Europe’s Rail Joint Undertaking

Master Plan (DRAFT)

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

**LEGAL NOTICE**

This document has been prepared for the European Commission however it reflects the views only of the authors, and the European Commission is not liable for any consequence stemming from the reuse of this publication. More information on the European Union is available on the Internet (http://www.europa.eu).

Table of Contents

[Executive Summary 6](#_Toc86306669)

[1 Introduction 8](#_Toc86306670)

[2 A renewed role for rail 8](#_Toc86306671)

[2.1 Transport Policy Context 8](#_Toc86306672)

[2.2 The rail sector vision 10](#_Toc86306673)

[2.3 Challenges 10](#_Toc86306674)

[3 Ambitious objectives for Europe’s Rail 12](#_Toc86306675)

[3.1 Objectives 12](#_Toc86306676)

[3.2 Impact of EU-Rail 13](#_Toc86306677)

[4 Delivery 14](#_Toc86306678)

[4.1 Strategy 14](#_Toc86306679)

[4.2 Implementation 21](#_Toc86306680)

[5 Monitoring progress and impact 39](#_Toc86306681)

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 means that the railway sector must undergo a significant transformation - 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 - thereby also addressing the key challenges it faces today already.

1. 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 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 services at reduced cost compared to today, including tackling all the elements of its lifecycle.
4. Climate change: rail is one of the most sustainable modes of transport. Increased use of rail is necessary to fulfil European climate objectives.
5. Legacy systems and obsolescence: rail system assets are procured assuming very long lifecycles and are based on national approaches.
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, this should result in:

1. Meeting evolving customer requirements
2. Improved performance and capacity
3. Reduced costs
4. More sustainable transport
5. Harmonised approach to evolution and greater adaptability
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
	1. Delivering a European rail traffic management system to achieve dynamic capacity management, improved performance, and cost efficiency.
	2. Providing systems for real time management of the network
	3. Supporting the rail’s key role in future transport and mobility systems
2. Digital and Automated Train Operations
	1. Delivering an adaptable and scalable trackside and onboard architecture and associated solutions - representing the next evolution of the system and incorporating the latest technological advances.
	2. Delivering scalable automation in train operations.
3. Sustainable and digital assets
	1. Solutions to reduce the environmental footprint, improve accessibility, and increase resilience of the rail system.
	2. Innovative solutions to minimise asset life costs.
4. Competitive digital green rail freight
	1. Developing and integrating new operational and technological solutions to make rail freight more competitive.
	2. Fully digitalising operations to support rail freight in the logistics value chain.
5. Smart solutions for low density lines (cost-efficient regional lines)
	1. To adapt solutions to the whole rail network, supporting 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 also work on forward-looking activities, tackling disruptive technologies and thinking, through performing exploratory research.

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.

# 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 and beyond the current programming period.

The Master Plan shall provide guidance on the tasks of EU-Rail as per the requirements of the Single Basic Act[[1]](#footnote-2), the Council Regulation which establishes EU-Rail and other Joint Undertakings.

# A renewed role for rail

## Transport Policy Context

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 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 with its new EU Framework Programme for Research and Innovation- Horizon Europe.

***European Green Deal[[2]](#footnote-3) & Fit for 55 Package[[3]](#footnote-4)***

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. 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.

**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, 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, 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’[[4]](#footnote-5) (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 healthy
* 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; and integrating with other transport and mobility solutions for passenger services and cargo logistics.

**Horizon Europe**

Horizon Europe[[5]](#footnote-6) – 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.

**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.

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 demands will require a holistic approach, to which EU-Rail will contribute.

