT meetings are the appropriate forum to discuss the status of indicators. If the process is well-documented, Use Case leaders will encounter fewer challenges when presenting their cases during TMT meetings, facilitating team solutions.
If deemed necessary by the TMT, they will launch a mitigation strategy.

As far as minimum threshold values for KPIs are concerned, the contribution of each Use Case to get a final aggregate value MAWP KPIs, will be thoroughly discussed during TMT meetings and defined later in the project.

FP3-IAM4RAIL coordinator proposes the following "Templates" to support Use Case's Leaders to gather data during trials and ease the later discussion.

8.2.1. MAWP-KPI Template

DEMOSTRATOR NAME	1. Asset Management & TMS	
KPI 1.1	Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS (Reducing time to transfer asset condition status to TMS by 50 %, in specific use cases)	
FORMULA	KPI 1.1= $\left(\frac{T_{baseline} - T_{target}}{T_{baseline}}\right) \times 100$	
GENERAL THRESHOLD	Up to 50%	
BASELINE	The Use Cases involved will test specific scenarios, i.e. events involving the monitored assets and the responses of the TMS operator or the time to make the information available to the interface. The baseline response time will be evaluated experimentally or from the standard operating procedures.	
Date		
BASELINE COMMENTS	Where: • $T_{baseline}$ is evaluated time to transfer assets condition status to TMS before the improvement provided by FP3-IAM4RAIL project, in the specific scenario of application. • T_{target} is the computed time to transfer assets condition status to TMS after the improvement provided by FP3-IAM4RAIL project, in the specific scenario of application.	
UCs with High Impact on this KPI	• UC3.1: Wayside and Infrastructure IAMS for TMS optimisation • UC3.2: Wayside monitoring in conventional and high-speed lines for TMS optimisation	
UC3.1	UC3.1 leader.	HITACHI RAIL-STS
	Are you able to calculate it? Do you propose a different threshold? If not, reason behind Have you experienced problems with baseline values? Explain further	
UC3.2	UC3.2 leader.	HITACHI RAIL-STS
	Are you able to calculate it? Do you propose a different threshold? If not, reason behind Have you experienced problems with baseline values? Explain further	
SOCIETAL IMPACTS	• Rail Connectivity: High/ direct impact • Congestion Savings in Transport and EU Rail Sector Competitiveness: little/ indirect impact	
	Comments. Further explanation	

Table 93. Example of KPI assessment template

8.2.2. FP3-IAM4RAIL – PIs Template

UC3.1	Wayside and Infrastructure IAMS for TMS optimisation
LEADING PARTNER	HITACHI RAIL-STS
Use Case Assumptions	Explain those assumptions that may impact on Indicators Final values
Assessment Date	
PI 3.1 -1	**Reduction of speed restrictions on trains due to deteriorating asset condition.**
Formula	$$PI_{3.1-1}\,(\%\ \text{speed restrictions}) = \frac{TSRn}{TSRt}x\ 100\ \%$$
Further Details	Where: • $TSRn$ is the number of total speed restrictions in Line (the particular section examined) due to deteriorating asset condition with new maintenance strategy. • $TSRt$ is the number of speed restrictions in Line (the particular section examined) due to deteriorating asset condition with current maintenance strategy.
Threshold	
Baseline	
Achieved?	
If not reasons behind	
change in formula or threshold?	
PI 3.1 -2	**Reduction of infrastructural data management time, useful for TMS connection.**
Formula	$$PI_{3.1-2}\,(\%\ time\ savings)\ = \frac{Time_{traditional\_method} - Estimated\ time_{new\_method}}{Time_{traditional\_method}} \times 100$$
Further Details	Where: • $Time_{traditional\_method}$ 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.
Threshold	
Baseline	
Achieved?	
If not reasons behind	
change in formula or threshold?	
PI 3.1-3	**Providing alarms to TMS in case of obstacles on the level crossing area.**
Formula	The obstacle detector will be tested on a trial site, in a representative environment and in different scenarios, with different type of obstacles. For each situation, the overall system shall provide on a dedicated output, the alarm to be read from the IXL. The system will be tested simulating faults on the single technology too, checking the capability of the system to work with just one technology. This will demonstrate the higher availability of the combined solution
Further Details	The calculation of this KPI is trivial. In fact, when comparing the level crossing clarence assessment by

UC3.1	Wayside and Infrastructure IAMS for TMS optimisation
LEADING PARTNER	HITACHI RAIL-STS
	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).
Threshold	
Baseline	
Achieved?	
If not reasons behind	
change in formula or threshold?	
PI 3.1.4	**Corrective maintenance prediction. Reduction of service disruption.**
Formula	$$PI_{3.1-4} = \frac{Sensitivity + Specificity}{2}$$
Further Details	Where: $$Sensitivity = \frac{n° \; of \; correct \; CM \; prediction}{n° \; of \; correct \; CM \; prediction + n° \; of \; missed \; CM \; prediction}$$ $$Specificity = \frac{n° \; of \; correct \; healthy \; prediction}{n° \; of \; correct \; healthy \; prediction + n° \; of \; wrong \; CM \; prediction}$$
Threshold	
Baseline	
Achieved?	
If not reasons behind	
change in formula or threshold?	
PI 3.1- 5	**Data processing time.**
Formula	$$PI_{\,3.1-5}[\%] = \left(\sum_{t=1}^{W} \frac{(\# \, corrective\_before_t - \; \# \, corrective\_after_t)}{\# \, corrective\_before_t} \right) * \frac{100}{W}$$
Further Details	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.
Threshold	
Achieved?	
If not reasons behind	
change in formula or threshold?	

Table 94. Example of specific PIs assessment template

9. Conclusions

FP3-IAM4RAIL has specifically defined Performance indicators (PIs) as a credible pathway towards the Programme KPIs, to be reached by the end of 2026 representing the overall goals of the EU-Rail JU MAWP. This document will provide the baseline of all future work concerning KPIs within FP3-IAM4RAIL and also will be kept as a reference for Flagship Area 3 framework.

This information will be communicated to the Academics4Rail consortium inside the frame of the Europe's Rail Joint Undertaking in charge of a dedicated assessment of the KPIs monitoring for the projects in the entire programme to check if the outcome reaches an adequate level of impact regarding its objectives. Also, if the successful implementation of demonstrators and use cases will have a measurable impact on society and economics. The project plans to quantitatively assess these impacts whenever possible. Other impacts (e.g., environmental, technological, political) will be qualitatively assessed.

