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ANNEX

ANNEX

to the

Commission Decision

on the submission of the Europe's Rail Joint Undertaking Master Plan for adoption by Europe's Rail Governing Board

Europe’s Rail Joint Undertaking

Master Plan (DRAFT)

October 2021

EUROPEAN COMMISSION

Directorate-General for Transport and Mobility
Directorate C — Land Transport
Unit C4 — Rail Safety and Interoperability

Contact:

E-mail:

European Commission
B-1049 Brussels

Europe’s Rail Joint Undertaking

Master Plan

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Abbreviations

AI	Artificial Intelligence
ALICE	Alliance For Logistics Innovation Through Collaboration in Europe
ATO	Automatic Train Operation Or Autonomous Train Operations
ATP	Automatic Train Protection
B2B	Business to Business
CCS	Control Command and Signalling
C-DAS	Connected Driver Advisory Systems
CDM	Conceptual Data Model
CEN/CLC/JTC	Cen / Cenelec /Joint Technical Committee
CER	Community of European Railway and Infrastructure
DAC	Digital Automatic Coupler
DT	Digital Twin
EC	European Commission
EDDP	European DAC Delivery Programme
EIM	European rail Infrastructure Managers
ERA	European Agency for Railways
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
EU-RAIL	Europe’s Rail Joint Undertaking
FA	Flagship Area
FFFiS	Form Fit Function Interface Specification
FRMCS	Future Railway Mobile Communication System
GoA	Grade Of Automation
HVAC	Heating, Ventilation, And Air Conditioning
IFC	Industry Foundation Classes
IoT	Internet Of Things
IP	Innovation Program (Of Shift2Rail)
IT	Information Technology
JU	Joint Undertaking
KPI	Key Performance Indicator
MAWP	Multi-Annual Work Program
MOD	Mobility On Demand
MS	Member State
PRM	Persons with Reduced Mobility
S2R	Shift2Rail
SERA	Single European Railways Area
SP	System Pillar
SRIA	Strategic Rail Research and Innovation Agenda
TCMS	Train Control Monitoring System
TMS	Traffic Management System
TRL	Technology Readiness Level
TSI	Technical Specification for Interoperability
UIC	Union Internationale des Chemins de fer (International Union Of Railways)
UITP	International Association of Public Transport

Executive Summary

Europe's Rail Joint Undertaking (EU-Rail) is the new European partnership on rail research and innovation.

This Master Plan provides an overview of the ambitions and the objectives of this new partnership and defines a systemic, long-term and result-oriented delivery strategy for research & innovation in the railway sector.

A new role for rail

EU-Rail works towards the twin green and digital transition of Europe.

The European Green Deal objective is to reach climate neutrality by 2050, the Fit for 55 package sets medium-term greenhouse gas emissions reduction objectives, and the Digital Decade sets the path to bring Europe to the forefront of digitalisation and automation.

The Sustainable and Smart Mobility Strategy articulates the pathways towards digitalising and greening the transport sector and sets specific milestones for the railway sector. The Industrial Strategy aims at enhancing Europe's industrial competitiveness, including in sectors at the forefront of the twin transitions such as the rail supply industry.

These Union policy goals are a major reason for the railway sector to undergo a significant transformation - increasing its capacity for passenger and goods transport, enabling an increase in the use of rail transport, and reducing further the greenhouse gas emissions of the railway sector itself. To achieve this change, the sector must address the following challenges:

1) Changing customer requirements: demographic, technological, market and political trends are changing the needs of passenger and freight customers. These shifts, along with disruptive events like the COVID19 pandemic, require rail to be more flexible than in the past.
2) Need for improved performance and capacity: in order to deliver an overall more sustainable transport mix, rail must be able to accommodate increased demand.
3) High cost: rail is currently often more expensive compared to other transport modes. To be more competitive and support future increased usage, rail must deliver more cost-efficient solutions and services compared to today.
4) Climate change: rail is the most sustainable motorised mode of transport, as indicated in a recent report of the European Environmental Agency, but cycling or walking. Increased use of rail is necessary to fulfil European climate objectives and rail assets need themselves to be climate resilient.
5) Legacy systems and obsolescence: rail system assets are procured assuming very long lifecycles and are based on national approaches, which makes fast and interoperable transformation difficult.
6) Interaction with other modes: rail networks and the services associated to them in some contexts link well with other transport modes. But such integration must be improved to better serve the needs of customers, and make rail central to future mobility and a more attractive mode overall.
7) Increased competition. The European rail supply industry is world leading. However, it faces many challenges at global level.

Objectives for EU-Rail

The objectives of EU-Rail have been set to address the EU policy objectives, rail sector vision, and the challenges inherent to the transformation of the rail system.

Specifically, these should result in:

1) Meeting evolving customer requirements
2) Improved performance, and capacity
3) Reduced costs
4) More sustainable and resilient transport
5) Harmonised and interoperable evolution of the rail system and greater adaptability to new technologies
6) Reinforced role for rail in European transport and mobility
7) Improved EU rail supply industry competitiveness.

To achieve this, five areas of priority for EU-Rail have been determined:

1) European rail traffic management and supporting rail's key role in a multimodal transport system
    (a) Delivering European rail traffic management complementing ERTMS to achieve dynamic capacity management, improved performance, and cost efficiency.
    (b) Providing systems for real time management of the network's operation
    (c) Supporting the rail's key role in future transport and mobility systems
2) Digital and Automated Train Operations
    (a) Delivering an adaptable and scalable trackside and on-board systems architecture and associated solutions - representing the next evolution of the command, control and signalling system and incorporating the latest technological advances.
    (b) Delivering scalable automation in train operations.
3) Sustainable and digital assets
    (a) Solutions to reduce the environmental footprint, to improve accessibility, and to increase resilience of the rail system.
    (b) Innovative solutions to minimise asset life-cycle costs.
4) Competitive digital green rail freight
    (a) Developing and integrating new operational and technological solutions to make rail freight more competitive.
    (b) Streamlining freight operations through digitalisation to ensure smooth integration of rail freight in the logistics value chain.
5) Smart solutions for low density traffic lines (cost-efficient regional lines)
    (a) Adapting solutions to revitalise and regenerate low density traffic lines, making them economically, socially and environmentally sustainable, creating seamless links across the whole transport infrastructure and, by all this, supporting the competitiveness of the whole sector.

These priorities will be underpinned by a system view to ensure a harmonised approach to the evolution of the Single European Rail Area.

EU-Rail will build on the achievements of the previous joint undertaking delivering results that are ready to deploy. These results will contribute to achieving the Sustainable and Smart Mobility Strategy rail objectives.

EU-Rail will also work on forward-looking activities, integrating disruptive technologies and thinking including from SMEs, start-ups and research community, through performing exploratory research.

EU-Rail will foster a close cooperation and ensure coordination with related European, national and international research, innovation deployment and investment activities in the rail sector and beyond, in particular under Horizon Europe, Connecting Europe Facility, and the Digital Europe Programme. The regional dimension will be a priority to ensure that EU-Rail will deliver

1 Introduction

The Europe's Rail Joint Undertaking (EU-Rail) is the European partnership on rail research and innovation established under Horizon Europe. Building on the achievements of the Shift2Rail Joint Undertaking (S2R), the partnership aims to accelerate research and development in innovative technologies and operational solutions supporting the fulfilment of European Union policies and objectives relevant for the railway sector and supporting the competitiveness of the rail sector and the European rail supply industry.

This document – the EU-Rail Master Plan - provides a high-level overview of the challenges in the railway sector, the objectives of the EU-Rail partnership, and the framework for the activities to be performed within the current programming period[1].

The Master Plan shall provide guidance on the tasks of EU-Rail as per the requirements of Council Regulation (EU) 2021/2085 of 19 November 2021, [2], hereafter the 'Single Basic Act', which establishes EU-Rail and other Joint Undertakings.

2 A renewed role for rail

2.1 Transport Policy Context

EU-Rail works towards the twin green and digital transition of Europe.

The European Green Deal[3] objective is to reach climate neutrality by 2050, the Fit for 55 package[4] sets medium-term greenhouse gas emissions reduction objectives, and the Digital Decade sets the path to bring Europe to the forefront of digitalisation and automation.

The Sustainable and Smart Mobility Strategy articulates the pathways towards digitalising and greening the transport sector and sets specific milestones for the railway sector.

The railway sector will contribute to those objectives by increasing its capacity for passenger and goods transport, enabling an increase in the use of rail transport, and by reducing further the greenhouse gas emissions of the railway sector itself.

In order to foster the transformation of the railway system, the EU encourages research and innovation in this area with its new EU Framework Programme for Research and Innovation - Horizon Europe. At the same time, the Industrial Strategy aims at enhancing Europe's industrial competitiveness, especially in sectors contributing to both green and digital transitions.

European Green Deal & Fit for 55 Package

The European Green Deal is an integral part of the European Commission's strategy to implement the United Nation's 2030 Agenda and associated Sustainable Development Goals.

The European Green Deal was presented in December 2019, setting out a clear vision of how to achieve climate neutrality in Europe by 2050 and presented as EU's new growth strategy.

[1] Some late actions of the Europe's Rail partnership may last beyond the current programming period, but will be launched during it.

[2] COUNCIL REGULATION (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe and repealing Regulations (EC) No 219/2007, (EU) No 557/2014, (EU) No 558/2014, (EU) No 559/2014, (EU) No 560/2014, (EU) No 561/2014 and (EU) No 642/2014

[3] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[4] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

Transport accounts for a quarter of the EU's greenhouse gas emissions (GHG). To achieve climate neutrality, a 90% reduction in transport GHG emissions is needed by 2050.

The transformation of the railway system will be pivotal to achieve the European Green Deal objectives by offering both decarbonised and time/cost-competitive transport solutions for passengers as well as for freight.

The EU has raised its 2030 climate ambition, committing to cutting emissions by at least 55% by 2030. The Fit for 55 package was adopted in July 2021. This package of proposals supports a faster roll-out, relative to prior objectives, of sustainable transport solutions such as rail. The green deal also sets ambitious goals in relation to overall environment protection. These are further expressed in the EU Action Plan: "Towards Zero Pollution for Air, Water and Soil" and "Circular Economy Action Plan".

Digital Decade

In its Communication of March 2021, the Commission indicated how digital transformation can improve the ecosystems related to mobility and transport. Digitalisation can improve environmental and cost performance and simultaneously increase safety levels contributing to a higher quality of life. It will be achieved through more advanced levels of automation, faster and more reliable connectivity, enhanced data sharing, and IT enabled profound transformation of the management of mobility services. The public could also benefit from fast internet connectivity for passengers on most stations and lines, e.g., Gigabit Train[5], user-oriented telematics and facilitated multi-modality.

The Sustainable and Smart Mobility Strategy

In December 2020 the European Commission presented its 'Sustainable and Smart Mobility Strategy'[6] (SSMS), the strategy that, *inter alia,* implements the European Green Deal and transport related digital policies in the transport sector.

The SSMS outlines a long-term vision, which has a significant impact on all rail customers, i.e., both passengers and freight transport:

- Making interurban and urban mobility more sustainable and healthier
- Greening freight transport
- Making connected and automated multimodal mobility a reality

Specifically for rail this includes the following milestones:

- By 2030
  - Doubling of high-speed rail traffic
  - Large-scale deployment of automated mobility
- By 2050
  - Tripling of high-speed rail traffic; and
  - Doubling of rail freight traffic.

To achieve the SSMS milestones, the railway sector must undergo a significant transformation, whilst leveraging its strengths, addressing long overdue changes in legacy operational processes, systems and governance models, upgrading its assets, and integrating with other transport and mobility solutions for passenger services and cargo logistics.

[5] See the 5G Strategic Deployment Agenda on Connectivity and Spectrum (5G) released in April 2020 by CER and EIM: Strategic Deployment Agenda for 5G Connectivity and Spectrum for Rail

[6] https://ec.europa.eu/transport/themes/mobilitystrategy_en

Horizon Europe

Horizon Europe[7] – the new EU Framework Programme for Research and Innovation (2021-2027) – is the EU's key funding programme for research and innovation with a budget of €95.5 billion. It tackles climate change, helps to achieve the UN's Sustainable Development Goals and boosts the EU's competitiveness and growth. The programme facilitates collaboration and strengthens the impact of research and innovation in developing, supporting and implementing EU policies. It supports the creation and dissemination of cutting-edge knowledge and technologies.