## The rail sector vision

The European Rail Research Advisory Council (ERRAC) is a research 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)[[6]](#footnote-7), an input to this Master Plan, ERRAC states:

“*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.”*

## Challenges

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

|  |
| --- |
| Changing customer requirementsPolitical, 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 digitalization and automation of operations, under a systemic approach, will create the vast bulk of future increased traffic leveraging existing infrastructure. |
| High costRail is currently often more expensive compared to other transport modes. To be more competitive and support future increased usage, rail must deliver services at reduced cost compared to today, including tackling all the elements of its lifecycle. |
| Climate changeRail is one of the most sustainable forms of transport. Increased use of rail is necessary to fulfil European climate objectives. In addition, steps can be taken to further improve the climate footprint of rail. Rail services and networks must also become more resilient against the impacts of climate change. |
| Legacy systems and obsolescenceRail system assets are procured assuming very long lifecycles and are based on national approaches. This situation results in a fragmented market, and great complexity in introducing new functions in a coordinated and cost effective way. Rail must move to one European network more unified finally delivering a 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 modesRail 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 competitionThe 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. |

# Ambitious objectives for Europe’s Rail

## 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, as set out in the Single Basic Act are:

1. contribute towards the achievement of the Single European Railway Area;
2. 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;
3. support the development of a strong and globally competitive European rail industry

The Specific objectives to the partnership are to:

1. 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;
2. 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[[7]](#footnote-8) 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;

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

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

## 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:

|  |  |
| --- | --- |
| Stopwatch | **More flexibility and punctuality for passengers / freight**EU-Rail will support the delivery of much more flexible approaches to planning and traffic management of rail services, allowing rail to better serve customer needs. |
| Gauge | **Improved performance and capacity**Through the development of cutting edge technologies designed to be implemented across the whole EU rail network, EU-Rail will help increase capacity and make best use of available assets. |
| Money | **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. |
| Open hand with plant | **More sustainable 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 of the rail sector itself.  |
| Playbook | **Harmonised approach to evolution and greater adaptability**EU-Rail will support the sector in coordinating on a common evolution of the system, and a greater harmonisation to support the delivery of the Single European Rail Area and improve the rate of deployment of new technologies. |
| Train | **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. |
| Upward trend | **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, supporting its position in global markets. |

# Delivery

## 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 lower usage 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, tackling disruptive technologies and thinking, through performing exploratory research to accelerate the pace towards game-changing system innovations.



Figure 1 - EU Rail delivery strategy

### 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, 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, and thus time consuming 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 more harmonised approaches have been achieved.

Ultimately, this fragmented approach 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 standardised interfaces, communication and data exchange.
* Considering the migration path from current systems to the future system.

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 avoid the perpetuation of national specific systems and technologies and to facilitate the introduction of harmonised solutions avoiding separate national assessements in terms of technical compatilibility and safety.

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

### The priorities of EU-Rail

#### European Rail Traffic Management and supporting rail’s key role in a multimodal transport system

|  |  |  |
| --- | --- | --- |
| *Contributes to the following expected impact:* |  |  |
| Stopwatch | Upward trend | Train | Playbook |
| More flexibility and punctuality for passengers / freight  | Improved EU rail supply industry competitiveness | Reinforce role for rail in European transport and mobility | Harmonised approach to evolution and greater adaptability |

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 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, AI 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.

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 management and traffic management system through, inter alia:

* Delivering an improved European rail traffic management system, building on 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 network management capabilities such as real-time connections and interaction between relevant resources and actors (for example on language) or incorporating new functional improvements such as automatic train operation (ATO).
* 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:

* Addressing the needs of final users, passenger or freight forwarders, with more predictability and punctuality of the rail services through a real-time management of the network in term of planning, scheduling, live operations and maintenance.
* Defining the interfaces to other transport modes to support the centrality of rail to future transport and mobility systems.

#### Digital and Automated Train Operations

|  |
| --- |
| *Contributes to the following expected impact:* |
| Stopwatch | Money | Open hand with plant | Upward trend |
| More flexibility and punctuality for passengers / freight  | Reduced cost | More sustainable transport | Improved EU rail supply industry competitiveness |

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

However, legacy operational rules and systems result in operators facing barriers in improving train operations and infrastructure managers 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 remain 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, formalized and interoperable manner.