To measure the progress of the project through the KPIs and PIs, FP3-IAM4RAIL has defined a baseline using data available from 2022 whenever possible or relevant, considering other public reports and statistics of the rail domain (e.g., EUROSTAT PRIME). Some FP3-IAM4RAIL KPIs and PIs do not require a baseline but rather have absolute goals to be reached.

A methodology is defined to make the results comparable and repeatable. The project has selected different approaches for measuring the progress towards KPIs, including as PIs, KPIs in the Grant Agreement included as per the EU-Rail JU Multi Annual Work Programme (MAWP) for the Demonstrators and PIs for Use Cases, due to their different nature in terms of objectives.

- KPIs will be measured using demonstrations, simulations or expert judgement, based on the data availability and overall timeline of demonstrations stated in the EU-Rail JU Multi- Annual Work Programme (MAWP).
- PIs for demonstrators and use cases will be measured by comparing the current Technology Readiness Level to the target level stated in the Grant Agreement.

Still, the level of complexity of the developments and the numerous interdependencies within the rail system and the real world make it impossible to calculate the impacts precisely or map certain technical enablers directly to a specific impact. The results of the project can only be evaluated in a holistic approach and taken as estimation. The next steps will be defining the correct level of the baseline and also the weight of each use case contribution into the corresponding KPIs into which its impact will be included. This reference and the aggregation will be defined during the course of the project and reflected in the deliverable D1.4 Technical/Impact KPIs report.

The assessment for the KPI monitoring has been established within the project during its lifespan defining templates and precise roles in the process for the Use Case proprietors, Workpackage and Cluster Leaders, and also the System Experts.

FP3-IAM4RAIL consortium has come to the conclusion that the selected methods and approaches are the best way forward to fulfil the objectives of this Flagship Project.

10. References

[1] Europe's Rail Joint Undertaking Master Plan, 17.02.22
[2] Europe's Rail Joint Undertaking Multi-Annual Work Programme, version 2.0 01.03.22
[3] FP3-IAM4RAIL D2.6 Definition of Use Cases, including Innovation, Business Assessment, KPIs definition and roadmap (first Issue)

11. Annex 1 – Mapping of PIs

CLUSTER B Wayside monitoring and traffic management system link

UC	Title	PI	PI's title	Formula	Baseline	Target
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-1	Reduction of speed restrictions on trains due to deteriorating asset condition	$PI_{3.1-1}\ (\%\ \text{speed restrictions}) = \frac{TSRn}{TSRt} x\ 100$	Data before the installation of IAMS platform and compared with data after the installation I4R solution	10%
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-2	Reduction of on infrastructural data management time, useful for TMS connection	$PI_{3.1-2}(\%\ cost\ savings)\ = \frac{Cost\ _{traditional\_method} - Estimated\ Cost_{new\_method}}{Cost_{traditional\_method}}\ \text{x}\ 100$	Cost of personnel before the installation of IAMS platform and compared after the installation I4R solution	10%
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-3	Providing alarms to TMS, via ixl, in case of obstacles on the level crossing area	TRIVIAL	Not Available	Not Available
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-4	Corrective maintenance prediction	$PI_{3.1-4} = \frac{Sensitivity + Specificity}{2}$ $Sensitivity = \frac{Number\ of\ correct\ CM\ prediction}{Number\ of\ correct\ CM\ prediction + n°\ of\ missed\ CM\ prediction}$ $Specificity = \frac{Number\ of\ correct\ healthy\ prediction}{Number\ of\ correct\ healthy\ prediction + n°\ of\ wrong\ CM\ prediction}$	Not Available	Not Available

UC	Title	PI	PI's title	Formula	Baseline	Target
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-5	Reduction of service disruption	$PI_{\ 3.1-5}[\%] = \left(\sum_{t=1}^{W} \frac{(Number\ corrective\_before_t - Number\ corrective\_after_t)}{Number\ corrective\_before_t}\right) x \frac{100}{W}$	Corrective maintenance activities before the installation of IAMS platform	0%
3.1	Wayside and Infrastructure IAMS for TMS optimisation	3.1-6	Data processing time	$PI_{3.1-6} = time\ of\ single\ datapoint\ processing$	NA	<10 s
3.2	Wayside monitoring in conventional and high-speed lines	3.2.-1	Reduction of delayed trains due to asset condition	$PI_{3.2-1} = \left(\frac{n_c - n_n}{n_c}\right) x\ 100$	Number of trains delays of the period prior to the project (2022-2024) will be compared to the same parameter computed in the period 2025-2026	<10%
3.2	Wayside monitoring in conventional and high-speed lines	3.2.-2	Reduction of human intervention time for detection of level crossing barrier failure due to electric motor breakdown	$PI_{3.2-2} = \left(\frac{\overline{tcv} - \overline{tnw}}{\overline{tcv}}\right) x\ 100$	The time required to diagnose a broken electric motor using the conventional diagnostic method shall be compared to the automated solution.	<20%
3.2	Wayside monitoring in conventional and high-speed lines	3.2.-3	Reduction of normalisation time in case of the monitoring of the point machine slack in the "locks" to closure	x $\text{Average normalisation time per failure} = \frac{SUM(normalisation\ times)}{Total\ failures}$ $PI_{3.2-2} = \frac{Avg\ norm.\ time\ before\ demo - Avg\ norm.\ time\ after\ demo}{Avg\ norm.\ time\ before\ demo} x100$	the values in the years before the demonstrator is set up (2021-2023) and after (2024-2026)	30%