The Horizon Europe Regulation had identified eight priority areas for possible institutionalised European partnerships. Based on this, a set of twelve initiatives were identified as candidates that were subject to a coordinated impact assessment. It is in this context that Europe's Rail partnership has been proposed to "*speed up the development and deployment of innovative technologies (especially digital and automation) to achieve the radical transformation of the rail system and deliver on European Green Deal objectives"* and to create a user-friendly, demand-driven and service-oriented railway of the future.

Following Horizon Europe's aim to facilitate collaboration, the EU-Rail will not only foster the cooperation of the rail stakeholders, but has a mandate to seek synergies with other research areas that can help solving rail related challenges and will also cooperate on development with other modes of transport to provide more coherent services.

Industrial Strategy

In its Communication "A new industrial strategy for Europe" updated in May 2021, the European Commission underlined the central role of the industry in Europe's future progress and prosperity. Its competitiveness will depend on its ability to adapt to the twin Green and Digital transitions that will impact all sectors of the economy.

The European rail supply industry is at the heart of this challenge and must help shape new international standards for safe, sustainable, accessible, secure and resilient mobility addressing the needs of operators and infrastructure managers.

Europe's competitiveness in the railway industry sector in particular is under severe pressure to innovate to face third countries competitiveness. Europe's global leadership and capacity to export will require a holistic approach, including addressing this sector's SMEs needs, to, which EU-Rail will contribute. In this context, innovation should also address processes, notably enabling the streamlining of certification and authorisation processes.

2.2 The rail sector vision

The European Rail Research Advisory Council (ERRAC) is the European Technology platform composed of representatives from most of the major European railway research stakeholders: manufacturers, operators, infrastructure managers, the European Commission, EU Member States, academics and users' groups.

ERRAC's mission is to deliver a vision of the railway's future enabled by Research and Innovation activities. In its 2050 Vision, and its R&I Priorities for 2030,, which inspired the Rail Strategic Research and Innovation Agenda (SRIA)[8], an input to this Master Plan, ERRAC states:

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[7] https://ec.europa.eu/info/horizon-europe_en

[8] https://shift2rail.org/wp-content/uploads/2020/12/RAIL-Strategic-Research-and-Innovation-Agenda-2020-_FINAL_dec2020.pdf

"*In 2050, rail transport in Europe is the backbone of an intermodal "Mobility as a Service" within cities and beyond, for both passengers and goods, meeting the needs of customers, EU citizens and society*."

"*The 2030 rail system will interact with other transport modes and with local, regional, national and European economic activities. Safe, reliable, comfortable and efficient rail services will influence and benefit lifestyle, spatial planning, people's everyday experience, health and standard of living*."

The sector is committed to transforming the railway system, putting the users at the forefront, using railways in combination with other transport modes, to become the backbone of Europe's mobility and the logistic chain. The SRIA anticipates a new paradigm for sustainable multimodal mobility, in which transport is not synonymous with individual vehicles and in which Europe's Rail is expected to play a central role:

"*Europe's Rail will deliver technological and operational solutions that respond to a new Concept of Operations for Rail, through a System of Systems service-oriented approach, in which an integrated rail system, including freight services, urban, suburban, regional and intercity passenger services, will realise its full potential."*

2.3 Challenges

The transformation of the rail system to achieve the ambitious policy and sector goals starts from recognising the significant challenges that the future rail system needs to address.

Changing customer requirements Political, demographic, technological and market trends are changing the needs of passenger and freight customers. These shifts, along with disruptive events like the COVID-19 pandemic, require rail to be more flexible than in the past. A customer-centric rail system means offering reliable services that are reactive to demand, adaptable to customer requests, and accessible for all passengers alike.
Need for improved performance and capacity In order to deliver an overall more sustainable transport system, rail must be able to accommodate increased demand. New infrastructure will be necessary in certain areas, but the vast bulk of future increased capacity must leverage existing infrastructure, through a systemic digitalisation and automation of operations.
High cost Rail is currently often more expensive compared to other transport modes, in some cases reflected on the intermediaries or passengers/users. To be more competitive and support future increased usage, rail must deliver more cost-efficient solutions and services compared to today.
Climate change adaptation and environmental sustainability Rail is the most sustainable form of motorised transport[9]. Increased use of rail is necessary to fulfil European climate neutral mobility and transport, while ensuring environment protection objectives. In addition, steps have to be taken to further improve the climate and environmental (e.g., reduce the noise) footprint of rail. Rail services and networks must also become more resilient against the impacts of climate change.
Legacy systems and obsolescence Rail system assets have very long lifecycles and are based on global and European requirements; additionally, legacy national requirements still survive.

[9] https://www.eea.europa.eu/publications/rail-and-waterborne-transport

The incompatibility of certain national requirements between EU Member States in conjunction with long life cycles results in market fragmentation, and greater complexity in introducing new functions in a coordinated way, while causing largely an escalation of costs. Rail must move to one European network with stronger implementation of the objective of having an increasingly integrated Single European Rail Area (SERA) - and be more flexible to introduce and scale up new technological and operational solutions to deliver new and improved client-oriented services.
Interaction with other modes Rail networks and the services associated to them in some contexts link well with other transport modes. But such integration must be improved to better serve the needs of customers, and make rail central to future mobility and a more attractive mode overall.
Increased competitiveness The European rail supply industry is world leading. However, it faces many challenges at global level. Innovative solutions, conceived, designed, and developed jointly creating new products to be deployed at European level will strengthen the competitiveness of the European rail supply industry, including its SMEs, providing major opportunities for system integrated solutions to be deployed at global level.

3 The ambitious objectives for Europe's Rail

3.1 Objectives

The objectives of EU-Rail have been set to address the EU policy objectives, rail sector vision, and the challenges inherent to the transformation of the rail system as set out in the previous chapter.

The general objectives for EU Rail in the Single Basic Act are[10]:

(a) contribute towards the achievement of the Single European Railway Area;

(b) ensure a fast transition to more attractive, user-friendly, competitive, affordable, easy to maintain, efficient and sustainable European rail system, integrated into the wider mobility system.

(c) support the development of a strong and globally competitive European rail industry.

The specific objectives of the partnership are to[11]:

(a) facilitate research and innovation activities to deliver an integrated European railway network by design, eliminating barriers to interoperability and providing solutions for full integration, covering traffic management, vehicles, infrastructure also including integration with national gauges, such as 1520, 1000 or 1668 mm railway, and services, and providing the best answer to the needs of passengers and businesses, accelerating uptake of innovative solutions to support the Single European Railway Area, while increasing capacity and reliability and decreasing costs of railway transport;

(b) deliver a sustainable and resilient rail system: by developing a zero-emission, silent rail system and climate resilient infrastructure, applying circular economy to the rail sector, piloting the use of innovative processes, technologies, designs and materials in the full life-cycle of rail systems and developing other innovative solutions to guided surface transport;

(c) develop through its System Pillar a unified operational concept and a functional, safe and secure system architecture, with due consideration of cyber-security aspects, focused on the European railway network to which Directive 2016/797[12] applies, for integrated European rail traffic management, command, control and signalling systems, including automated train operation which shall ensure that research and innovation is targeted on commonly agreed and shared customer requirements and operational needs, and is open to evolution;

(d) facilitate research and innovation activities related to rail freight and intermodal transport services to deliver a competitive green rail freight fully integrated into the logistic value chain, with automation and digitalisation of freight rail at the core;

(e) develop demonstration projects in interested Member States;

[10] Article 85(1) of the Single Basic Act; the objectives, principles and operational objectives of all Joint Undertakings are mentioned in articles 4 and 5 of the same regulation.

[11] Article 85(2) of the Single Basic Act.

[12] Directive 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union.

(f) contribute to the development of a strong and globally competitive European rail industry;

(g) enable, promote and exploit synergies with other Union policies, programmes, initiatives, instruments or funds in order to maximise its impact and added value.

3.2 Impact of EU-Rail

The delivery of the objectives will contribute towards addressing the identified challenges of rail and is expected to produce the following results:

	Meeting evolving customer requirements EU-Rail will support the delivery of much more flexible approaches to planning and traffic management of rail services, and seamless operations, allowing rail to better serve customer needs.
	Improved performance and capacity Through the development of cutting-edge technologies and improved harmonised operational rules designed to be implemented across the whole EU rail system, EU-Rail will help increase capacity and make best use of available assets.
	Reduced costs EU-Rail outputs are expected to help improve the efficiency of the rail system and reduce overall lifecycle costs, including on less used lines.
	More sustainable and resilient transport EU-Rail will contribute to a more sustainable transport and mobility system by enabling an increase in the use of rail services and improving the sustainability and resilience of the rail sector itself.
	Harmonised approach to evolution and greater adaptability EU-Rail will work with the sector in coordinating on a common and interoperable evolution of the system, with a greater level of harmonisation, to support an overall adaptable Single European Rail Area, improving the rate of deployment of new technologies
	Reinforced role for rail in European transport and mobility EU-Rail work will support smart and cost-efficient rail connectivity, key to future sustainable mobility systems, to deliver better services for passengers and freight.
	Improved EU rail supply industry competitiveness Increasing the R&I intensity of the European rail supply industry will enhance its capacity to retain its global leadership. By supporting the transformation of the current rail system into a central transport mode of tomorrow's European mobility, EU-Rail will build unique capabilities in the European rail industry, including its SMEs, supporting its position in global markets.

4 Delivery

4.1 Strategy

With a view to translating the EU-Rail objectives into impactful result-oriented Research and Innovation, five areas of priority for EU-Rail have been determined:

- European rail traffic management and supporting rail's key role in a multimodal transport system
- Digital and automated train operations
- Sustainable and digital assets
- Competitive digital green rail freight
- Smart solutions for low density traffic lines (cost-efficient regional lines)

These priorities will be underpinned by a system view to ensure a harmonised approach to the evolution of the Single European Rail Area.

EU-Rail will also work on forward-looking activities, integrating disruptive technologies and thinking, through performing exploratory research to accelerate the pace towards game-changing system innovations.