Automation and digitalization 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 harmonized solutions that need to be put it in place to achieve it, including, for example, on-board localisation, 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 onboard CCS+ system architecture, based on radio-based ERTMS, representing the next evolution of the system and incorporating the latest technological advances. This will be a major transformation of rail operations, and also a stepping stone setting the basis for future evolution(s) of the system.
* Delivering scalable automation in train operations, for example up to Grade of Automation 4, 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.

#### Sustainable and Digital Assets

|  |
| --- |
| *Contributes to the following expected impact:* |
| Upward trend | Money | Open hand with plant | Gauge |
| Improved EU rail supply industry competitiveness | Reduced cost | More sustainable transport | Improved performance and capacity |

Rail is one of the most sustainable modes of transport, yet it still can improve its environmental performance. The system energy efficiency must be continuously improved both to improve environmental impact and to mitigate rising energy costs. Railways also need to reduce life cycle, including in particular operational, costs and this should result in lower ticket prices and improved affordability. This should help meeting the societal objective to travel and transport more sustainably, such as by rail.

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. 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 the railway operations and reduce both construction and maintenance costs.

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 as these are less stable compared to conventional sources and require equipment to stabilise the energy supply.
* Further reduce energy usage: more energy efficient stations, trains and infrastructure.
* Reducing noise and vibrations.
* Solutions to increase the resilience of the rail system:
* Analyse risks rail assets face due to adverse climate impacts, new safety or cyber-security threats, analyse the cost-efficiency of possible counter-measures, propose most-appropriate counter-measures, and, if missing, develop such counter-measures for existing and new rail assets. Operational methods and their implementation to redirect and re-plan rail traffic in the event of sudden infrastructure disruptions due to above mentioned risks or other causes (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 extend life cycle while meeting safety requirements and improving capacity and reliability or replacing assets with a circular economy approach. This will rely among other on digitalisation and on the common use of shared data.
* 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.
* Automation of construction and interventions to improve working and health conditions, reduce costs and increase quality and consistency of the results.

These innovative solutions stem from R&I work whose results will be scalable and deployable on the European rail network.

#### Competitive digital green rail freight

|  |
| --- |
| *Contributes to the following expected impact:* |
| Upward trend | Open hand with plant | Train | Gauge |
| Improved EU rail supply industry competitiveness | More sustainable transport | Reinforced role for rail in European transport and mobility | Improved performance and capacity |

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

Rail freight currently lacks flexibility and often hinders the capacity of current networks.

Rail will be able to attract existing and future freight customers through improving services. This requires new technologies to reduce costs, improve average speed and reliability.

There is a need for 24/7 dynamic capacity management, eliminating cross-border barriers between infrastructure managers complemented by the deployment of new operational and technological solutions, starting from those already indicated by the Rail Freight Forward initiative and in liaison with the logistic value chain principles (e.g. with ALICE [[8]](#footnote-9)).

EU-Rail will support rail freight by:

* Developing and integrating new operational and technological solutions (such as to automate services, e.g. with the use of technology enabled by the introduction of a European digital automatic coupler), including adapted logistics process and customer relations. This will shorten average transportation time and increase reliability offering more attractive and cost-efficient rail freight.
* fully digitalizing 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 systems of exchange of information. 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 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.

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

|  |  |
| --- | --- |
| *Contributes to the following expected impact:* |  |
| Upward trend | Open hand with plant | Money |
| Improved EU industry supply industry competitiveness | More sustainable transport | Reduced cost |

Achieving the milestones of the SSMS for rail transport require not only a transformation on 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 as enabling more sustainable local and regional transport, by connecting other public transport services and first and last mile services. These lines support social cohesion and inclusiveness by providing public transport to a broader population and facilitate the functioning of businesses in more remote areas.

Despite this, currently, services that could use lower usage lines are often replaced by other modes of transport, while the rail infrastructure remains underutilised.