CLUSTER C Rolling Stock Asset Management: On-board and Wayside Technologies

UC	UC title	PI	PI title	Formula	Baseline	Target
5.1	Bogie monitoring system (on-board)	5.1-1	Number of components / assets that could be monitored with each sensor	$\mathrm{PI}_{5.1-1} = \mathrm{N}$	1	≥ 2
5.1	Bogie monitoring system (on-board)	5.1-2	Accuracy of detecting faulty components	$\mathrm{PI}_{5.1-2}\ \mathrm{Accuracy}_{\mathrm{Average}} = \frac{\sum_{i=1}^{n} \frac{(\mathrm{TP_i} + \mathrm{TN_i})}{(\mathrm{TP_i} + \mathrm{TN_i} + \mathrm{FP_i} + \mathrm{FN_i})} * 100}{n}$	50%	70%
5.1	Bogie monitoring system (on-board)	5.1-3	Reduction of in-service failures	$PI_{5.1-3} = \frac{Number\ of\ failures_{without\ sensors} - Number\ of\ failures_{with\ sensors}}{Number\ of\ failures_{without\ sensors}} \times 100$	Baseline will be the same of MAWP KPI 3.2.2	25%
5.2	Health Monitoring & Analytics of HVAC & Brake systems (ES)	5.2-1	Reduction of maintenance costs	$PI_{5.2-1A}\ (\%\ material\ savings) = \frac{Material\ cost\ _{current\_method} - Estimated\ Material\ Cost_{new\_method}}{Material\ Cost_{current\_method}} \times 100$ $PI_{5.2-1B}\ (\%\ time\ savings) = \frac{Time_{current\_method} - Estimated\ time_{new\_method}}{Time_{current\_method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.1	10%
5.2	Health Monitoring & Analytics of HVAC & Brake systems (ES)	5.2-2	reduction of in-service failures	$PI_{5.2-2A}\ (in\ \%) = \frac{Estimated\ in{-}service\ failures\ _{current\ method} - Estimated\ in{-}service\ failures_{new\ method}}{Estimated\ in{-}service\ failures\ _{current\ method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.2	25%

UC	UC title	PI	PI title	Formula	Baseline	Target
				$PI_{5.2-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current\_method} - Estimated\ Reliability_{new\_method}}{Time_{current\_method}} \times 100$ $PI_{5.2-2C}\ (\%\ Monitored\ failure\ modes) = \frac{Monitored\ Failure\ Modes_{current\_method} - Monitored\ Failure\ Modes_{new\_method}}{Monitored\ Failure\ Modes_{current\_method}} \times 100$		
5.3	Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)	5.3-1	Reduction of maintenance costs	$PI_{5.3-1A}\ (\%\ material\ savings) = \frac{Material\ cost\ _{current\_method} - Estimated\ Material\ Cost_{new\_method}}{Material\ Cost_{current\_method}} \times 100$ $PI_{5.3-1B}\ (\%\ time\ savings) = \frac{Time_{current\_method} - Estimated\ time_{new\_method}}{Time_{current\_method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.1	10%
5.3	Health Monitoring & Analytics of HVAC, Sanitary Systems & Brakes (NL, NS/KB)	5.3-2	reduction of in-service failures	$PI_{5.3-2A}\ (in\ \%) = \frac{Estimated\ in\!-\!service\ failures\ _{current\ method} - Estimated\ in\!-\!service\ failures_{new\ method}}{Estimated\ in\!-\!service\ failures\ _{current\ method}} \times 100$ $PI_{5.3-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current\_method} - Estimated\ Reliability_{new\_method}}{Time_{current\_method}} \times 100$ $PI_{5.3-2C}\ (\%\ Monitored\ failure\ modes) = \frac{Monitored\ Failure\ Modes_{current\_method} - Monitored\ Failure\ Modes_{new\_method}}{Monitored\ Failure\ Modes_{current\_method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.2	25%

UC	UC title	PI	PI title	Formula	Baseline	Target
5.4	Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes, (ES, CAF fleet)	5.4-1	Reduction of maintenance costs	$PI_{5.4-1}\ (in\ \%) = \frac{Maintenance\ cost_{current\ maintenacne\ strategy} - Estimated\ Maintenance\ cost_{new\ maintenance\ strategy}}{Maintenance\ cost_{current\ maintenacne\ strategy}} \times 100$	Baseline will be the same of MAWP KPI 3.2.1	10%
5.4	Health Monitoring & Analytics and ML algorithms development of HVAC, Doors, & Brakes, (ES, CAF fleet)	5.4-2	reduction of in-service failures	$PI_{5.4-2}\ (in\ \%) = \frac{Estimated\ in{-}service\ failures_{current\ maintenance\ strategy} - Estimated\ in{-}service\ failures_{new\ maintenance\ strategy}}{Estimated\ in{-}service\ failures_{current\ maintenance\ strategy}} \times 100$	Baseline will be the same of MAWP KPI 3.2.2	25%
5.5	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)	5.5-1	Reduction of maintenance costs	$PI_{5.5-1A}\ (\%\ material\ savings) = \frac{Material\ cost_{current\_method} - Estimated\ Material\ Cost_{new\_method}}{Material\ Cost_{current\_method}} \times 100$ $PI_{5.5-1B}\ (\%\ time\ savings) = \frac{Time_{current\_method} - Estimated\ time_{new\_method}}{Time_{current\_method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.1	10%