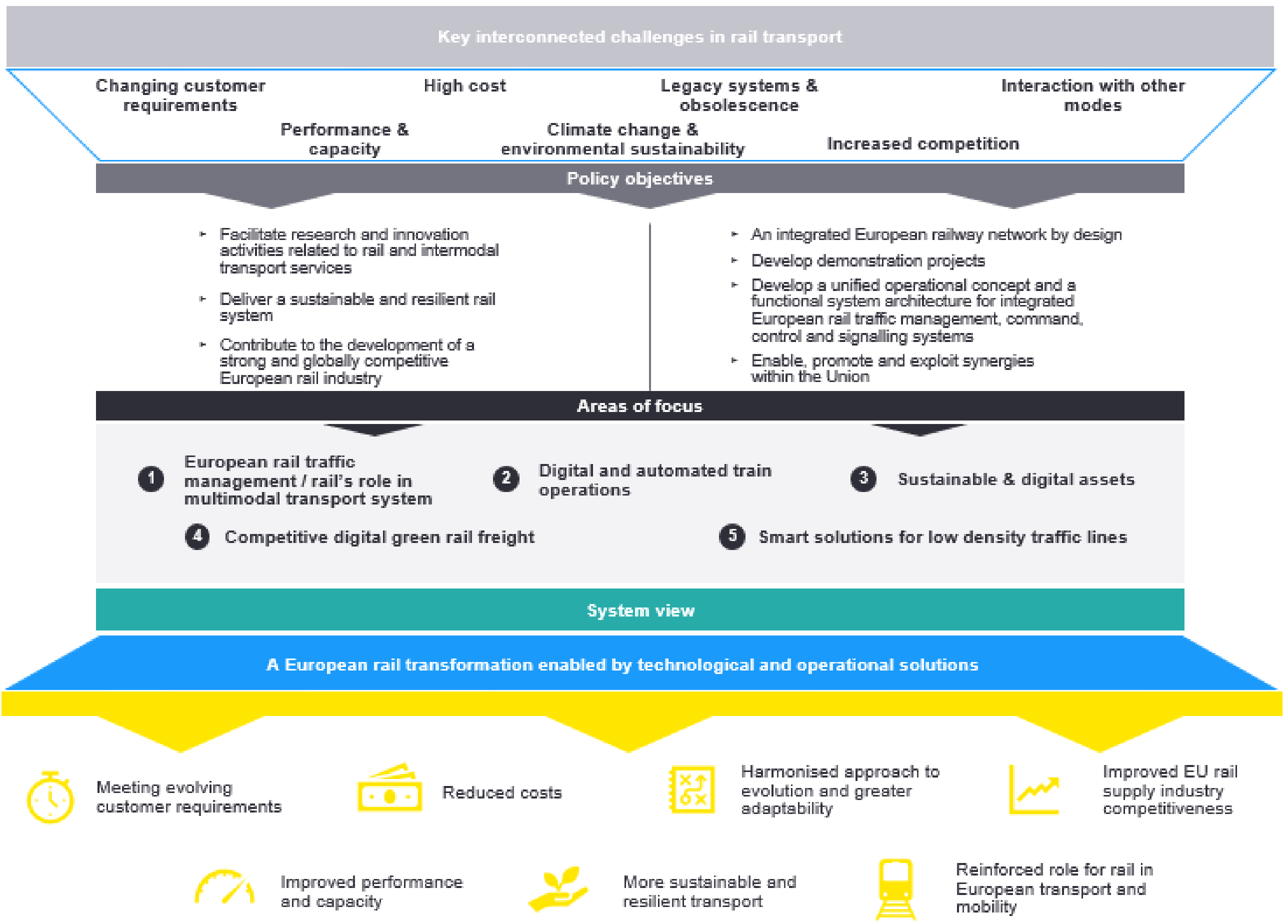

Figure 1 - EU Rail delivery strategy

4.1.1 The system view

Starting from the building blocks and technology enablers delivered by S2R, EU-Rail is adopting a system view to deliver a future-proof, safe and reliable interoperable European railway system[13], integrated with other transport modes.

Despite advances on the harmonisation of certain critical interfaces, railways across Europe do not operate in the same manner and use a variety of technical systems, which are neither integrated nor interoperable.

Innovations to the European rail system are often bespoke and country or system specific; thus slow to deploy and costly. At the same time, the market potential and the return on investment are limited. This is in contrast to other modes or sectors, where a higher degree of harmonised and coordinated deployment has been achieved.

Ultimately, this fragmentation of the rail sector undermines the performance and competitiveness of the European rail system as well as of the European railway supply industry in global markets.

The purpose of reinforcing the system view within EU-Rail is to provide governance, resources, and outputs to allow the sector to coordinate and converge on the evolution of the system through:

- Defining the fundamental design principles and a layered functional architecture for rail as a system (as has been used for decades in many industries such as aviation, defence, energy, and telecoms).
- Harmonising this system architecture approach at European level, including standardisation of interfaces, communications and data exchange.
- Considering the migration path from current systems to the future system.
- Ensuring that the long-term system view can be reflected in a predictable regulatory framework, while modularity ensures the necessary flexibility to innovate.

The system view aims to mirror best practice from other complex fields in order to simplify and speed up the introduction of innovation into the railway system, supporting improvements to interoperability, capacity, productivity and quality of rail operations and business.

This work does not start from zero. Valuable initiatives, both within the current S2R and outside, address the evolution of the rail system, and fundamental design principles of open network architectures and standardised interfaces have already emerged.

To be successful, this effort needs to be complemented and supported by regulation to move away from specific national solutions, to facilitate harmonised solutions avoiding specific and separate national assessments of technical compatibility and safety.

The business case for such changes also needs to be justified.

The system view will underpin the overall work of EU-Rail.

[13] As per the Single Basic Act, the System Pillar will focus on the European railway network to which Directive (EU) 2016/797 of the European Parliament and of the Council (39) applies

4.1.2 The priorities of EU-Rail

4.1.2.1 *European Rail Traffic Management and supporting rail's key role in a multimodal transport system*

Contributes to the following expected impact:

Meeting evolving customer requirements	More sustainable and resilient transport	Harmonised approach to evolution and greater adaptability	Reinforced role for rail in European transport and mobility	Improved EU rail supply industry competitiveness

With the mobility landscape changing quickly, the railway sector has to address the evolving needs of end-users and citizens.

Rail customers require more flexibility and door-to-door mobility solutions.

Rail needs to move away from only defining services with a very long planning horizon to include also a much more dynamic approach, attuned to the needs of passengers and freight customers, and able to quickly adapt to local or short-term issues and demand changes.

Thanks to advances in digitalisation, artificial intelligence and automation, the rail sector has the opportunity to transform itself to deliver truly customer-centric services, where mobility solutions fulfil passenger and logistic expectations and create immediate customer satisfaction.

We have today the opportunity to be ambitious in the planning and execution of a harmonised approach to European rail traffic management, supporting a multimodal mobility system.

The immediate challenge for the European railway system is to increase its traffic management flexibility so that it can offer services that accommodate increased traffic on a seamless cross-border network.

The ultimate aim is to have a unified dynamic network and traffic management at European scale, built upon a harmonised functional system architecture to ensure agile, borderless and mixed-traffic operations.

EU-Rail will support the shift from long-term service planning towards a dynamic system by developing the solution towards a European dynamic capacity planning and management and traffic management system through, inter alia:

- Delivering the new generation of European rail traffic management, leveraging existing systems, to achieve dynamic capacity management, and improved performance and cost-efficiency. This should include harmonised rail traffic management processes and methods with decision support and automation over the planning and control aspects of network management.
- Supporting the development of advanced transformational digital capabilities such as the digital twin.

- Ensuring the resilience, performance and flexibility of the connected rail network by improving its management capabilities, such as real-time connections and interaction between relevant resources and actors or incorporating new functional improvements such as automatic train operation (ATO).
- Improving predictability and punctuality of the rail services through a real-time management of the network in term of planning, scheduling, live operations and maintenance.
- Ensuring that rail assets are used at their optimum capacity in combination with other transport modes

In addition, the EU-Rail work will contribute to:

- Developing a long-term demand forecast, in addition to real time demand forecasting, for the rail and the connected transport modes, to develop a rail system reactive to demand.
- Offering reliable services at interconnection, accessible for all passengers alike, serving end-users needs, and enabling an increase in the use of rail transport.
- Defining the interfaces to other transport modes to support the centrality of rail to future transport and mobility systems.
- Improving high speed rail by the activities listed above in particular the ones that improve punctuality and predictability, as well as improve demand forecasts.

4.1.2.2 Digital and Automated Train Operations

Contributes to the following expected impact:

Meeting evolving customer requirements	Improved performance and capacity	Reduced costs	Harmonised approach to evolution and greater adaptability	Reinforced role for rail in European transport and mobility	Improved EU rail supply industry competitive-ness

Improving the performance of rail is central to strengthening the role of rail in the European transport system, and in supporting European competitiveness.

However, legacy operational rules and systems result in operators facing barriers in improving train operations and in infrastructure managers facing barriers in offering increased and dynamic capacity of train lines; in many areas the rail network is substantially under-exploited.

Cutting edge technologies need to be developed for rail and quickly implemented to allow rail to become more competitive.

This requires R&I to be done in the framework of a system view, to allow flexible upgrading of the system in a rapid, harmonised, formalised and interoperable manner.

Automation and digitalisation are at the heart of this approach. ATO inclusion in ERTMS, will drive significant system capacity, punctuality, safety, resilience, flexibility, reduced operating costs and energy consumption of the rail network. ATO is only the most visible result of a series of technologically and operationally harmonised solutions that need to be put it in place to achieve it, including, for example, on-board localisation, on-board train integrity, new telecommunications, moving block, and Digital Automated Coupling (DAC).

Such approaches will revolutionise the way in, which trains operate, by making it possible to accommodate more trains on the same infrastructure, thus managing better performances in high density traffic networks area (in particular mixed traffic operation) and offering more flexibility in less congested areas.

EU-Rail will drive the shift towards the rapid development and implementation of digital and automated train operations by:

- Delivering an adaptable and scalable trackside and on-board extended Command, Control and Signalling system architecture (CCS+), based on radio-based ERTMS, representing the next evolution of the system and incorporating the latest technological advances, including advanced positioning technologies. This will be a major transformation of rail operations, and also a steppingstone setting the basis for future evolution(s) of the system.
- Delivering scalable automation in train operations, for example up to Grade of Automation 4 (GoA4), meaning that the rail system is ready for fully unattended train operations including setting a train in motion, driving and stopping the train, opening and closing the doors, remote train controlling and recovery operations as well as in the event of disruptions.
- Both developments of CCS+ and automated train operations up to GoA4 will substantially enhance the performance of high speed train network and its operations in the EU.

4.1.2.3 Sustainable and Digital Assets

Contributes to the following expected impact:

Meeting evolving customer requirements	Improved performance and capacity	Reduced costs	More sustainable and resilient transport	Improved EU rail supply industry competitiveness

Rail is the most sustainable mode of motorised transport, yet it can still improve its own and contribute to the whole transportation system's reaching climate neutrality. The energy efficiency and environmental performance of the rail system must be continuously improved both to reduce its environmental impact and to mitigate rising environmental and energy costs.

Railways also need to reduce total life cycle costs, including in particular operational costs and this should result in improved affordability to customers. A holistic approach to building, maintaining and monitoring rolling stock – e.g., common platforms for different type of services – and infrastructure assets as one European system can optimise railway operations and reduce both construction and maintenance costs.

Given expected increases in demand for rail and the occurrence of adverse situations, such as natural disasters, pandemics, or cyber-attacks, the system needs to be rendered more resilient overall.

Given that such challenges are often faced across national borders, a European approach is needed.

Developing such innovative solutions at European level increases efficiency through economies of scale and facilitates the reuse of assets in many locations across the Union.

Realising these changes will make the rail system a fundamental contributor to meeting the European societal objective of sustainable, resilient, accessible and affordable transport services for individual citizens and businesses.

To support this approach, EU-Rail will provide:

- in synergy with other partnerships, solutions to reduce the environmental footprint and increase accessibility of the rail system, for example:
    - Provide alternatives to diesel and other fossil fuels (e.g., hydrogen or battery powered trains).
    - Integrate better the energy from renewable sources,, which are less stable compared to conventional sources and require equipment to stabilise the energy supply.
    - Further optimise energy consumption by integration of energy storage systems and better integration with smart grid: more energy efficient stations, trains and infrastructure.
    - Various solutions to reduce noise and vibration emissions.
    - Increasing resources efficiency, recyclability and recycled material, having in mind circular economy principles.
    - Develop electro-mechanical components to reduce energy consumption, lower emissions, and lower noise and vibrations levels.
- Solutions to increase the resilience of the rail system:
    - Analysis of risks rail assets face due to adverse climate events, new safety or cyber-security threats; analysis of the cost-efficiency of possible counter-measures, providing most-appropriate counter-measures, and, if missing, developing such counter-measures for existing and new rail assets.
    - Operational methods and their implementation managing extreme climate events, including for redirecting and re-planning rail traffic (in cooperation with the traffic management priority).
- Open and common innovative solutions (methods, products and services) based on modular leading-edge technologies to minimise asset life-cycle costs and, where appropriate, either to extending the life cycle while meeting safety requirements and improving capacity and reliability, or replacing assets designed having the circular economy principles in mind. This will rely among others on digitalisation and on the common use of shared data.
- Modular concepts for stations.
- Non-invasive and unmanned technologies to monitor and inspect rail assets, and other technologies to automate maintenance, thereby reducing life-cycle costs and possible traffic disruptions as part of a cost-effective asset management.
- Automation of construction and interventions to improve working and health conditions, reducing costs and increasing quality and consistency of the results.
- Introduction of new industrial production methods, such as additive manufacturing, for the environmental production of new assets as well as a possible repair techniques for existing assets extending the lifecycle of assets.
- The improved production, maintenance and intervention methods will also contribute to a European high-speed network.
- Solutions and associated standards relative to the air-circulation inside the trains to minimise risks of cross contamination for passengers.

These innovative solutions should stem from R&I work whose results will be scalable and deployable on the European rail network, including in relation to existing assets where economically viable.