A coherent, unified, interoperable solution of how those lines will be operated in conjunction with the rest of the European network and with other modes of transports is needed. This will enable achieving economies of scale and lower costs, as well as create seamless links with the rest of the rail network and other modes of transport.

Solutions for innovative rail services to 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, which may also result in providing a new opportunities for a scale up at network level or targeted uses beyond the regional lines.

Ultimately, a paradigm shift is needed on the approach from both rail infrastructure (zero- or low-cost trackside signalling) and rolling stock (self-powered sustainable vehicles) that may serve, 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 models.

This area is expected to deliver:

* New operational concepts, where appropriate (including more flexible operation up to ad hoc on demand services)
* Suitable and appropriate system architecture (with appropriate functionality and lower Life Cycle Cost) but being a European harmonized system
* Cost efficient performant control and command system (ERTMS-based)
* Optimized railways assets – leading to a significant reduction of existing signalling and to lower infrastructure life-cycle cost
* Sustainable Rolling Stock (light, cost-efficient, modular, flexible, zero-emission)
* Suitable customer services (adapted passenger information systems, congestion management, ad-hoc on demand services)

## 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-industrialization 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, that includes subordinate capability demonstrators.

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. Flexibility will be required to enable the respective pillars to adjust and update based on the outputs of the other.

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.

### System Pillar

#### 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 and freight 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:

1. 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;
2. 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[[9]](#footnote-10) or standardisation processes to lead to higher levels of digitalisation and automation;
3. ensuring the system is maintained, error-corrected and able to adapt over time and ensure migration considerations from current architectures;
4. 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, and to the legal and regulatory framework, to ensure an overall harmonised approach.

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.

#### 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, 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 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.

#### 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 onboard 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).
* 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, for the whole system not just ERTMS, and 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 specifications, with manageable upgrade mechanisms.

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) 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 harmonization 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 dysfunctional models. 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

#### 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:

* An agreed plan and timeline for the evolution of the CCS+ system, consistent with the agreed operational concept and system architecture
* A clear picture of the role of the EU-Rail in delivery, including the allocation of those elements that will be delivered by the Innovation Pillar, and the System Pillar.

### 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 be based on and support when relevant the system view.

The Multi-Annual Work Programme, 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 Programme 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 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.

#### 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 – at a European level, rather than national level, 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 term of planning, scheduling, live operations and maintenance purposes on a European scale.

A first pilot demonstrator is planned for [2025], with extended functionalities and geographical scope by [2029/31].

This will encompass, inter alia:

* Development of a functional system for strategic, tactical and short-term planning based on System Pillar outputs on traffic management principles and functional requirements
* Specifications for planning and operational tools and associated interfaces
* Automated solutions for improved strategic and tactical planning that supports cross border scheduling.
* Harmonised methods for capacity planning with intelligent functions with optimization and simulation support.
* Tactical and short-term timetable planning with improved models and functions.
* Use of simulation including capabilities and best practices, needs for future TMS modules.
* Decision support for better functionality to help capacity planning and operations for yards/stations and rail network.
* Dynamic timetables are demonstrated, including real-time infrastructure availability/status/condition, rolling stock capacity, passenger flows, forecasts and crowd management.
* Decision support for improved control of nodes, yards and stations, and improve connection to industry sidings and ports, as well as interaction with other rail networks are demonstrated.
* 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
* Assessment of the opportunities to migrate to TSI compliant track circuits and axle counters
* Full consideration of cyber-security aspects

Planning and operational management will be interconnected with all relevant resources (e.g. rolling stock, crew, shunting yard resources) and will integrate components improving network performance, flexibility, energy optimization, and resource utilization.

This approach will connect the network to international corridors, to stations and yards, and will consider all relevant resources affecting the traffic.

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.