UC	UC title	PI	PI title	Formula	Baseline	Target
5.5	Health Monitoring & Analytics and ML algorithms development of Traction, HVAC, Doors, Batteries, Brakes & auxiliary system (NL, NS/CAF)	5.5-2	reduction of in-service failures	$PI_{5.5-2A}\ (in\ \%) = \frac{Estimated\ in\text{-}service\ failures_{\ current\ method} - Estimated\ in\text{-}service\ failures_{new\ method}}{Estimated\ in\text{-}service\ failures_{\ current\ method}} \times 100$ $PI_{5.5-2B}\ (\%\ Reliability\ Improvement) = \frac{Reliability_{current\_method} - Estimated\ Reliability_{new\_method}}{Time_{current\_method}} \times 100$ $PI_{5.5-2C}\ (\%\ Monitored\ failure\ modes) = \frac{Monitored\ Failure\ Modes_{current\_method} - Monitored\ Failure\ Modes_{new\_method}}{Monitored\ Failure\ Modes_{current\_method}} \times 100$	Baseline will be the same of MAWP KPI 3.2.2	25%
6.1	Development of next generation Traction control unit hardware and gate drive communication link	6.1-1	Increase the number of monitored subsystems	$PI_{6.1-1} = Nw - No$		Not Available
6.2	Traction Component Health Monitoring & predictive Maintenance	6.2-1	Maintenance costs reduction	$PI_{6.2-1}\eta = (N_p - N_d)c_p$		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
6.2	Traction Component Health Monitoring & predictive Maintenance	6.2-2	Increase service availability	$PI_{6.2-2}\eta = \frac{\tau_f}{\tau_0}$		Not Available
6.2	Traction Component Health Monitoring & predictive Maintenance	6.2-3	Increase the number of monitored subsystems	$PI_{6.2-3} = Nw - No$		Not Available
6.3	Set up of adaptive wireless telecom network between train elements	6.3-1	Coupling Time & distance	Not applicable. No formula available		Not Available
6.3	Set up of adaptive wireless telecom network between train elements	6.3-2	Usual IP Metrics	Measured in laboratory tests or in real environments		Not Available
6.4	Adhesion estimation for management	6.4-1	Accuracy of COF estimation	$PI_{6.4\text{-}1} = abs(DAI - COF) / (COF)$		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
6.5	Wayside Signalling Equipment Monitoring System - TALGO	6.5-1	Compliance with cybersecurity standards	No formula, 15% of the cybersecurity requirements set out in ISA62443-3.2		15%
6.5	Wayside Signalling Equipment Monitoring System - TALGO	6.5-2	Reduce the impact of top threats	No formula		5 of the top 7
6.6	On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany	6.6-1	Application of SMO bogie diagnostic solution	No formula, evaluating the availability of results provided by the SMO bogie diagnostic solution.		Not Available
6.6	On-board bogie diagnostic solution for fault detection applied to train(s) operating in Germany	6.6-2	Integration of results to maintenance process	No formula, this KPI evaluated if the results of the SMO bogie diagnostic solution are used within the maintenance process		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
6.7	Digital twin for energy	6.7-1	Accuracy of the energy consumption model	No formula, from NSR fleet data		5%
6.7	Digital twin for energy	6.7-2	Expected improvement in energy reduction	No formula, from NSR fleet data		5%
6.8	Smart maintenance scheduling tool	6.8-1	Savings in maintenance cost	No formula, measured computing the maintenance cost in a simulated scenario		10%
6.8	Smart maintenance scheduling tool	6.8-2	Increase in fleet availability	No formula, measure the gains in availability thanks to the application of a smart maintenance scheduler system		5%
7.1	Bogie Monitoring System (wayside – acoustic, 2D-images, video,laser and RFID)	7.1-1	Wheel defects	$PI_{7.1-1} = \frac{Number\ of\ derailments\ due\ to\ the\ wheel}{kilometers - train} \times 100$		Not Available
7.1	Bogie Monitoring System (wayside – acoustic, 2D-images, video,laser and RFID)	7.1-2	Wheel profile defects	$PI_{\ 7.1-2} = \frac{Number\ of\ reprofiles\ kilometers}{kilometers - train}$		Not Available
7.1	Bogie Monitoring System (wayside –	7.1-4	Degree of network utilization – all trains	$\text{PI}_{\ 7.1\text{-}3}\ \text{Degree of network utilization} = \left(\frac{Total\ monthly\ train{-}km}{Main\ track{-}km{\cdot}30}\right) \cdot \left(1 - \frac{Delta}{100}\right)$		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
	acoustic, 2D-images, video, laser and RFID)					
7.1	Bogie Monitoring System (wayside – acoustic, 2D-images, video,laser and RFID)	7.1-4	Accuracy	$PI_{7.1\text{-}4}\ \mathrm{Accuracy} = (\mathrm{TP} + \mathrm{TN}) / (\mathrm{TP} + \mathrm{TN} + \mathrm{FP} + \mathrm{FN})$		Not Available
7.2	Pantograph Monitoring System	7.2-1	Pantograph defects	$PI_{7.2-1} = \frac{N° \ of\ pantograph\ defects}{N° \ of\ total\ pictures\ per\ month}$		Not Available
7.2	Pantograph Monitoring System	7.2-2	Accuracy	$PI_{7.2-2}\mathrm{Accuracy} = (\mathrm{TP} + \mathrm{TN}) / (\mathrm{TP} + \mathrm{TN} + \mathrm{FP} + \mathrm{FN})$		Not Available
7.3	General physical anomaly detection Monitoring System (wayside – Video and 2D-3D images)	7.3-1	Effort spent in visual inspections	$PI_{7.3-1} = \Sigma$ hours for visual inspection in a month (or % shorter inspect time)		Not Available
7.3	General physical anomaly	7.3-2	Anomalies detected with new technologies	$PI_{7.3-2} = \Sigma$ detected defects via new inspection techniques		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
	detection Monitoring System (wayside – Video and 2D-3D images)					
7.4	Data path diagram Use Case	7.4-1	Reduction of the timespan	$PI_{7.4-1}$ [Delta]ts $= ts_0 - ts_1$		Not Available
7.5	CBM algorithms for freight	7.5-1	Detection of anomalies	$PI_{7.5-1} = \frac{N° \; of \; anomalies \; detected \; by \; algorithms \; and \; confirmed \; in \; ground \; truth \; data}{\# \; of \; anomalies \; in \; ground \; truth \; data} \times 100$		Not Available
7.5	CBM algorithms for freight	7.5-2	Diagnosis of anomalies	$PI_{7.5-2} = \frac{N° \; of \; anomalies \; diagnosed \; by \; algorithms \; and \; confirmed \; in \; ground \; truth \; data}{\# \; of \; anomalies \; in \; ground \; truth \; data} \times 100$		Not Available

CLUSTER D Infrastructure Asset Management

UC	UC title	PI	PI title	Formula	Baseline	Target
8.1	Long term asset management and LCC	8.1-1	Accuracy of estimated response to traffic loads based on the bridge modelling	No formula, this PI will be computed by comparing responses	Current method for estimate response to traffic will serve as the base line	Not Available
8.1	Long term asset management and LCC	8.1-2	Overall cost of operation (OPEX and CAPEX)	No formula, this PI will be computed by calculating CAPEX and OPEX costs	Current practice for each decision support in UC8.2 will be served as a base line.	Not Available
8.2	Holistic long term asset management	8.2-1	Availability	$PI_{8.2-1} = \frac{\text{MUT}}{MUT + MDT}$	Not existing. Baseline is not accessible. The UC provides a new approach for calculating availability	Not Available
8.2	Holistic long term asset management	8.2-2	Total maintenance cost (resources used)	No formula, this PI will be calculated as a percentage change in total maintenance cost	The cost for current tamping practice will serve as a base nine	Not Available
9.1	Sensing railway superstructure system components	9.1-1	Reduction of the maintenance cost	There are no defined formulas yet. The results obtained in the laboratory between conventional concrete and graphene-additivated concrete will be tested and compared.	Concrete sleepers are one of the most used and, therefore, most resource-consuming elements; currently, no parameters are measured or monitored. Laboratory tests will be carried out with normal and additive concrete in order to perform the KPIs. Visual inspection is typically used to estimate the parameters of the ballast layer. This UC aims to	10%
9.1	Sensing railway superstructure system components	9.1-2	Reduction of in-service failures	There are no defined formulas yet. The results obtained in the laboratory between conventional concrete and graphene-additivated concrete will be tested and compared.		25%