4.1.2.4 Competitive digital green rail freight

Contributes to the following expected impact:

Meeting evolving customer requirements	Improved performance and capacity	Reduced costs	More sustainable and resilient transport	Reinforced role for rail in European transport and mobility	Improved EU rail supply industry competitiveness

Rail is competing with other transport and mobility solutions for customers. Competition will most likely intensify under the effects of the implementation of new technologies and digital solutions, such as autonomous electrified road transport.

Rail freight currently lacks flexibility, productivity, seamless operations and often hinders the exploitation of available capacity of current networks also due to its different speed compared to passenger services.

Rail will be able to attract existing and future freight customers through improved services. This requires new technologies to reduce costs, facilitate planning, access to (new) services, increase average speed (by optimising planning and operations and increasing maximum speed of trains) and improve reliability.

There is a need for 24/7 dynamic capacity management and eliminating cross-border barriers between infrastructure managers and railway undertakings. These improvements must be complemented by the deployment of new operational and technological solutions, considering those already indicated by the Rail Freight Forward initiative and liaising with the logistic value chain principles (e.g., with ALICE [14]).

EU-Rail will support rail freight by:

- Developing and integrating new operational and technological solutions (such as service automation, particularly based on the introduction of a European digital automatic coupler), including adapted logistics process and customer relations. Such solutions will be applied to existing assets where economically viable to speed up deployment. This will shorten average transportation time as well as improve reliability, the level of exploitation of existing rail infrastructure and operational functions and processes. The result will lead to more attractive and cost-efficient rail freight.

[14] ALICE is a European Technology Platform set-up to develop a comprehensive strategy for research, innovation and market deployment of logistics and supply chain management innovation in Europe

- Fully digitalising operations, planning and management functions as well as delivering specific solutions for integrated rail cargo systems, including connected digital services (e.g., capacity and yield management, multimodality with predictive Planned Time of Arrival, load and empty flows equilibrium) and terminal improvements that drive innovation in customer interactions: the objective is to ensure rail is integrated in the logistics value chain, feeding into logistic information exchange systems. This should considerably increase productivity (including shortening the average transportation time and increasing capacity utilisation), reliability and flexibility of rail freight.
- Delivering innovative solutions to minimise energy consumption, noise emission and associated environmental footprint for the rolling stock and infrastructure, building upon the work done in different priority areas and in synergy with other partnerships.

4.1.2.5 Smart solutions for low density traffic lines (cost-efficient regional lines)

Contributes to the following expected impact:

Meeting evolving customer requirements	Reduced costs	More sustainable and resilient transport	Reinforced role for rail in European transport and mobility	Improved EU industry supply industry competitiveness

Achieving the milestones of the Sustainable and Smart Mobility Strategy (SSMS) for rail transport requires a transformation not only of the Trans European Network, but across the whole rail network.

Lower usage lines or secondary network lines play a crucial role not only in serving Europe´s regions, but also as feeder lines for passenger and freight traffic for the core and comprehensive network.

They have an essential function of enabling more sustainable local and regional transport, by connecting other public transport services and first and last mile services, for both passenger and freight transport. These lines support social cohesion and inclusiveness by providing public transport and facilitating the functioning of businesses in more remote areas.

Despite this, services that could use lower use or regional lines are currently often replaced by other less environmentally-sustainable and socially-inclusive modes of transport, while the rail infrastructure remains underutilised.

A coherent, unified, interoperable solution for operations of those lines in conjunction with the rest of the European network and with other modes of transport is needed. This will enable achieving economies of scale and lowering costs, as well as creating seamless links across the whole transport infrastructure.

Solutions for innovative rail services to strengthen or revitalise these lines are needed through providing technological and operational solutions interoperable with those used on main lines, but at a viable cost. This will require making use of advanced technologies and updated operational methods, which may also result in providing new opportunities for scaling them up at the network level or for targeted uses beyond the regional lines.

Ultimately, a paradigm shift is needed in the approach to both rail infrastructure (zero- or low-cost trackside signalling) and rolling stock solutions (self-powered sustainable vehicles) that may service, also on demand, passengers and freight in those areas.

Achieving this result requires a coordinated collaboration of all railway actors. An economically self-sustainable, integrated, interoperable, flexible (up to on-demand) railway system needs to be created, migrated and operated to be effective in different business scenarios.

This area is expected to deliver:

- New operational concepts, where appropriate (including more flexible operation up to ad hoc on demand services) taking into account human resources related challenges.
- Suitable and appropriate system architecture (with appropriate functionality and lower life cycle cost) harmonised at European level
- Cost efficient performant control and command system (ERTMS-based)
- Optimised railways assets – leading to a significant reduction of existing signalling equipment and to lower infrastructure life-cycle cost
- Sustainable Rolling Stock (light, cost-efficient, modular, flexible, accessible, zero-emission and designed taking into account circular economy principles)
- Suitable customer services (adapted passenger information systems following also 'design for all' principles, congestion management, ad-hoc on-demand services, improved availability of internet connectivity on-board)

4.2 Implementation

In order to deliver its objectives and strategy, EU-Rail will be set-up around one single Research and Innovation Programme based on a system view.

This will be delivered by two integrated pillars and complemented by a Deployment Coordination Group, all together covering the full life cycle of R&I from blue sky to pre-deployment and pre-industrialisation processes.

The System Pillar will provide governance, resource, and outputs to support a coherent and coordinated approach to the evolution of the rail system and the development of the system view, based on a formal functional system architecture approach to speed innovation and deployment. The System Pillar brings rail sector representatives under a single coordination body.

The Innovation Pillar is set up to deliver user-focused research, innovation and large-scale demonstrations.

Continuous exchange will happen between the System Pillar and Innovation Pillar activities as part of the Integrated R&I Programme, with a bi-directional flow: both pillars should provide input and output to each other against a clearly defined series of priorities and objectives to be achieved. A clear framework for interaction and flexibility will be required to enable the respective pillars to adjust and update based on the outputs of the other.

EU-Rail will build upon Shift2Rail (S2R) results with the aim to reach higher technology readiness levels and offer solutions that are ready to deploy. A number of S2R results will be particularly important: the digital automatic coupler on which numerous automation services will be based or the developments of ERTMS and related automated train operations capabilities, which will allow the development of more advanced command, control and signalling systems and fully automated trains. The Multi-Annual Work Plan provides details on how each of the priority areas will rely on S2R results.

Moreover, EU-Rail will foster a close cooperation and ensure coordination with related European, national and international research and innovation activities in the rail sector and beyond as necessary, in particular under Horizon Europe, Connecting Europe, and the Digital Agenda. The regional dimension will be a priority to ensure that EU-Rail will deliver services to connect European regions in an integrated network approach.

EU-Rail will play a major role in both applied innovation but also in exploratory research, pushing the boundaries of the current system and paradigms, and benefiting from scientific and technological advances in other sectors as well.

4.2.1 System Pillar

4.2.1.1 The System Pillar to achieve a modern harmonised interoperable European railway system

As set out in the Single Basic Act, EU-Rail will develop in its System Pillar a system view that reflects the needs of the rail manufacturing industry, the rail operating community, Infrastructure Managers, Member States and other rail private and public stakeholders, including bodies representing customers, such as passengers, freight forwarders, and staff, as well as and relevant actors outside the traditional rail sector. This will be reflected in the System Pillar governance, through the System Pillar Steering Group.

The ‘system view’ shall encompass, as defined in Article 86 of the Single Basic Act:

(a) the development of the operational concept and system architecture, including the definition of the services, functional blocks, and interfaces, which form the basis of rail system operations;

(b) the development of associated specifications including interfaces, functional requirement specifications and system requirement specifications to feed into Technical Specifications for Interoperability (TSI) established pursuant to Directive (EU) 2016/797 of the European Parliament and of the Council[15] or standardisation processes to lead to higher levels of digitalisation and automation;

(c) ensuring the system is maintained, error-corrected and able to adapt over time and ensure migration considerations from current architectures;

(d) ensuring that the necessary interfaces with other modes, as well as with metro and trams or light rail systems, are assessed and demonstrated, in particular for freight and passenger flows.

A successful System Pillar will:

- Make the most efficient use of scarce resources (EU and Member States, rail sector, both financial and human capital), coordinating and consolidating initiatives under one umbrella.
- Align public and private EU Research and Innovation initiatives with a long-term operational concept and system architecture, supporting interoperability, and to the legal and regulatory framework, to ensure a strategic plan for an overall harmonised approach.

[15] Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union (OJ L 138, 26.5.2016, p. 44).

To deliver this, the System Pillar will be based around two tasks, the whole EU rail system (as defined in Directive (EU) 2016/797) and a deeper focus on the Control-Command and Signalling and associated subsystems.

4.2.1.2 System Pillar Task 1: EU rail system

The European railway system is an open, shared, dynamic structure composed of assets that are either fixed in space or mobile, and that are owned and managed by a range of different actors. Geographic position, speed and operational conditions of mobile assets matter. Mobile assets have either local interaction with fixed assets, and/or through a wide-area communications network. Both types of assets can be connected to a control network for operations and maintenance.

The System Pillar Task 1 will develop a functional system architecture and operating concept for the full rail system based on SERA principles i.e., no technical and operational boundaries for trains, standardisation (allowing economies of scale), safety (including learning from information sharing) and resilience.

The target architecture(s) will consider the optimal level of technical and safety harmonisation building on cutting-edge technologies, with due consideration of cyber security aspects, to facilitate, improve and develop railway services within the Union, and with third countries, to contribute to the completion of the SERA. Interoperability must be achieved, and safety maintained.

Consistency with the definitions in the Interoperability Directive, in particular the various Subsystems and Interoperability Constituents, need to be considered. However, these definitions may evolve, if necessary, based on the results delivered by Europe’s Rail.

The scope of Task 1 should not be time-bound, and can consider several iterations of development i.e., it should be ambitious and flexible to take into account the impact of new technologies and processes with regards to rail (e.g., from the Innovation Pillar), which may require a substantial revision of, inter alia, safety concepts and the regulatory framework underpinning operations.

The Task 1 deliverables will be:

- As-is analysis of the railway system
    - The analysis of the current railway system architecture will be to identify the pain points, including safety considerations, of the system with respect to the existing operational, functional, logical & physical assets deployed in Europe and the work force associated to deliver it.
- Concept of operations of the railway system
    - The outcome of this subtask aims for future concepts for the operation of EU railways that in parallel with rail system architectures will guide technological solutions needs as well as the development of specifications and standards.
- Target functional system architecture of the railway system
    - The architecture developed within this subtask will include the mapping with the regulatory basis and subsystems, modularity and interface specifications.
- Railway system architecture migration roadmap
    - With the target system defined and taking into consideration the as-is analysis of the railway system, a high-level migration roadmap will be delivered.

4.2.1.3 System Pillar Task 2: CCS+

The regulation and implementation of European rail control-command and signalling (CCS) is of central importance in the running of safe, efficient, and reliable rail service in Europe.

CCS deals with all the on-board and trackside equipment required to ensure safety and to command-and-control movements of trains authorised to travel on the network.

The current harmonisation at European level, through the CCS TSI, addresses the safety and interoperability requirements, the on-board functions and the interfaces between trackside and on-board related to train protection, signalling the permission to move the train and radio communication - ERTMS. This is not the full CCS system, which also includes interlockings, radio block centres, and other infrastructure and on-board assets.

The aim of the System Pillar Task 2 is to:

- Develop the operational concept(s) and functional system architecture for the full CCS system and associated subsystems including Traffic Management and Operations – hence CCS+.
- Incorporate important advances such as ATO GoA4, Digital Automated Coupling, and enhanced positioning (including use of satellite positioning), based on the evolution of the communication system FRMCS..
- Include a sector-wide harmonised approach towards the linked digital architecture and digital enablers like digital twins and virtual certification.

The purpose of the focus on CCS+ is to take advantage of the fact that networks and Member States are migrating to CCS systems of radio-based ERTMS. There is therefore the opportunity through the migration to move to much more harmonised wider CCS+ European system, beyond the scope currently harmonised in TSIs.

Success in such an approach would significantly reduce the fragmentation currently observed in CCS+ systems beyond ERTMS, increasing the opportunity for more open and competitive markets across Europe, and speeding the deployment of innovation across the system.

The architecture – both on-board and trackside – shall be based on a functional modular system architecture using standardised interfaces.