The Innovation Pillar will develop:

* Specifications for planning tools and interfaces for:
* Decision support for short term planning;
* Optimization methods for capacity efficiency and energy saving;
* feedback loops from operations
* Technical specifications for operation tools and interfaces (including with the control and command layer) for:
* Automation and decision support;
* Improved real-time connection of the networks;
* Real-time convergence between planning & operation.
* Dispatching and incident management
* Disruption management
* Conflict detection & resolution
* Speed regulation and dynamic timetables;
* Real-time crew / rolling stock dispatching
* System requirements for Cross border scheduling including specifications for exceptional consignments and eFTI related transportation
* Interface specifications and data set for interoperable connected TMS
* Interface specifications and data set to integrate rail traffic within door-to-door mobility

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

* Demand forecasts based on big-data sources, real-time processing and new models such as activity based and AI-based
* Integration in digital twin to check KPI and the adjustment of current offer
* Simulation of alternatives complemented by other modes
* 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:

* Deliver short- and long-term demand forecast calculation
* Integrate demand forecasts in the digital twin

##### 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.

The Innovation Pillar will:

* Building on the Conceptual Data Model develop a harmonised approach to open, standardised, and harmonised data structures based on a data architecture consistent with the System Pillar, which enables all railway stakeholders to participate digitally in common data space ecosystems within railway and other domains. Such an approach should take into account existing regulations and standards, and consider fully appropriate approaches to cyber-security.
* Enable the processing of data by:
* Facilitated data availability and accessibility through the development of standardised services,
* Processing of standardised services. The services shall therefore include generic platform minimum architecture (such as data dictionary and common standardised railway ontology) as well as functionalities for distributed platform architectures.
* Incorporation of the use of Powerful data and communication infrastructure.
* Deliver a digital twin, which is a virtual representation able to imitate the behaviour of a physical system during the spans its lifecycle.
	+ Within the railway, digital twins will be merging the knowledge on the fundamental behaviour of systems and sub-systems along into digital simulations in predicted or operational regimes.
	+ A digital twin will enable a more efficient way to predict and control the present and future performance of assets, and therefore has the potential to transform many different aspects of the business.
	+ In particular, a digital representation of a real railway system (infrastructure, vehicles and operation) will allow
		- Visualising, simulating and predicting current and future status of the system in view of enhancing rail operations
		- Allow the assessment of the reliability of existing inventory
		- Development of new prediction models for rail infrastructure
		- Allow evaluation of future needs such as increasing capacity or speed
		- Improved safety, availability and lower operational costs for the complete rail system by predicting future events and support the development and deployment of innovations with low and event non-field operational impact tests. The digital twin will cover all rail market segments and their subsystems, including urban.

#### 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 onboard tintegrity with wired on-board communication on low-density 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 signaling detection technologies, to support the introduction of autonomous operations (i.e. AI based CCTV).

##### A scalable and adaptable trackside and onboard CCS+ system

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

The aim is to develop the specifications and 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 supported by formal methods.
* 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 onboard CCS system,
* Solutions that would allow for high-precision localization, 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.
* The full incorporation of advanced train positioning techniques (including satellite).
* L3 moving block.
* 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], 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 localization, cybersecurity, environment perception, V2X connectivity. These have to be implemented with limited dependency between on-board and trackside, must be interoperable, plug-and-play[[10]](#footnote-11) 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 & optimization 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 supporting virtual validation and certification ensuring the exact 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 onboard 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 Pilar (for CCS including GoA3/4 system).
* Further specification of general GoA3/4 operational concept in coordination with System Pilar.
* 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
* Interfaces ATO-ETCS + ATO-TCMS + ATO-trackside
* 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.

#### 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 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.
* New freight wagon designs have been also tested and advanced propulsion system investigated for locomotives. 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 must also be shared and linked with the traffic management and power supply systems to improve the functioning of each of these interrelated systems. 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 in the Digital Twin 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 leaning on digital twin principles at a much lower cost.

Second, non-invasive and/or unmanned solutions for automated monitoring, inspection and intervention need to be developed. 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.

Third, both rolling stock and rail infrastructure need to be designed in a way that 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 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.