UC	UC title	PI	PI title	Formula	Baseline	Target
					estimate profiles and volumes. The BIM model exchange for overhead contact lines is mostly reduced to the exchange of 3D objects. Importing those models into design applications is impossible since all crucial semantic data is missing.	
9.2	Railway infrastructure monitoring using fibre optics	9.2-1	Detection of infrastructure anomalies and assets monitoring	$PI_{9.2-1}\%\ Anomalies\ detected = \frac{Number\ of\ Detections}{Total\ number\ of\ anomalies}\ x\ 100$	Baseline is the comparison with existing technologies, such as rockfall detection net, and the analysis of maintenance optimization when no detection technology is available.	10 %
9.2	Railway infrastructure monitoring using fibre optics	9.2-2	Detection of vehicle anomalies	$PI_{9.2-2}\%\ Anomalies\ Detected = \frac{Number\ of\ Detections}{Total\ number\ of\ anomalies}\ x\ 100$	Fiber optic measurements will be compared to traditional wayside measurement systems.	100%
9.3	Track Geometry and S&C condition monitoring	9.3-1	Optimisation of track work prioritisation	$PI_{9.3-1} = \left\lvert\frac{CBPW_{UC}^{BW} + CBPW_{UC}^{FW} + CBPW_{UC}^{NEW}}{CBPW_B} - 1\right\rvert$	1) Detecting and accessing plain track defects relies on visual inspection, and requires proper lighting conditions. 2) After visual inspection, a manual ultrasonic measurement is conducted,	10%
9.3	Track Geometry and S&C condition monitoring	9.3-2	Optimisation of turnout work prioritisation	$PI_{9.3-2} = \left\lvert\frac{CBWP_{UC}}{CBWP_B} - 1\right\rvert$		10%
9.3	Track Geometry and	9.3-3	Performance of inspection solutions	No formula, calculated by dividing the number of defects found in a set of switches and crossings by both methods by the number of defects found by an individual		5 %

UC	UC title	PI	PI title	Formula	Baseline	Target
	S&C condition monitoring			method	requiring person hours. 3) For SC, mobile devices are used to measure turnout geometry, fixed wayside monitoring systems are used to measure vibrations at turnouts due to train passages, and track and rail vision systems are used for reporting surface irregularities and component clearances.	
9.4	Prescriptive Maintenance for Railway Infrastructure	9.4-1	Completed campaigns	$PI_{9.4-1} = \frac{N_a}{N_b}$ planned	Total number of campaigns planned	100 %
9.4	Prescriptive Maintenance for Railway Infrastructure	9.4-2	Detection of anomalies	$PI_{9.4-2} = \frac{N_t}{N_r}$	Number of anomalies detected by an alternative means, i.e. by means of inspection. Some technologies do not have an alternative competitive approach to compare (for instance, when detecting phenomena that current systems do not report).	50 %
9.4	Prescriptive Maintenance for Railway Infrastructure	9.4-3	Correlation between anomalies and track geometry deterioration	$PI_{9.4-3} = \frac{N_a}{N_b}$	Total number of sections with track geometry deviation.	20 %

UC	UC title	PI	PI title	Formula	Baseline	Target
9.4	Prescriptive Maintenance for Railway Infrastructure	9.4-4	Validation of track geometry prediction	$PI_{9.4-4} = \frac{N_{\alpha \leq 10\,\%}}{N_{total}}$	N_t total number of sections	90 %
11.1	Linking (new) monitoring technologies to asset management issues	11.1-1	Detection of anomalies	$PI_{11.1-1} = \frac{Number\ of\ anomalies\ detected\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$	Ground-truth datasets – Use Cases 11 take into account different applications and apply a holistic approach. For each application, a dataset is being set up and will be analyzed to define the ground truth, serving as the basis for testing the developments. Baselines and targets are established for each application and will be addressed in WP11 during the course of the project.	Not Available
11.1	Linking (new) monitoring technologies to asset management issues	11.1-2	Diagnosis of anomalies	$PI_{11.1-2} = \frac{Number\ of\ anomalies\ diagnosed\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$		Not Available
11.2	Fusion of (on-board and wayside) monitoring data for an enhanced fault detection and diagnosis	11.2-1	Detection of anomalies	$PI_{11.2-1} = \frac{Number\ of\ anomalies\ detected\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$		Not Available
11.2	Fusion of (on-board and wayside) monitoring data for an enhanced fault detection and diagnosis	11.2-2	Diagnosis of anomalies	$PI_{11.2-2} = \frac{Number\ of\ anomalies\ diagnosed\ and\ confirmed\ in\ ground\ truth\ data}{Number\ of\ anomalies\ in\ ground\ truth\ data} \times 100$		Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
12.1	Multiscale monitoring of civil assets	12.1-1	Bridge inspection - reduction of maintenance costs	$PI_{12.1-1} = \frac{Time/Cost_{traditional\_method} - Estimated\ time/cost_{new\_method}}{Time/Cost_{traditional\_method}} x100$	Data (man hours/cost) from historical inspection reports provided by IM (performed with scaffolding /cranes & manual classification).	10%
12.1	Multiscale monitoring of civil assets	12.1-2	Bridge inspection - reduction of traffic disruption caused by traditional bridge inspection in the railway infrastructure	$PI_{12.1-2}(\%\ disruption) = \frac{TSRn}{TSRt} x\ 100$	Data (disruptions) from historical operational reports provided by IM (in case of bridges related issues).	25%
12.1	Multiscale monitoring of civil assets	12.1-3	Reduction of on track data collection time	$PI_{12.1-3} = \frac{Time/Cost_{traditional\_method} - Estimated\ time/cost_{new\_method}}{Time/Cost_{traditional\_method}} \times 100$	Time (man hours) required for data collection and surrounding with traditional approaches (in situ surveys data from maintenance reports)	10%
12.2	Bridges and earthworks assets management aided by geotechnics	12.2-1	Failure mode predictability	No formula, the frequency and characteristic traces of failures that evolve in time will be a model	New model	25%
12.2	Bridges and earthworks assets management aided by geotechnics	12.2-2	Reduction of theoretical time per circulation by failures in the railway infrastructure	$PI_{12.2-2} = \frac{TTLa}{TTLt} x\ 100$	Data derived from the temporary speed restrictions currently in force on the General Interest Railway Network in Spain due to actions on bridges and slopes. From this list, we will extract those exclusively caused by failures in POT	25%