The software and hardware installed on board or trackside should be operated and maintained following principles and standards as used in the IT or industrial automation domain: regular, scheduled updates with pre-tested configurations ensuring errors and shortcomings are eliminated, maintaining all the products and system throughout the EU in line with interoperability and safety specifications, with manageable upgrade mechanisms. This would be a major step forward from the current situation, where updates are time consuming and costly.

In order to preserve investments, the System Pillar should not only create adequate interfaces but also address migration feasibility (i.e. clear and affordable transition steps, taking into account all stakeholders) and find paths for moving beyond the current system with proprietary interfaces to allow modularity of components.

The detailed Task 2 deliverables will include:

- As-is CCS+ analysis
  - Existing operational, functional, logical & physical assets for CCS+ deployed in Europe will be analysed from a pain point perspective, including safety, security, robustness and Human and Operational factor considerations.

- CCS+ concept of operations
  - The focus shall be on the development of the operational concept based on cab signalling and radio-based ERTMS-only networks with broad harmonisation of safety, security and operational principles,, which is key to achieve generic subsystems and phase out national requirements. This aspect also considers human factors of railway staff (drivers) operating across borders allowing common training and licensing requirements for future cross-border operations.
  - The ambition is high in order to reach harmonisation of operations based on the simplification provided by radio based ERTMS. Hence, processes, security and safety considerations both for nominal but also degraded operation will be unified, allowing that unique operational and engineering requirements are set to CCS+ systems and products. For example, harmonisation of basic interlocking rules or traffic management.
- Target CCS+ system architecture
  - The functional, logical and physical target architecture for CCS+ will be developed.
  - Initial deliverables will include concept papers and models and will be complemented by the railway data structure and semantic rules.
  - The deliverables for architecture and data will be completed with the relevant models for degraded modes. These models are expected to include the necessary requirements related to degraded situations that will need to be incorporated to the system requirements and interface specifications mentioned before.
  - The necessary system requirements and interface specifications will be delivered together with the Innovation Pillar
  - Distinct sub tasks will include:
    - On-board CCS+
    - Trackside CCS+
    - Manage rail terminals

4.2.1.4 The System Pillar as the pathway to standardisation and regulation

A central task of the System Pillar is not only to define the target system architecture and operational concept, but also coordinate and deliver the sector inputs to Technical Specifications for Interoperability and harmonised standards.

To provide a strategic overview of the TSI and standardisation outputs produced by EU-Rail, the System Pillar will develop a strategic Standardisation and TSI Input Plan, in consultation with ERA, and subject to endorsement by the Commission.

This plan will also be made on the basis of migration considerations and alignment with Innovation Pillar flagship projects.

This will enable a strategic view on the regulatory and standardisation changes planned from the EU-Rail outputs through:

- An agreed plan and timeline for the evolution of the CCS+ system, consistent with the agreed operational concept and system architecture
- High quality input to TSI and their updates, ensuring the rapid deployment of new technologies based on proven solutions.
- A clear picture of the role of the EU-Rail in delivery of inputs to standards and regulations, including the allocation of those elements that will be delivered by the Innovation Pillar, and the System Pillar.

4.2.2 Innovation Pillar

The Innovation Pillar activities of Europe's Rail are designed to cover all necessary stages of the innovation cycle, ranging from low to high TRLs and targeting large-scale integrated demonstrations.

The research areas that are addressed should be relevant as of and up to 20 years from now: this requires going well beyond the current system to ensure rail is ready to embrace the future challenges.

The Innovation Pillar will be working on the priorities identified in section 4.1 of this Master Plan, and will be based on and support when relevant the system view.

The Multi-Annual Work Plan, through setting out flagship areas, will define in detail the activities to be carried out to deliver the Master Plan priorities. The flagship areas will comprise one or more flagship projects,, which are an integrated set of R&I activities designed to achieve a system impact and measured with one or more TRL7-9 demonstrator. Successful demonstrators and technologies can be used in large scale demonstrations around Europe, with the aim of testing scalability and preparing the ground for large deployment activities.

The Multi-Annual Work Plans will be adopted by the Governing Board on a proposal of the Executive Director and amended as needed during the life of the JU.

The work of the Innovation Pillar will take into account the System Pillar, and, where justified, adjust as a consequence of system architecture activities.

Beyond a more structured and focused Programme, research and innovation requires the continuous scouting of new and disruptive ideas that would help accelerating the transformation of rail, while keeping in mind its integrated system nature. In this respect, the EU-Rail programme will integrate exploratory research activities, including concepts that have the potential to challenge the traditional rail approach, including those that break from current practices and those that enable behaviour and organisational changes.

4.2.2.1 European Rail Traffic Management and supporting rail's key role in a multimodal transport system

The tasks of the Innovation Pillar on European Rail Traffic Management and supporting rail's key role in a multimodal transport system will build on several S2R R&I activities on traffic management, smart planning, integrated management of passenger flows and IT solutions for integrated railway services.

In S2R, traffic control related developments have focused on the usage of the Conceptual Data Model (CDM) to connect national traffic management systems with other business service applications, and with validations in relevant environment with connected Driver Advisory System (linked with ATO), Conflict Prediction systems, conflict detection, and field status information with different modules.

Additionally, prototypes were developed related to freight application, for different exchanges between TMS and freight operation for example on rolling stock information and crew management. First pilots were implemented regarding the interaction with yards (e.g., video gates and decision support).

EU-Rail JU will widen the scope from planning to operation, with a higher ambition to achieve European-wide traffic management and strengthening the role of rail as a central component of door-to-door multimodal transport.

Development of European dynamic capacity management and traffic management systems

The aim is to develop a European approach on dynamic capacity and traffic management, which can manage in real-time the networks in terms of planning, scheduling, live operations and maintenance purposes on a European scale.

Some demonstrators are planned for 2025, with extended functionalities and geographical scope by 2029/31.

This will encompass, *inter alia*:

- Definition of a functional system and tools for strategic, tactical and short-term planning taking into account high level principles traffic management principles and functional requirements defined in cooperation with the System Pillar.
- Specifications and developments of planning and operational tools and associated interfaces
- Solutions for improved strategic and tactical planning including cross border scheduling.
- Harmonised methods for capacity planning with intelligent functions with optimisation and simulation support.
- Tactical and short-term timetable and offer planning with improved models and functions.
- Use of simulation including capabilities and best practices needed for future planning and TMS modules.
- Dynamic timetables and disruption management, based on real-time infrastructure availability/status/condition, power supply capacity, rolling stock capacity, passenger flows, forecasts and crowd management.
- Decision support to help capacity planning and operations of rail network, nodes, yards and stations, and improve connection to industry sidings and ports, as well as interaction with other rail networks.
- Demonstrations of decision support and interaction between actors handling maintenance and failure risks for rolling stock and infrastructure in real time.
- Demonstrations of decision support and real time traffic plan, nodes and network, with feedback loops from planning to operation
- Demonstrations of real-time effects of ATO and ERTMS potential and effects

Planning and operational management will be interconnected with all relevant resources impacting the rail traffic (e.g., rolling stock, crew, shunting yard resources) and will integrate components improving network performance, flexibility, energy optimisation, and resource utilisation.

This approach will smoothly connect the network to international corridors, to stations and yards.

Traffic management will be enhanced by more automated methods and functions for train prediction, conflict resolutions and decision support based on a full set of real-time information from all systems, enabling an improved dispatching and incident management.

The System Pillar will address extensively the CCS+ interfaces, and will develop interoperability principles of the CCS+ data models as well as developing the traffic management principles, and functional requirements for the overall system with input and close collaboration from the Innovation Pillar. The Innovation Pillar will develop the specifications and the required innovations.

Supporting rail's key role in a multimodal transport system

The work on rail traffic management will strengthen the role of rail in future mobility systems. This will encompass, inter alia:

- Developing a rail system reactive to demand building upon demand forecast, long term and real time multimodal transport system. The methods to achieve these goals are based on big-data sources, real-time processing and new models such as activity based and AI-based.
- Developing reliable services at interconnection, accessible for all passengers alike, serving end-users needs (based on "user driven" innovation principles), and enabling an increase in the use of rail transport.
- Continuous processing of prediction within the digital twin to check KPI and the adjustment of current offer
- Simulating alternatives complemented by other modes of transportation
- Improving event and disruption management based on big-data sources, advanced analytics and real-time processing. AI-based decision-making tools will help identifying the best use of capacity.

The System pillar will address the interfaces between the railway system and other modes of transport, developing functional requirements on expected mobility resources that could match multimodal demand. The Innovation Pillar will develop the technical specifications and the required innovations.

4.2.2.2 Digital & Automated Train Operations

The tasks of the Innovation Pillar will build on and extend the R&I from S2R.

Research and Innovation in S2R focused on ATO over ETCS, with high TRL demonstrations outputs on GoA2 in both mainline and freight conditions and reaching validations for GoA3/4 on pilot lines, with high TRL demonstrations to validate the capabilities of FRMCS specifications from high-speed to freight environments.

Other related work included:

- Demonstrations on absolute train positioning with use of additional new sensors and digital maps.
- High-TRL demonstrations on train on-board integrity with wired on-board communication on low-density traffic lines and with wireless on-board communication in case of freight and regional lines (incl. energy harvesting solutions to power the wireless devices).
- Experiments on virtual coupling technologies, and high TRL demonstrations outputs for on-board functional architecture with a safe train communication network for TCMS and wireless train-to-train communication.
- Demonstration results from new braking and adhesion management systems and integration of SIL3/4 solutions for brake control.
- Demonstration on obstacle and lateral signalling detection technologies, to support the introduction of autonomous operations
- Demonstration and validation of 5G network sharing solutions, encompassing passive and/or active network infrastructure elements deployed with the support of CEF, for the provision of dedicated connectivity supporting both FRMCS and Gigabit Train services.

A scalable and adaptable trackside and on-board CCS+ system

The harmonised evolution of the rail system must be comprehensive, modular, and scalable.

The aim is to develop the detailed specifications and detailed interface specifications for the evolution of the CCS+ system consistent with Task 2 of the System Pillar to allow a system that:

- Can interface and optimise traffic management.
- Be easily adaptable to allow new functionalities to be introduced
- Reflects the next evolution of the CCS system incorporating known functionalities to improve the system overall.

Based on the functional architecture and operational concept developed in Task 2 of the System Pillar, the Innovation Pillar will develop, inter-alia:

- Form Fit Functional Interface Specification (FFFIS) for identified interfaces in the CCS+ trackside architecture.
- Revised FFFIS of the train architecture based on the innovative solutions developed in EU-Rail, in particular the on-board CCS system,
- Solutions that would allow for high-precision localisation, digital topology information and safe absolute near real-time on-board train positioning techniques.
- A FFFIS odometry platform (enhanced train localisation interface between technology independent sensors and the EVC).

Beyond the architectural concepts, the Innovation Pillar will, inter alia, support

- The future radio system. FRMCS, with a common and unified trial platform framework permitting to achieve and validate all the aspects for the finalisation of FRMCS services in view of GSM-R replacement and enhancement, including the testing of the evolutions of ETCS, ATO and TCMS services foreseen all along the duration of EU-Rail.
- The full incorporation of advanced train positioning techniques (including satellite).
- L3 moving block, including required functions such as train integrity.
- The perception and decision-making systems.
- Full consideration of cyber-security related aspects of the system.

Demonstration of fully Automated GoA4

EU-Rail will deliver ATO GoA4 systems to be demonstrated at large scale as from 2025 on different rail transport segments and possibly enter the pipeline of deployment as from 2029/31, subject to the necessary safety and certification procedures.

Current systems do not allow GoA4 and as no significant legacy systems implementation exists for automated nor autonomous train operations, research and development activities can deliver EU harmonised solutions for ATO GoA4 over ETCS.

The automation of railway operation requires full digitalisation of the rail operations combining ERTMS, TMS, route setting, automatic operation and perception systems into one system: Digital ATO.

The execution of this is dependent on many inter-related workflows in EU-Rail:

- The operational concept for Digital ATO both for nominal and degraded operations, and the overall functional system architecture, as defined in the System Pillar.
- Technological enablers (up to GoA4) needed for the Digital ATO innovation concern automatic wake up capability and train preparation, train localisation, cybersecurity, environment perception, connectivity. These have to be implemented with limited

dependency between on-board and trackside, must be interoperable, plug-and-play[16] and developed according to a modular system architecture, facilitating certification and migration.