##### Zero-emissions, silent 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 use means integrating more energy from renewable sources, developing smart energy storage, energy storing and refuelling spots (for both hydrogen and batteries). Energy management technologies and methodologies need to be further developed mainly for the stations and the rolling stock. Regarding stations, the aim is to develop a net-zero 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 allows the further development of rail infrastructure. It supports keeping the attractiveness and acceptance for rail in the society, as rail, as a mass transport means, needs to be part of densely populated areas.

Furthermore, railways need to improve its accessibility for all passengers. Accessibility objectives should be precise and ambitious. The final objectives are independent (no assistance) and spontaneous access (no pre-notification), including to high- speed trains. As another side of accessibility, the connection with other modes need to be considered, how to efficiently combine trains with other modes including personal mobility devices and new sustainable cargo concepts.

To ensure the successful achievements of the tasks in relation to a zero-emission, silent and accessible rail system the innovation pillar will deliver:

* "Green traction" using hydrogen and other alternative fuels, as well as newer hybrid solutions using these sources of power and when possible classic electricity from the catenary;
* Solutions that can provide more sustainable services to the final users, passengers and freight forwarders.
* Environmental (including energy) footprint methods and tools 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. This includes the possible re-use of existing assets by improving the recycling potential and practices.
* Technologies and operational methods to increase the use of greener resources, more efficient energy management and smarter energy storage.
* Technologies lowering the noise of rail equipment.
* Technologies and operational methods to make new and existing rail assets and rail operations resilient to climate change.
* Technologies and operational methods to improve the accessibility of persons with reduced mobility and to efficiently link trains with local sustainable transport mode.

#### 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 focused mainly on 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 demonstrations were done on a full solution for condition-based maintenance, a 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.

Modular and logistic capable new wagon concepts have been tested with telematics/communication solutions. Distributed power technologies in locomotives have been developed using LTE up to a 835m train demonstrator.

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

The Innovation Pillar will:

* Enable seamless cross-border planning and operation of freight trains by integrated corridor wide path management, including for ad-hoc path requests and simplifying the process significantly in cooperation with the traffic management priority.
* Develop innovative concepts aimed at the efficiency of transport operations, including capacity trading between different customers and rail freight supply services with real-time management capabilities, based on data sharing solutions.
* Develop solutions to integrate the last mile operations and to rapidly deliver high-value goods. This will increase the customer experience. Innovative loading concepts introduced for smaller shipments can be investigated to create further flexibility and minimising shunting.
* Develop 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. This should increase productivity, reliability and flexibility.
* Develop innovative and integrated rail management tools (e.g. capacity and yield management, load and empty flows equilibrium) 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 and intermodal terminals.
* Improve the monitoring of freight wagons by new emerging telematics solutions for condition/ health monitoring, performance monitoring and load supervision.
* Smart inspection processes and supporting training and equipment.
* Harmonised training for locomotive drivers to facilitate cross-border operations, supported by a translation tool.

#### Smart solutions for lower density 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 lines around Europe that have lower usage. 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 controlling technology (e.g. use of satellite positioning) or making such infrastructure devices autonomous in term of energy needs and smart/connected. The previously described Adapted Communication System demonstration results will also be an important basis for the task of this Innovation Pillar with the ability to work with heterogeneous communication networks, including public ones from mobile network operators.

The innovative work based on semantics and ontologies undertaken in Shift2Rail with the delivery of high TRL demonstration of a functional ecosystem in a multimodal complex environment between different cities, regions and countries will be important to offer attractive services to customers who need easy multimodality also to access remote locations. The demonstrations included as well Mobility as a Service integration with ride-sharing possibilities and the final demonstration for a door to door solution includes rail, bus, metro, aviation and all new personal mobility transport modes.

This priority will focus on developing smart solutions for low density lines, allowing to maintain or even revitalise them. Also here a system view is necessary 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 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.

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 road side 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:

* 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, 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.