UC	UC title	PI	PI title	Formula	Baseline	Target
					bearings on bridges and risks of landslides on slopes. Additionally, each Temporary Speed Restriction is associated with a theoretical time loss per track, which is recorded in ADIF's database.	
12.2	Bridges and earthworks assets management aided by geotechnics	12.2-3	Cost reduction of instrumentation equipment for earthworks	$PI_{12.2-3} = \left(\frac{COSTS_{\ n} - COSTS_{\ n-1}}{COSTS_{\ n-1}}\right) x\ 100$	Data from historical monitoring equipment costs provided by ADIF	10%
12.2	Bridges and earthworks assets management aided by geotechnics	12.2-4	Reduction of costs in the pot bearings replacement	$PI_{12.2-4} = \left(\frac{COSTEW - COSTPT}{COSTPT}\right) x100$	Data from historical POT bearings replacement costs provided by ADIF Costs of typical emergency work will be carried out with respect to the cost through an open public tendering procedure	10%
12.2	Bridges and earthworks assets management aided by geotechnics	12.2-5	Effectiveness of slope stabilization measures	$PI_{12.2-5} = \left(\frac{\mathrm{Tb} - \mathrm{Ta}}{\mathrm{Tb}}\right) x100$	This indicator can only be measured if the installation of the sensor network is carried out before the execution of the corrective works (still in preparation).	10%
12.3	Monitoring of tunnel, sub-ballast layers, subsoil and predictive	12.3-1	Reduction of maintenance times	$PI_{12.3-1} = \frac{Time_{traditional\_method} - Estimated\ time_{new\_method}}{Time_{traditional\_method}} \times 100$	This will be estimated with the help of maintenance operators and geophysical companies; we need to finalise the processing of	10%

UC	UC title	PI	PI title	Formula	Baseline	Target
	maintenance for tunnels				data gathering.	
12.3	Monitoring of tunnel, sub-ballast layers, subsoil and predictive maintenance for tunnels	12.3-2	Reduction of the maintenance cost	$PI_{12.4-2A} = \frac{Equ.cost_{t.m.} - Equ.Esti_{n.m.}}{Eu\ cost_{t.m.}} \times 100$ $PI_{12.2-2B} = \frac{(Equ.cost_{t.m.} + Wf.cost_{t.m.}) - (Equ.Esti_{n.m.} + Wf.Esti_{n.m.})}{Equ\ cost_{t.m.} + Equ\ cost_{t.m.}} \times 100$	The baseline for KPI evaluation will be based on the data communicated to us by i) maintenance operators and ii) geophysical companies to estimate the cost of geophysical services.	10%
12.4	Data Analysis for condition monitoring	12.4-1	Track condition monitoring	$PI_{12.4-1} = \frac{(\mathrm{defect_{ABA}} - \mathrm{defect_{TG}})}{\mathrm{defect_{TG}}} \times 100$	The baseline for standard practice solely relies on track geometry parameter limit values. A positive KPI value suggests that ABA measurements more effectively detect defects (poor embankment conditions) than track geometry parameter measurements	10%
12.4	Data Analysis for condition monitoring	12.4-2	Detectability of incipient known failures	$PI_{12.4-2} = \frac{n_{mon}}{n_{mon} + m_{ins}} \times 100$	Fault detection level from manual inspection as per today's method.	10%

CLUSTER E Railway Digital Twins

UC	UC title	PI	PI title	Formula	Baseline	Target
15.1	Decision support systems for railway station asset management	15.1-1	The number of assets covered by predictive maintenance	$PI_{15.1-1} = \frac{N}{M} \cdot 100$	Survey	25%
15.1	Decision support systems for railway station asset management	15.1-2	The number of accessibility assets covered by predictive maintenance	$PI_{15.1-2} = \frac{N_a}{M_a} \cdot 100$	Survey	50%
15.1	Decision support systems for railway station asset management	15.1-3	Average time of cleanliness incident detection	$PI_{15.1-3} = \left(1 - \frac{\hat{T}_{dss}}{\hat{T}}\right) \cdot 100$	Survey	25%
15.2	Blockchain for certification	15.2-1	System Response Time	$PI_{15.2-1}\ (\text{System Response Time}) = \frac{\sum_{i=1}^{n}(response\_time_i)}{n}$	Not Available since the calculation will be response time.	<10 sec
15.3	Track Condition data fusion in Point Clouds	15.3-1	The number of data anomalies found in asset digitalization	$PI_{15.3-1} = \sum aA$	Not Available. We can assume that the baseline is the total number of assets or asset properties digitalized that can be compared to the total number of assets or asset properties with anomalies	>25%
15.4	Point Machine Digital Twin simulation	15.4-1	Number of tests enabled by Digital Twin	No formula, it is an enumeration measure as observed by the assessor in a given situation	Not Available	Not Available

UC	UC title	PI	PI title	Formula	Baseline	Target
15.5	Automatic track visual inspection by drones	15.5-1	THE Number of Assets Mangaed and Monitored by Digital Twins	$PI_{15.5-1} = \frac{VMTF_{UC}+\sum_{AC} k_{ACi} VMAF_{ACi_{UC}}}{VMTF_{B}+\sum_{AC} k_{ACi} VMAF_{ACi_{B}}} - 1,$	Not Available. We can assume that the baseline is the total number of assets or asset properties digitalized that can be compared to the total number of assets inspected by drones	15%
15.5	Automatic track visual inspection by drones	15.5-2	Reduction of maintenance costs	$PI_{15.5-2} = 1 - \frac{MRC_{UC} + MDC_{UC} + MMC_{UC}}{MRC_{B} + MDC_{B} + MMC_{B}}$	Personal costs (technical report)	10%
15.6	BIM model as support to communicate an populate the Station's Asset Management System	15.6-1	Number of assets managed and monitored by Digital Twins	$PI_{15.6-1} = \frac{(\mathrm{TNA} * \mathrm{ANIA}) + \mathrm{AAIAA}}{\mathrm{AAIAA}}$	Survey	25%
15.6	BIM model as support to communicate an populate the Station's Asset Management System	15.6-2	Data quality treated in the digital twin	No formula	Not Available	Not Available
15.6	BIM model as support to communicate an populate the Station's Asset Management System	15.6-3	Time reduction to create a data base for asset management	No formula	Not Available	10%