- To maximise Digital ATO performance, a new generation of brake systems is needed to bring adjustable/configurable emergency brake control, the holding brake function and integrated adhesion management among other enhanced functionalities.
- ATP evolution & optimisation including:
    - New generation safe train positioning, environment perception and wheel/rail adhesion management methods will be developed.
    - Enhanced on-board communication networks, train-to-train and train-to-ground communication allowing for adequate latency, volumes and security of data, as well as a need for safe computing platforms.
- Realisation of the digital twin for virtual validation and certification ensuring the exact virtual replica of real assets.
- In addition, a combination of ETCS L3 full Moving Block and Digital ATO will be key to increase the capacity of railway lines. It is important that innovation on Digital ATO itself is accompanied by innovation on trackside and on-board ATP, for instance in the direction of novel CCS architectures enabling ETCS L3 moving block with minimum infrastructure elements and based on a digital topology, as Digital ATO and ATP can ultimately achieve the envisioned increased system capacity, punctuality, resilience and flexibility if a joint approach is followed.

The Innovation Pillar will deliver:

- Further detailing of the higher-level functional architecture in coordination with System Pillar (for CCS including GoA3/4 system).
- Further specification of general GoA3/4 operational concept in coordination with System Pillar.
- Information exchange protocols between on-board and trackside, especially with the TMS, which is crucial for automated train operation. Furthermore, the overarching automation process (from TMS to Digital ATO and ATP - ETCS and non-ETCS) shall also support end-to-end customer solutions independent from the existing infrastructure to guarantee the automation of the operation over the entire value chain.
- Updated specifications for Digital ATO (in coordination with the System Pillar):
    - System requirements.
    - Requirements for the communication channel.
    - Requirements for diagnose.
    - Communication layers.
    - ATO Interfaces e.g., ATO-ETCS + ATO-TCMS + ATO-trackside.
    - Updated specifications for FRMCS taking into account e.g., new specifications for ATO GoA3/4
- Unique set of engineering rules to deploy the different stages for Digital ATO.
- To complete the idea of the Digital ATO, the overall optimisation of the rail operation including the demand-orientation and network capacity improvement technologies, route setting methodologies and ATP evolution & optimisation (e.g., adhesion related braking optimisation) will also be covered.

[16] Plug&Play means to define the interface in a way that the system can be exchanged, extended and modified independent from the full integration and approval, according to state-of-the-art engineering rules, process and certification required by the safety authority and without any dependency on the initial supplier.

4.2.2.3 Sustainable & Digital Assets

The tasks of the Innovation Pillar will build on the R&I from Shift2Rail on rolling stock and on infrastructure, which included:

- Creating a direct connection with results of asset status nowcasting and forecasting and its integration into the intelligent asset management system.
- Rail infrastructure with innovative assets and optimised frameworks, processes and maintenance strategies.
- Solutions for smart energy management in electrical traction system and at station level.
- Cross cutting activities enabling a concept for a possible standardised smart maintenance approach and a conceptual data model to support and enhance information exchange across Europe.
- High TRL demonstration outputs on new traction systems using advance architecture and silicon carbide for powertrain in all markets applications but freight. The other subsystem with new design and high TRL demonstrations touched comprises train control management system, brakes, running gear, doors and intelligent PRM access systems, carbody shells, interiors and HVAC. Several of these innovations have been accompanied by virtual certification/validation concepts.
- In freight an end-to-end solution has been tested in order to evaluate the possibility of an integrated approach for handling predictive maintenance for locomotives and wagons, although it was limited in its use cases and applicability over Europe.
- Specific process enhancement for monitoring aging assets, like bridges and tunnels, have been prototyped and tested.

Holistic asset integration and a life-cycle framework

Achieving objectives for life-cycle and holistic asset management will require carrying out several tasks.

First, secure information sharing solutions that cover the entire supply chain and the complete asset life-cycle must be developed. Information generated by different technical subsystems must be shared[17] and linked between the traffic management system to improve its functioning. Once the information is shared, a holistic use of this information should be enabled, to increase automated decision making about rail assets. An overall better integration of such data, and its use in Digital Twin applications for prediction, (co-)simulation and analysis, will allow more cost-efficient operation and maintenance of the infrastructure for the whole life span. This can enable accelerated testing delivering benefits especially in the CCS+ domain, by ensuring the same level of performance than on-site testing through digital twin formal validation at a much lower cost.

Second, non-invasive and/or unmanned solutions for automated monitoring, inspection and intervention need to be developed. This is especially needed due to the shortage of skilled human resources and the aging of rail staff, as well as due to the goal to reach higher availability of the railway network for rolling stock operations. The monitoring and inspection should evolve toward non-invasive and self-healing systems (including additive manufacturing) that lead to no or minimal service disruptions and safer conditions for operators. With a similar goal in mind, interventions need to rely on automated and digitised solutions, such as robotics and wearables to increase the safety and efficiency of infrastructure and rolling stock interventions.

[17] Or otherwise made available and accessible to relevant stakeholders

Third, both rolling stock and rail infrastructure need to be designed in a way that is in line with the circular economy principles and supports their optimised maintenance. It will rely amongst others on modular design and additive manufacturing technologies. Rolling stock and infrastructure design should also be oriented towards an improvement of its resilience towards climate change and other extreme natural and man-made hazards. Besides the design of new assets, there is a need to conceive solutions to retrofit the selected existing assets to optimise the maintenance and make them more resilient to various hazards.

For most of these tasks, the technologies are tested and already exist, but EU-Rail needs to further develop these technologies on individual components to adapt it and support the holistic approach in the rail environment.

To ensure the successful achievement of these tasks the Innovation Pillar will deliver:

- Digital and operational solutions to maximise the benefit of also developed digital twins for selected assets; the rail Common Data Model, shared datasets, shared AI, and of accelerated testing.
- Cybersecurity solutions to ensure resilience of the digital solutions.
- Tailor-made maintenance and assistance thanks to life-cycle cost models and processed data, including optimised / predictive / automated stock orders with better information sharing across stakeholders.
- Real-time monitoring and measurements of both infrastructure and rolling stock (including weather conditions) for achieving a smart and more automated management of maintenance operations, including planning. This will rely among other on satellite monitoring or other communication means (e.g., 5G/FRMCS).
- Solutions to automate inspections and interventions using among others advances in robotics, IoT, and augmented reality.
- Methods and tools to design and to refurbish rolling stock and infrastructure to withstand possible natural and man-made risks, and also to optimise maintenance, as well as identify methods and tools to reduce the costs of construction and upgrading of infrastructure.

Zero-emissions, silent, sustainable and accessible rail system

Achieving objectives for a zero-emissions and silent rail system will require carrying out several tasks. First, alternatives to diesel engines are needed for various size and purpose locomotives, trains and inspection vehicles. This will include hydrogen or battery powered vehicles or hybrid solutions using electricity from the catenary, when available, and, when not, relying on batteries or hydrogen.

Second, rail needs to use less energy, and to use it more efficiently. This means integrating more energy from renewable sources, developing smart energy storage to increase autonomy and decrease consumption cutting relative peak and refuelling spots (for both hydrogen and batteries). Energy management technologies and methodologies need to be further developed mainly for the infrastructure, the stations and the rolling stock. In this particular sense, secure information resulting from energy management models must be shared and linked between the traffic management and power supply systems to improve energy efficiency and management. Regarding stations, the aim is to develop a net-zero emissions railway station. Regarding rolling stock, alternative and more sustainable energy solutions need to be developed, and lightweight parts and better aerodynamics of the vehicles need to be researched.

Rail needs to reduce its noise and vibrations impact. It is part of the effort to render rail also neighbour friendly and allowing the further development of rail infrastructure. It supports keeping the attractiveness and acceptance for rail in the society, because rail, as a mass transport mode, needs to be part of densely populated areas.

In a period of potential greater pandemic, the rolling stocks and the associated operations should be better considered in terms flow/circulation of air, persons-vehicles interactions, management of the passenger flows.

Furthermore, railways need to improve its accessibility and attractiveness for all passengers. Accessibility objectives should be precise and ambitious. The final objectives for accessibility are independent (no assistance) and spontaneous access (no pre-notification), including to high- speed trains, tested by users. As another side of accessibility, the connection with other modes needs to be considered, how to combine trains efficiently with other modes including personal mobility devices and new sustainable cargo concepts. The objective for attractiveness concerns quick upgradability of the rolling stock for continuous adaptability. The mobility evolving quicker, the modular interior design based on circular economy principles will allow quicker modifications, facilitated also by the definition of European industrial standards. To ensure the successful achievements of the tasks in relation to a zero-emission, silent and accessible rail system the innovation pillar will deliver:

- "Improved green traction" using hydrogen, other alternative fuels, as well as improved hybrid solutions using these sources of power and when possible classic electricity from the catenary equipped with efficient energy storage systems increasing autonomy while decreasing consumption. This will be complemented with flanking technologies in relation to infrastructure, transportation of fuels and refuelling/recharging and will rely on cooperation with other joint undertakings, namely fuel-cell hydrogen and batt4EU;
- More efficient energy management in a system view but also specifically for stations and vehicles and smarter energy storage, as well as better integration with the smart grid.
- Technology and operational solutions for the rolling stock that can provide more sustainable, accessible (especially for persons with reduced mobility) and attractive services/assets to the final users, passengers and freight forwarders. The development of these solutions will, in particular, take into account user feedback.
- Environmental (including energy) footprint methods and tools, as well as whole life cycle approach, to allow public information, including quantification of the monetary value contributing to public authorities work in this area.
- More environmentally friendly rail assets available quicker relying on new eco-design, new materials, use of digital twins and/or accelerated testing facilities and designed with circular economy principles in mind. This includes the possible re-use of existing assets by improving the recycling potential and practices.
- Solutions of modular stations, which development considers the environment, the mobility and the urbanism.
- Technologies and operational methods to increase the use of greener resources.
- Development of electro-mechanical components and sub-systems (air-conditioning systems, braking systems, bogies…) to improve the eco efficiency of the system, avoiding air use.
- Technologies monitoring and reducing noise and vibrations emitted by rail equipment.
- Definition of adaptation strategies for the resilience to climate change. Relative technologies and operational methods for new and existing rail assets and rail operations.

- Design and technologies for the air quality on-board and the reduction of non-exhaust emissions (wear particles…).

4.2.2.4 Competitive digital green rail freight

The tasks of the Innovation Pillar will build on the R&I from Shift2Rail on different technologies for rail freight operations and assets around fleet Digitalisation and Automation, digital transport management, smart freight wagon and new freight propulsion concepts.

Research and Innovation in Shift2Rail included:

- Telematics and electrification proposing a Digital Automatic Coupling concept, with the delivery of a high TRL demonstration leading to the selection of a European DAC.
- High TRL demonstration for semi-automated freight operation using the ERTMS based ATO.
- Other high TRL activities comprises demonstration around improved terminal operations, for example with the use of intelligent video gate captured information.
- Testing of modular and logistic capable new wagon concepts with telematics/communication solutions.
- Investigation of advanced propulsion system for locomotives.
- Development of distributed power technologies in locomotives using LTE up to an 835m train demonstrator.

Achieving the EU’s ambitions to boost rail transport, including freight, will require solutions to increase average speed and reliability and support a revolutionised interaction with the customer (by digital means), allowing innovative rail freight services to be developed and facilitating the integration of new technologies into intermodal, multimodal and rail freight services.

Such a key new technology is the Digital Automatic Coupler, which is, aside being the mechanical connection of wagons, the platform for many applications for the intelligent freight train. The technology and its applications are fundamental for significant overall increase in attractiveness and cost-efficiency for rail freight, as well as to improve the possibilities of provision of intermodal, multimodal and combined transport services. There is a need for standardisation already now to ensure the rollout until 2030.

In order to transform the European rail freight system and to establish “fully digital operations of freight train”, further applications and technology explored in EDDP need to be developed in the Innovation Pillar. The System Pillar will support coordination and input on the development of the operational concept and system architecture to support DAC integration and deployment.