#### 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 shifts activities address the following (non-exhaustive) list of topics of scientific and socio-economic relevance:

* 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.
* Socio-economic and market influencing factors analysis, including user-acceptance studies.
* Research on emerging technologies, also including mag-lev/propulsion and vacuum tube technologies.
* Research on business, innovation and transport models.
* Research on emerging safety issues.
* Personalised rail infrastructure/vehicle concepts moving over different transport modes infrastructures.
* Multimodal shared-mobility solutions including full integration with other modes of transport.
* Studies of ultra-high speed trains and synergies with non-traditional and/or emerging new modes of transport.
* Impact of innovation on operations and human factors.

### 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 doubling 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. The most evident example is ERTMS where, on the one hand, deployment decisions of some countries did not give consideration to the preparedness of the operators making use of such network(s) and, on the other hand, deployment obligations have been simply ignored contributing to substantially limiting a competitive rail market.

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 consist of European rail representatives, in particular of Infrastructure Managers and Rail Operators, but also of suppliers (from all concerned supplying sectors, e.g. ICT) to ensure the preparedness of products, to advise the JU on the way coordinated and integrated deployment can be organised, in particular on the following elements to be proposed by the JU Executive Director, and in consultation with rail stakeholders (such as users associations, logistics associations, environment NGOs etc.), including a representative of the state representative group:

* 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.
* Consideration of human factors as a result of deployment.
* Ensure consideration of diversity of situations across the Union.
* Alignment of deployment and investment plans.
* Risks and opportunities associated to uncoordinated initiatives.
* Phasing out of existing legacy systems and consideration on the necessary accompanying funding and financial measures.
* 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 governance of the Deployment Group will be established based on the rules of the System Pillar as stipulated in Article 93 2, 3 and 4 of the Single Basic Act.

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.

### 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 Programme of the EU-Rail JU. They may evolve and be amended as part of the Governing Board decision making process on proposals of the Executive Director.

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.

Moreover, EU-Rail will develop 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, Digital Agenda, 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.

# 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.

The KPI model shall be based on input delivered by each of the projects put in place by the JU and reported on a yearly basis, through its Annual Activity Report. Each project will be required to ensure that relevant quantitative and qualitative metrics are provided.

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

As already indicated, the monitoring of the progress and impact of Europe’s Rail will be carried out within a two layered approach. On the first layer, quantitative impacts will be evaluated, originating from technological and operational advances generated by the projects under the different projects.

Then, these will be converted into societal impacts, in the second layer, related to the expected impacts described in Section III. Societal impacts will translate technical (technological and operational) achievements into higher level and more straightforward indicators.

The Deployment Group will play a key role in providing the elements to be considered for the successful market implementation conditions. The benefits of Europe’s Rail innovations will in fact be fully materialised only if these solutions are rapidly and widely implemented in the EU network.

This work will provide transparency for all stakeholders and the broader society on the actual status of delivery on the identified priority areas and, even more importantly, it will help identify and address criticalities, as well as possible re-developments and opportunities, in the most appropriate way.

Layer 2: Societal impact

Layer 1: Quantitative impact

Figure 2 - TBU

1. [to insert when adopted] [↑](#footnote-ref-2)
2. <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en> [↑](#footnote-ref-3)
3. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal\_en [↑](#footnote-ref-4)
4. <https://ec.europa.eu/transport/themes/mobilitystrategy_en> [↑](#footnote-ref-5)
5. <https://ec.europa.eu/info/horizon-europe_en> [↑](#footnote-ref-6)
6. https://shift2rail.org/wp-content/uploads/2020/12/RAIL-Strategic-Research-and-Innovation-Agenda-2020-\_FINAL\_dec2020.pdf [↑](#footnote-ref-7)
7. 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. [↑](#footnote-ref-8)
8. 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 [↑](#footnote-ref-9)
9. 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). [↑](#footnote-ref-10)
10. 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. [↑](#footnote-ref-11)