CLUSTER F Environment, User and Worker Friendly Railway Assets

UC	UC title	PI	PI title	Formula	Baseline	Target
16.1	Green turnout	16.1-1	Time reduction	$PI_{16.1-1} = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$	Traditional method from design to manufacturing	20%
16.1	Green turnout	16.1-2	Extension of remaining lifetime	$PI_{16.1-2} = \frac{Lifetime_{traditional\_method} - Lifetime_{new\_method}}{Lifetime_{traditional\_method}} \times 100$	Traditional method	20%
16.1	Green turnout	16.1-3	Reduce maintenance cost	$PI_{16.1-3} = \frac{Cost_{traditional\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$	Traditional method	20%
16.2	Innovative sleeper system	16.2-1	Time reduction	$PI_{16.2-1} = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$	Traditional method from design to manufacturing	20%
16.2	Innovative sleeper system	16.2-2	Extension of remaining lifetime	$PI_{16.2-2} = \frac{Lifetime_{traditional\_method} - Lifetime_{new\_method}}{Lifetime_{traditional\_method}} \times 100$	Traditional method	20%
16.2	Innovative sleeper system	16.2-3	Reduce maintenance cost	$PI_{16.2-3} = \frac{Cost_{traditional\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$	Traditional method	20%
16.3	Maintenance reducing	16.3-1	Time reduction	$PI_{16.3-1} = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$	Traditional method from design to manufacturing	20%

UC	UC title	PI	PI title	Formula	Baseline	Target
	squat resistant rail					
16.3	Maintenance reducing squat resistant rail	16.3-2	Extension of remaining lifetime	$PI_{16.3-2} = \frac{Lifetime_{traditional\_method} - lifetime_{new\_method}}{Lifetime_{traditional\_method}} \times 100$	Traditional method	20%
16.3	Maintenance reducing squat resistant rail	16.3-3	Reduce maintenance cost	$PI_{16.3-3} = \frac{Cost_{traditional\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$	Traditional method	20%
16.4	Bridge dynamics	16.4-1	Cost reduction	Compared to the current state of the art, it is believed that the developed use cases will contribute to 20% cost reductions in design of railway bridges. Recent studies has shown that the current dynamic amplification factor may be over-conservative, especially for short- and medium span bridges. The use case will provide a more realistic understanding of dynamic effects on bridges and will allow existing bridges to be upgraded to support higher allowable axle loads without strengthening or replacement. This will also allow for more cost-efficient design of new bridges.	Traditional method for railway bridge design	20%
16.5	Platipus	16.5-1	Extension of remaining life	While the precise computation is not detailed, the evaluation involves measuring the reduction in emergency interventions by detecting weaknesses early and planning regeneration works. A detailed analysis of long-term data on maintenance costs before and after implementing PLATIPUS, comparing the longevity of the structures, would be necessary for precise computation.	Current maintenance cost	10%
16.5	Platipus	16.5-2	Reduction of maintenance cost	The computation of this PI would involve analysing maintenance costs over several years to determine cost savings. The project should show cost savings through reduced emergency interventions and optimized maintenance schedules, comparing maintenance costs before and after implementing the PLATIPUS system, as well as assessing train regularity and infrastructure availability indicators.	Current maintenance cost	10%
16.6	Diagn'eau	16.6-1	Infrastructure long-term Asset Management	No formula is possible to use during the duration of the project, the computation of this PI would involve analysing project strategies over several years (post ERJU) to determine the enhancement of asset resilience and projects having benefited from the	Current assets refistered in tool	30%

UC	UC title	PI	PI title	Formula	Baseline	Target
				developed tool. (or in other words the "the rate at which the tool is used") Improve integration of flood risk in design or regeneration projects with a target of at least 30 % of assets registered in the tool. This target value would not be attained during ERJU but afterwards after a prolonged duration of tool use.		
16.7	Geogrids	16.7-1	Time reduction	Time needed with traditional methods is compared with an expected solution using geogrid (according to other railway infrastructure managers). A positive PI indicates that the estimated time for the new method is less than the time required for traditional methods.	Traditional methods for earthworks	30%
16.7	Geogrids	16.7-2	Cost reduction for renewal	Cost of renewal with traditional methods is compared with an expected cost with the geogrid solution (according to other railway infrastructure managers). A positive PI indicates that the estimated time for the new method is less than the time required for traditional methods.	Traditional methods for earthworks	30%
16.7	Geogrids	16.7-3	Cost reduction for maintenance	The cost of the life of a line with trackbed disorders (tampings, etc) is compared to the cost of trackbed renewal cost. A positive PI indicates that the estimated cost of the trackbed renewal using geogrid is less than the cost of maintenance operations at the scale of the life of a line with trackbed disorders.	Traditional methods for earthworks	20%
17.1	In-situ AM repair machine for rails, switches and crossings	17.1-1	Extension of remaining life of the rail	$PI_{17.1-1} = \frac{WearRate_{baseline\_solution} - WearRate_{I4R\_solution}}{WearRate_{baseline\_solution}} \times 100 + \frac{ErrorRate_{I4R\_solution}}{ErrorRate_{baseline\_solution}} \times 100$		25 %
17.2	AM repair machine for wheels	17.2-2	Extension of remaining life	$PI_{17.2-1} = 1 + \frac{WearRate_{I4R\_solution}}{WearRate_{baseline\_solution}} \times 100$		25%
17.3	In situ repair of track metallic assets	17.3-1	Extension of remaining life	$PI_{17.3-1} = \frac{WearRate_{baseline\_solution} - WearRate_{I4R\_solution}}{WearRate_{baseline\_solution}} \times 100$		25%
17.4	Stationary solution for AM repaired turnout	17.4-1	Extension of remaining life	$PI_{17.4-1} = \frac{WearRate_{baseline\_solution} - WearRate_{I4R\_solution}}{WearRate_{baseline\_solution}} \times 100$		25%