The Innovation Pillar will shorten transportation time, increase productivity, flexibility and reliability and integrate services into (full) logistic chains by:

- Enabling seamless cross-border planning and operation of freight trains including last mile by integrated corridor wide path management and booking, including for ad-hoc path requests and simplifying the process significantly in cooperation with the traffic management priority (‘smart capacity’).
- Developing innovative concepts aimed at the efficiency of transport operations in connection with improved traffic management, e.g., including capacity trading between different customers, prioritisation of wagon/train capacity according to customers’

urgency[18] and rail freight services with real-time management capabilities, based on data sharing solutions and customer feedback.
- Developing solutions to integrate the last mile operations like dynamic dispatching tools for yards, including their connection to the mainline TMS, and to rapidly deliver high-value goods, integrating feedback from customer experience. Innovative loading concepts introduced for smaller shipments can be investigated to create further flexibility and minimising shunting.
- Developing new technologies, including digital ones, to speed up certain processes at borders and other operational stopping points to enable further automation and better interactions for achieving a seamless transport that do not stop at the borders.
- Developing innovative and integrated rail based multimodal transport planning management and operation tools (e.g., optimised routing, capacity and yield management, load and empty flows equilibrium[19]) improving the cooperating with other modes to further increase the efficiency and capacity of rail freight, which enable real-time management of offers, resources and transport flows.
- Intelligent freight trains relying on the digital automatic coupling (DAC) where automation is applied to its full capacity, e.g., automated yards, train preparation, operation and maintenance, and intermodal terminals.
- Improve the monitoring and management of freight trains, intermodal containers and loading units by AI-based prediction models and new emerging telematics solutions for condition/ health monitoring, performance monitoring, load supervision and for improved interaction with service co-providers and customers.
- Smart inspection processes and supporting training and equipment.
- Harmonised training for locomotive drivers to facilitate cross-border operations, supported by a translation tool.

4.2.2.5 Smart solutions for low density traffic lines (cost-efficient regional railways)

The tasks of the Innovation Pillar will build on the R&I from Shift2Rail on different technologies for control command and signalling, multimodal journey integrations and other potential adapting technologies for revitalising lower-use lines around Europe. These lines face the risk of closure if life cycle costs cannot be reduced, and safety ensured at current levels in the near future.

Research and Innovation in Shift2Rail focused mainly on:

- Concepts for removing as much as possible infrastructure-side controlling equipment (e.g., leveraging satellite positioning) or making such infrastructure devices smart/connected, and autonomous in term of energy needs.
- The previously described Adapted Communication System demonstration results providing the ability to work with heterogeneous communication networks, including public ones from mobile network operators.
- Semantics and ontologies with the delivery of high TRL demonstration of a functional ecosystem in a multimodal complex environment between different cities, regions and countries. This will support the offer of attractive services to customers who need easy multimodality also to access remote locations.

[18] Apply the concept of synchromodality, a system of priorities, urgencies and a period of possible departures / arrivals could help to make the best and maximum use of rail capacities (e.g., by defining different service levels and using less urgent cargo as fillers to maximise the utilisation of rail).
[19] See also previous footnote

- Mobility as a Service integration with ride-sharing possibilities and the final demonstration for a door-to-door solution integrating rail, bus, metro, aviation and all new personal mobility transport modes.

This priority of the Innovation Pillar will focus on developing smart solutions for low density traffic lines, allowing to their preservation or even their revitalisation. This also requires a system view to develop consistent infrastructure and rolling stock that are affordable upfront and in running costs. The aim is to make operations economically self-sustainable in the long term and renewed in the short term by increasing the attractiveness for regional rail customers.

Innovative low-cost rail system solutions should include a more affordable infrastructure, redesigned lighter rolling stock, adapted operational rules and a digital customer system that ensures a complete journey experience for passengers. This should rely, as far as possible, on adapted solutions from research and innovation under other priorities of this Joint Undertaking. This local system should also be designed barrier-free to be accessible for all passengers.

A more affordable infrastructure for regional lines, will rely on advanced automatic traffic management systems, low-cost Automated Train Operation, associated to simplified ERTMS, reduction of wayside signalling and installations (also roadside of level crossings) relying increasingly on satellite and wireless technologies. Further necessary wayside installations will be built with autonomous power and wireless communication with the remaining infrastructure. Stations and train stops will need to be developed in modular standardised manner to be able to reduce their costs by economies of scale. To ensure these lines are green and cost-efficient, there is a need to design a concept for multi-modal refuelling stations (e.g., hydrogen or battery recharging).

Rolling stock can be made more affordable by new vehicle designs for light trains as well as become more attractive and easier to adapt with modular interiors. Such trains will need to be sustainable, i.e., if not electric, operate on batteries, hydrogen or other alternative fuel (and be able to be refuelled at multi-modal refuelling points), to be automated and be adaptable to both passenger and freight use. The automation and dual use will be especially game changing allowing for much cheaper operations and adaptability to the current demand for services.
Rail operations need to be reviewed to match broader customers' needs using innovative technologies. The use of digital platforms should give customers a full travel experience providing access to complementary services (such as shared mobility, taxi, bike and car parking and charging stations). The overall broadened offer, its adaptation (in flexibility and capacity) to the customer demand (relying on advanced traffic management) will lead to increased attractiveness for rail as a backbone for reduced mobility-emissions in regions and helps making Europe´s regions stronger.

The Innovation Pillar will deliver for lower usage lines:

- Analysis of demand and customer studies to support the optimisation of operations, development of attractive services and of the rail equipment that will enable such services.
- Automated train of at least GoA2, for both freight and passengers and with cooperation with cost-effective signalling systems for both rolling stock and infrastructure ensuring interoperability with the mainline/core network as well as addressing the lower functional requirements on this lower usage lines.

- Automated train of GoA3-4, testing of a lightweight design of a vehicle that can serve both freight and / or passengers (designed barrier-free for passengers), with obstacle detection and automated shunting, testing of multimodal integration with main lines and road.
- A Command and Control system adapted to regional lines, based on ETCS L3, FRMCS/5G and/or satellite communications, automated train of GoA3-4, full multimodal integration with main lines and road and a digital platform to provide customers with a seamless journey or shipment experience[20].
- Harmonised low-cost solutions to increase the safety level for lower usage lines, that may if needed be tailor-made for such lines
- Strategies for adaptation of operations to innovations. These strategies will take human factors fully into account.

4.2.2.6 Transversal topics: data and digital enablers

The availability of real-time and historical data from across the whole rail system, but also from external data sources, is essential in the development of a revitalised, digitalised rail system.

A fully-digital connected rail system will be characterised by a complex landscape comprising multiple heterogeneous enterprise-level mission-critical systems interacting with a very large number of networked stationary and mobile devices and sensors, generating requirements for new mechanisms to be embedded in the digital infrastructure. The digital infrastructure equipped with these features will constitute a ‘railway digital enabler’ environment for the entire rail system, supporting the development of advanced transformational digital capabilities, including, but not limited to, the ability to analyse, predict and simulate the dynamic behaviour of physical components systems and processes using their digital representation in an interoperable digital processing environment.

The activities will:

- Building on the Conceptual Data Model to develop an open, common, shared and standardised machine-readable ontology of the rail system domain formally describing syntactic and semantic data structures consistent with the System Pillar architectural guidelines, enabling railway system stakeholders to participate in a federation of data spaces that can be extended to other domains. To ensure the interoperability with other domains, this approach should be consistent with the development of the common European mobility data space and with the architecture and data infrastructure requirements for data spaces defined by the Data Spaces Support Centre, supported under the Digital Europe Programme.
- Providing a cybersecure, reliable and high-performance federated dataspace infrastructure incorporating data sovereignty, identity and trust management, and powerful networking and communications mechanisms to enable data, including data streams, processing through:
  - Facilitated data availability, discovery and accessibility through standardised interfaces,
  - Deployment, management and processing of standardised services over the federated dataspace infrastructure

[20] Including planning with other public transport means (buses, coaches, metro, trams, etc.), and with sustainable shared mobility devices (e.g., bikes/e-scooters, e-cars, etc.)

- Provide a Digital twin design-time environment consisting of a set of software tools and procedures allowing domain model experts to develop the digital models of components, systems and processes, and to store them as compiled 'black-box' units with standard interfaces for reuse in the composition of higher-level models.
- Provide a Digital twin run-time environment allowing compiled model units to be used in simulations using instance coefficient and variables data available on the federated data space. The run-time environment will in addition provide powerful visual analytical interfaces for controlling and rendering the results of simulations.

Digital twins accessing resources on the federated dataspace infrastructure will provide the digital tooling for new advanced operational capabilities:

- Visualising, simulating and predicting current and future status of the system in view of enhancing rail operations
- Assessing the reliability of existing inventory
- Developing new prediction models for rail infrastructure
- Allowing evaluation of future needs such as increasing capacity or speed

Improving safety, availability and lower operational costs for the complete rail system by predicting future events and supporting development and deployment of innovations with virtual formal validations, minimising in-field, operations-disrupting tests. Digital twins will cover all rail market segments and their subsystems, including urban.

4.2.2.7 Exploratory research and paradigm shifts

Europe's Rail will promote forward looking activities, tackling disruptive technologies and thinking, performing exploratory research to accelerate the pace towards radical system innovations in the guided transport modes and supporting the evolution of the Innovation Programme in scope and targets. Some of these activities may be related to the extension of the scope of guided transport towards more affordable transport in less densely populated areas and towards rail services at much higher speed than today for distances above 1000km. All exploratory research will be developed with a European system in mind and in a user-centred multi-modal setting.

Exploratory research and paradigm shift activities may address the following (non-exhaustive):

- Study on upcoming enabling technologies and general/breakthrough innovations coming also from other sectors as well, that can be applicable to the rail system and sub-systems.
- Disrupting the innovation cycle itself by applying game changing methodologies with the goal of significantly shortening time to market and significantly reducing costs of the innovation process itself and the resulting solutions.
- Socio-economic and market influencing factors analysis, including user-acceptance studies (reflecting changes in demand), taking various geographic settings into account (regional, intercity, urban, etc.).
- Research on emerging technologies or their critical subsystems, including mag-lev/magrail/aerodynamic propulsion and vacuum tube technologies, such as Hyperloop™ solutions.
- Research on business, innovation and transport models.
- Research on emerging safety, security and certification issues.
- Personalised rail infrastructure/vehicle concepts moving over different transport modes infrastructures.

- Multimodal, customer-centric and sustainable, shared-mobility solutions including full integration with other modes of transport, including in an urban environment.
- Studies of ultra-high speed (beyond 500 km/h) trains and synergies with non-conventional and/or emerging new modes of transport (e.g., Hyperloop™).
- Impact of innovation on operations and human factors.
- Setting up networks bringing together different rail communities, such as in relation to regional hydrogen rail, rail research centre around specific concepts, etc.
- Programmes for PhDs on EU-Rail related activities.

Exploratory research, in particular, may require EU-Rail to engage with non-European partners to promote at global level Europe's rail research and innovation excellence and inclusiveness, under the policy of the European Commission.

4.2.3 Arrangements between the pillars

Continuous exchange will happen between the System Pillar and Innovation Pillar activities as part of the Integrated R&I Programme, with a bi-directional flow: both pillars should provide input and output to each other against a clearly defined series of priorities and objectives to be achieved.

The aforementioned objectives and priorities are derived from the Single Basic Act, translated in the present Master Plan and operationalised in the Multi-Annual Work Plan of the EU-Rail JU. They may evolve and be amended as part of the Governing Board decision making process.

It is within this context that both Pillars define and organise their activities. It will be critical that there is flexibility between the Pillars to adjust scope and priorities as the work develops.

4.2.4 Synergies with other innovation programmes and relevant investment opportunities

Moreover, EU-Rail will develop a close cooperation and ensure coordination with related European, national and international research, innovation deployment and infrastructure investment activities in the rail sector and beyond as necessary, in particular under Horizon Europe, the other Joint Undertakings, Connecting Europe Facility, Digital Europe Programme, investment financed by European Investment Bank etc. EU-Rail will play a major role in rail-related research and innovation while also benefiting from scientific and technological advances reached in other sectors.

More specifically the Europe's Rail Joint Undertaking will cooperate with the Clean Hydrogen joint undertaking and with the BAtt4EU co-programmed partnership to develop alternative traction as well as with digital joint undertakings to support the information technologies necessary for digitalisation of rail.

4.3 Deployment

4.3.1 Deployment Group

The Single Basic Act establishes the Deployment Group to advise the Governing Board on the market uptake of the future rail research and innovation solutions, as well as to support their deployment.

Although S2R has already contributed to shortening the innovation cycle in rail via an integrated research and innovation programme, the structure of the new JU, built upon its two pillars is expected to accelerate further the introduction of innovative solutions. In order to complete the innovation cycle, the deployment of novel solutions requires to move towards new ways of working within the sector,, which would encourage the transformation of rail as one European integrated system. Only a strong and collective commitment may ensure reaching the milestones established in the Sustainable and Smart Mobility Strategy.

The work performed in the System Pillar ensures the convergence of the sector on the future concept of operations and underpinning system architecture that will transform the performance of the European rail system and contribute to eliminating physical and digital barriers; the Innovation Pillar will deliver the operational and technological solutions, which provide the necessary capabilities to transform the European rail system. Only via a coordinated and integrated deployment of system integrated solutions can rail reap the benefits of the investments made, accelerate its transformation and deliver new services to its clients.

In the past years, the deployment of innovative solutions has too often resulted in a patchwork system, where the intrinsic benefits of investments were lost and even resulted in additional costs as, in many cases, such solutions have been deployed as additional layers on existing systems or a patchwork. This resulted in increasing the maintenance costs, in additional complexities, in a lack of trust in the new solutions and, de facto, has anchored Europe rail systems to their legacy, missing the opportunity for a major transformation.

There is a clear and shared sector vision that accelerating the deployment of future technological and operational solutions requires decisions that will shape also the execution of the future EU-Rail projects and a different approach: where the introduction of innovative solutions has a clear impact on rail in its systemic nature, deployment shall be coordinated and consistent to accelerate the return on investment and phase out legacy products. This new way of working shall be based on more flexibility and adaptability to user needs, creating solutions much more focused on prototyping and large-scale demonstrations, and increased collaboration integrating new entrants, leading to a shorter innovation cycle and delivering impactful results.

The Deployment Group should:

- Examine and provide recommendations on alternative scenarios for the rollout of innovative solutions.
- A roadmap for the coordinated and integrated deployment of the relevant rail research and innovation results, where relevant in cooperation with other modes of transport.
- Consideration of human factors and needed behaviour and organisational changes as a result of deployment.
- Ensure consideration of diversity of situations across the Union, including most cost-effective possibilities of retrofitting from a medium and long-term perspective.
- Alignment of deployment and investment plans also including other modes of transport and other relevant infrastructures.
- Risks and opportunities associated to uncoordinated initiatives.
- Phasing out of existing legacy systems and consideration on the necessary accompanying funding and financial measures, from public and private sources, including EIB.
- Use of a performance scheme that would contribute to accelerating deployment and/or any other relevant measures.
- Any other relevant matter that would contribute to reducing the innovation lifecycle and increase the performance of rail, maintaining the same level of safety or increasing it.

The new structure of the JU should allow covering all phases of the rail research and innovation lifecycle, potentially up to TRL9, in order to allow phasing in deployment as from 2025.

4.3.2 Collaboration with the European Union Agency for Railways

The Europe's Rail Joint Undertaking will cooperate with the European Union Agency for Railways[21], in particular with regard to the implementation of the Master Plan. This collaboration will consist of:

- ERA's suggestions on research needs relating to the realisation of the Single European Railway Area for the Master Plan and its amendments as well as in the work programmes;
- ERA's feedback and advice on interoperability and safety to be considered in the research innovation activities and, more specifically, in the activities of the System Pillar.
- ERA identifying needs for any additional specific validation or studies by the joint undertaking, including via the involvement of national safety authorities;
- ERA ensuring that the development of specifications including interfaces, functional requirement specifications, and system requirement specifications takes into consideration the experience and feedback on TSI or standards.

4.3.3 Communication

The communications strategy of Europe's Rail will aim to

- Showcase the innovative technological and operational solutions that result from the research and innovation activities, and in particular those ready to enter industrialisation and deployment, in particular demonstrating concrete impact.
- Raising awareness on the research and innovation activities outreaching to the stakeholders at European level as well as engaging at global events/conferences to promote Europe's Rail results.
- Enhance the partnership nature of the JU through communications and dissemination activities that will create opportunities for inclusiveness.

[21] based on Article 40 of Regulation (EU) 2016/796 of the European Parliament and of the Council

5 Monitoring progress and impact

The results of the Joint Undertaking shall be measured via a series of KPIs addressing, on the one hand, the technological and operational outcomes and, on the other hand, the impact that they expect to realise once deployed. The set of KPI shall cover the full lifecycle of R&I, from exploratory research to deployment coordination.

Layer 1: The KPI model shall be based on quantitative input delivered by the innovative technological and operational solutions generated by the JU Programme and its projects, reported on a yearly basis through its Annual Activity Report. Projects will report agreed relevant quantitative and qualitative metrics that contribute to the JU's overall Impact KPIs

Layer 2: The Layer 1 results will be analysed, assessed, and translated into societal impacts showing higher level indicators, related to the expected impacts described in Section 3.2.

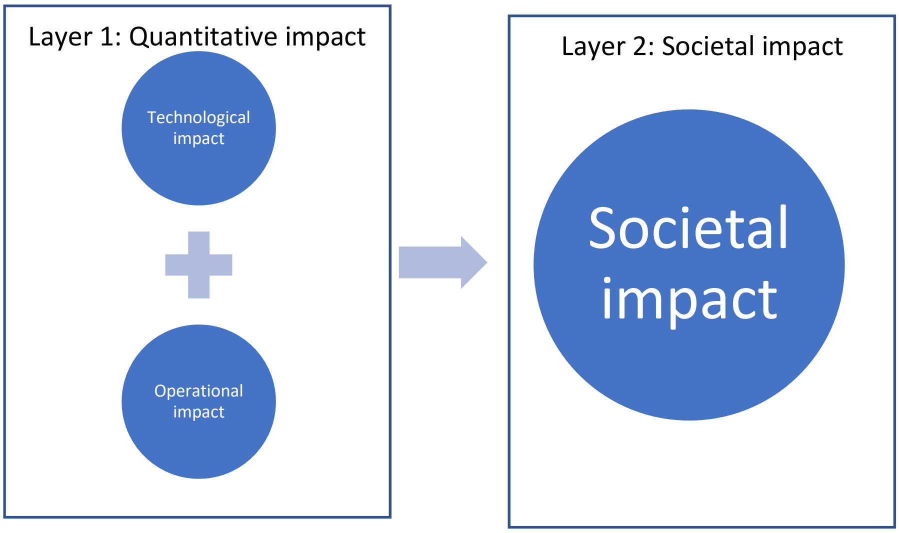

Figure 2 - Relation between technological, operational and societal impact assessment

In addition, specific Horizon Europe implementation indicators are also defined and reported.

A number of Key Performance Indicators (KPIs) have been identified in the Multi-Annual Work Programme for each Flagship Area. Each JU project will produce consistent quantitative and qualitative metrics during its implementation, so as to determine the actual R&I progress and results achieved.

Starting from this comprehensive list of KPIs that will constitute the basis for the Layer 1, a selection of the most relevant ones by Impact areas is presented in the table below. It is to be noted that further consolidation of KPIs, accompanied by modelling of the rail system/sub-systems impacts, will be performed in the course of the programme.

This selection, using as a reference baseline the state of the art in 2020 (including results from S2R), will allow a more focused transformation of the operational work delivered with Projects technical and operational results into more tangible Societal Impact qualifications.

The Societal Impact measurement methodology will be developed in the first two years of the functioning of the Joint Undertaking on the basis the technical and operational KPIs provided here. The calculations of the impact will be provided after each round of demonstrators that is in 2025, 2027 and 2031.

Impact areas	Key performance indicators	Rationale	Driver Targets[1]
1. Customer requirements	Accuracy in total planned travel time of passengers from improved matching between supply and demand, #	Increase availability and predictability of intermodal rail transport offer	75%
	Traffic planning certainty, #	Planning certainty, considering the demand forecast, is a key requirement for planning on time, reliable and efficient service delivery	between 65% and 80%[1]
	Handling/response time for intermodal freight offers and regional passenger services, mins	Improve overall customer experience, including growing intermodal freight transport and regional passenger services	-50%
2. Improved Capacity	Trains on line per hour and direction, #	Increased frequency is a key element for improved capacity	At least +10%[2]
	Reduction of total freight transport time, *mins*	Reduced freight transport time leading to better asset utilization and increased capacity	-33%
	Increased average freight train length in existing infrastructure limitations or higher loads, meters	Increased length directly leads to more available capacity	Up to 1.500m
3. Reduced Costs	Overall OPEX and CAPEX costs of regional lines, incl. maintenance, infrastructure and vehicles	Direct link to lower costs of the regional lines	tbc[3]
	Maintenance costs, including thanks to the use of digital twins, €	Direct link to lower costs	-10%[4]
	Design and manufacturing costs, €	Leading to reduced investment cost	-20%
	Virtual certification tasks that can be conducted in a laboratory, #	Cost of virtual certification activities is much lower than cost of physical certification activities, hence more tasks done virtually leads to lower costs	+80%[5]
4. Sustainable and resilient transport	Optimized energy consumption and higher punctuality in regional services, *kWh per pax-km or tons-km;mins*	More efficient operations, leading to lower energy consumption (with lower CO2 emissions)	-10% (energy); +15% (punctuality)
	CO_2 equivalent emissions	Further decrease rail carbon intensity	Up to 30% for specific use cases (e.g. regional operation and heavy duty inspection vehicles)
	Traffic prediction performance, secs	Improve network resilience through dynamic infrastructure restriction handling, train regulation and automated conflict resolution	<120 secs[6]
	Time to respond and resolve a vulnerability (regarding cyber security), *mins*	Reduced impact of events and increased availability of the rail system	tbc[7]

Impact areas	Key performance indicators	Rationale	Driver Targets[1]
5. Harmonized approach	CCS system CAPEX and OPEX (of main line and regional lines systems), while maintaining or increasing the present safety level	Reducing costs associated with the interoperability of the network will enhance harmonization	CAPEX: -25% (regional lines) and -10% (main lines); OPEX -20% (regional and main lines)
	No new national technical rules triggered by innovative solutions coming from the Joint Undertaking and potential reduction of national rules in relation to ERTMS and interlocking	By decreasing the amount of national rules in force, rail transport will evolve towards the Single European Railway Area	N/A
	Reduction of answering time between the short term request of a cross-border train path and the answer with a firm offer, *mins*	Indicator for more efficient border crossing	down to 5 mins
	Operational dwell time at borders and other handover points relying also on relying on more homogenous system approaches (leading to increase number of trains on given infrastructure), *mins*	Indicator for more efficient border crossing	-50%
6. Reinforced role for rail	Accuracy in total planned travel time of passengers from improved matching between supply and demand, %	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	75%
	Traffic planning certainty, #		between 65% and 80%[1]
	Handling/response time for intermodal freight offers and regional passenger services, *mins*		-50%
	Overall OPEX and CAPEX costs of regional lines, incl. maintenance, infrastructure and vehicles		Tbc3
	Maintenance costs, including thanks to the use of digital twins, €		-10%[4]
	Design and manufacturing costs, €		-20%
	Virtual certification tasks that can be conducted in a laboratory, #		+80%[5]
7. Improved	Maturity of innovative technologies	Innovative technologies will deploy rail capabilities and leverage potential competitive advantages for the EU rail industry	TRL 8

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1 *Depending on point in time, e.g. one week in advance or one hour in advance*
2 *At the moment this KPIs is linked with the outcome of FA2 only, in the course of the programme a consolidated KPI will be measured*
3 *The nature of the activity requires a full system approach analysis from improvements at components level, which will be conducted during the course of the programme*
4 *In specific use cases for both rolling stock and infrastructure and asset management*
5 *Costs only related to the execution of the on-site tests*
6 *In a typical scenario of at least 100 trains running in a 2h interval ahead of actual time*
7 *Due to the confidentiality nature of the baseline, a KPI measure will be assessed and consolidated during the course of the programme*
8 *As reflected in the ERA database(s) in relation to OPE TSI Appendix A, annex C and other TSIs in relation to ERTMS and interlocking*