UC	UC title	PI	PI title	Formula	Baseline	Target
	crossings using WAAM technology					
17.5	Additive Manufacturing of large & flame-retardant polymer spare parts	17.5-1	Time reduction (from design to manufacturing)	$PI_{17.5-1} = \frac{Time_{baseline\_method} - Time_{I4R\_method}}{Time_{baseline\_method}} \times 100$		30%
17.5	Additive Manufacturing of large & flame-retardant polymer spare parts	17.5-2	Cost reduction in parts and assets	$PI_{17.5-2} = \frac{Cost_{baseline\_method} - Cost_{I4R\_method}}{Cost_{baseline\_solution}} \times 100$	The demonstrator costs produced by conventional process and additive manufacturing will be compared.	30%
17.6	Digital warehouse	17.6-1	Time reduction (from design to manufacturing)	$PI_{17.6-1} = t_{saving} = \frac{t_{traditional} - t_{digital\ warehouse}}{t_{traditional}}$	For the demonstrator the time reduction is calculated by comparing the process time in days from spare part request to the date the first part is delivered for the traditional process, *t traditional* route with the route of a digital warehouse,tdigital warehouse . digital warehouse. The calculation is done by comparing samples with similar characteristics.	30%

UC	UC title	PI	PI title	Formula	Baseline	Target
17.6	Digital warehouse	17.6-2	Cost reduction in parts and assets	$PI_{17.6-2} C_{total} = \frac{C_{spare\ part\ order}}{N_{parts\ in\ order}} + \frac{C_{spare\ part\ order}}{2} * \left(\frac{i+l}{100}\right)^{\frac{N_{parts\ in\ order}}{D_{yearly\ average\ demand}}} - C_{opportunity\ savings}$	The cost between a standard order with classical minimum order quantities will be compared to a reduced order quantity enabled by a digital warehouse.	30%
18.1	Light and flexible on-track inspection	18.1-1	Cost per measured kilometre	$PI_{18.1-1} C_{WF} = \#\,workforce \times 8 \times 200 \times \#\,work\ session\ per\ day \times 100 C_{NRJ} = NRJ\ Cost\ for\ 1\ hour\ of\ operation \times 8 \times 200 \times \#\,work\ session\ per\ day\ \#\,insp.track\ length = operational\ rate \times 8760 \times service\ life \times average\ insp.speed Cost\ per\ km = \frac{C_{WF} + C_{PURCH} + C_{MAINT} + C_{NRJ}}{\#\,inspected\ track\ length}$		32 €/km
18.1	Light and flexible on-track inspection	18.1-2	Confusion	$PI_{18.1-2A} = \frac{N°\ of\ false\ positive\ detections}{\#\,of\ real\ defects}$ $PI_{18.1-2B} = \frac{N°\ of\ false\ negative\ detections}{\#\,of\ real\ defects}$		10%
18.2	Automated installation of ERTMS balises and axle counters	18.2-1	Use of robotised tools	No formula, but statement of the stakeholders qualifying the end results	Will be measured during a test campaign	25%
18.2	Automated installation of ERTMS balises and axle counters	18.2-2	Tender offer	$PI_{18.2-2}\ \text{tender offer development} = 1 - \frac{\text{tender offer price with robot}}{\text{tender offer price conventional}}$		
18.2	Automated installation of	18.2-3	Heavy repetitive work	$PI_{18.2-3}\ \text{shifts by robot development} = 1 - \frac{\text{shifts performed by robot}}{\text{shifts performed by humans}}$		

UC	UC title	PI	PI title	Formula	Baseline	Target
	ERTMS balises and axle counters					
18.3	Disinfection of trains and small stations	18.3-1	Disinfection Time (DT)	$PI_{18.3-1}\ DT = \frac{\text{Volume of the disinfection area}}{\text{Disinfection device flow rate}}$	±30 min/8-coach train (in France)	20 min
18.3	Disinfection of trains and small stations	18.3-2	Disinfection Cost (DC)	$PI_{18.3-2}DC = \frac{\text{LCC of the technical system}}{\text{N}_{\text{TRAINS}}}$	60€/train	10%
18.4	Train underbody inspection	18.4-1	Maintenance Costs (MC)	$PI_{18.4-1}MC = \frac{C_{\overline{ARGO}}}{C_{ARGO}} \quad [< 1]$	Internally calculated, because of different companies	60%
18.4	Train underbody inspection	18.4-2	Maintenance Time (MT)	$PI_{18.4-2}MT = \frac{T_{\overline{ARGO}}}{T_{ARGO}} \quad [< 1]$	3 hours	50%
18.4	Train underbody inspection	18.4-3	Defects Index (DI)	$PI_{18.4-3}DI = \frac{D_{\overline{ARGO}}}{D_{ARGO}} \quad [> 1]$	To be define after some tests	
18.5	Automated fixed crossing repair	18.5-1	Accuracy of inspections	$PI_{18.5-1}Time\_finishing = \frac{T_{automated}}{T_{manual}} \leq 0{,}75$	To be measured during tests for defined repair cases	25%
18.5	Automated fixed crossing repair	18.5-2	Reproducibility of inspections	$PI_{18.5-2}\ Geometry\_average = \frac{GA_{automated}}{GA_{manual}} \leq 0{,}75$	To be measured during tests for defined repair cases	25%
18.5	Automated fixed crossing	18.5-3	Cost reduction	$PI_{18.5-3}\ Costs = \frac{C_{automated}}{C_{manual}} \leq 0{,}9$	To be measured during tests for defined repair cases	10%

UC	UC title	PI	PI title	Formula	Baseline	Target
	repair					
19.1	Upper-body exoskeleton for worker's support in railway industry	19.1-1	Societal Impact	$PI_{19.1-1} = \frac{Value_{new\_method} - Value_{traditional\_method}}{Value_{traditional\_method}} \times 100$		10%
19.2	Augmented Reality tools to help and guide railway workers in maintenance operations	19.2-1	Cost reduction of the interventions	$PI_{19.2-1A}\ (\%\ time\ savings) = \frac{Time_{traditional\_method} - Time_{new\_method}}{Time_{traditional\_method}} \times 100$ $PI_{19.2-1B}\ (\%\ cost\ savings) = \frac{Cost_{\ traditional\_method} - Cost_{new\_method}}{Cost_{traditional\_method}} \times 100$		10%