

Flagship Initiative 4: Innovative EU high-speed rail corridors

Europe's high-speed rail network is central to achieving faster, cleaner, and more connected mobility across the continent. As the EU pursues ambitious modal shift targets and seeks to triple high-speed rail traffic by 2050, the sector faces significant challenges: fragmented national approaches to high-speed development, rising infrastructure and rolling stock costs, inconsistent energy integration, and the need for seamless cross-border interoperability. New high-speed development must evolve beyond today's fragmented architecture, integrating next-generation digital and clean technologies within a single European framework.

At the end of 2025 European Commission unveiled “a comprehensive plan to accelerate the development of high-speed rail across the EU, offering passengers significantly reduced travel times. By boosting fast, comfortable, safe and reliable rail services, the plan supports the EU’s twin goals of becoming carbon-neutral by 2050 and strengthening Europe’s global competitiveness.”¹ The aim of this plan to accelerate investments and harmonising a truly interoperable European high-speed rail network, creating an attractive and competitive framework for rail services, supporting a strong, innovative and harmonised European rail sector and strengthening EU-level governance to coordinate and deliver the vision, fits well under the remit of this Flagship Initiative and the PPP structure of a Joint Undertaking.

The European Commission encouraged to bring the needed underlying technologies to the market, indicating in the high-speed Plan that “the rail supply industry, infrastructure managers and railway companies must continue joint research under the 2028-2034 Horizon Europe programme and the proposed European Competitiveness Fund”.

The Innovative EU high-speed rail corridors Flagship Initiative addresses today’s challenges by developing a harmonised, fully digital, and climate and cyber-security resilient high-speed system that ensures efficient, zero-emission operations across national borders. By unifying traffic management, advancing new technologies, deploying digital twins, pioneering materials innovation, and implementing predictive maintenance within an interoperable European model, this initiative enables dramatic improvements in reliability, cost efficiency, and energy performance.

Those improvements are essential for the realisation of an EU high-speed network. To complete the currently planned TEN-T high-speed rail network by 2040, the European Commission estimated that EUR 345 billion will be required. An independent EU-Rail study estimated that going beyond the TEN-T and tripling the size of the existing EU high-speed rail network at speeds of 250 km/h or above would cost more, but it will also bring significant bigger socio-economic benefit to Europe². Every euro saved during implementation thanks to pre-deployment activities, every unit of electrical energy not consumed and every improvement in asset availability and performance resulting from this Flagship Initiative will directly strengthen the business case and support the successful system-wide implementation of the EU high-speed network.

As indicated in the EC High Speed Plan, “transport infrastructure works as a network, so if a small segment does not comply or is not operational, it can hamper the efficiency and competitiveness of the system as a whole”. Through harmonised corridors implemented as early pre-deployment pilots, the initiative will reduce the risks faced by early adopters and build investor confidence in system-wide deployment. This will ultimately contribute to reducing travel times between major European urban nodes, create seamless multimodal links with regional networks and airports, and strengthen Europe's industrial and technological sovereignty in high-speed mobility. This Flagship Initiative also address additional key socio-economic objectives: balancing the benefits of high-speed connectivity while mitigating territorial exclusion through integrated planning and ensuring equitable accessibility to all regions.

The flagship builds on outcomes of Europe's Rail Joint Undertaking, notably on ERTMS, traffic management systems (TMS), asset management and cybersecurity. While Europe's Rail has provided foundational core technologies, this flagship represents the first dedicated, system-level focus on integrated high-speed innovation at European scale. The initiative will pioneer harmonised pre-deployment corridors serving as early implementation pilots for future pan-European high-speed expansion, testing new

¹ https://transport.ec.europa.eu/news-events/news/commission-launches-plan-accelerate-high-speed-rail-across-europe-2025-11-05_en

² <https://rail-research.europa.eu/publications/smart-and-affordable-rail-services-in-the-eu-a-socio-economic-and-environmental-study-for-high-speed-in-2030-and-2050/>

technologies – including ETCS Level 2-only operations, predictive maintenance, and harmonised EU capacity management—under real operational conditions, ensuring safe, reliable, and cost-effective scaling.

Pre-deployment coordinated activities across EU and associated R&I

Pre-deployment is essential because the transformation that Innovative EU high-speed rail corridors envisions cannot be implemented through isolated national initiatives. Harmonised European high-speed rail mobility requires coordinated testing and validation across multiple Member States to prove interoperability, operational efficiency, and economic viability at system level before large-scale deployment.

Areas of pre-deployment and associated research and innovation coordinated activities for or Innovative EU high-speed rail corridors

1) High Speed automated operations, modular onboard (including full Advanced Safe Train Positioning) and full trackside CCS system solutions for ETCS only operations

a. Context

As indicated in the Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS), the development and deployment of higher levels of automation is key enabler to future operational efficiency, system resilience and increased flexibility across the European rail network. It will contribute significantly to improving service reliability, optimising network capacity, and reducing operational costs while maintaining the highest safety standards. In this context, the automation of the high-speed rail network should be considered a strategic opportunity for the European rail sector, enabling more efficient traffic management, better utilisation of infrastructure, and enhanced passenger service performance across European corridors. The progressive introduction of automated operations up to Grades of Automation (GoA) 3 and 4, supported by modular onboard architectures and advanced safe train positioning technologies, will facilitate a more flexible and scalable deployment of rail services, supported by the new digital railway capabilities. Such technologies will allow high-speed rolling stock to integrate seamlessly with next-generation traffic management systems, enhance interoperability and support real-time operational decision-making. Additionally, in order to address the challenges of increasing costs and complexity it is essential for pre-deployment activities on a full trackside CCS to fully test, validate and demonstrate the operational and costs benefits of an harmonised approach for high-speed rail operation.

Specific pre-deployment activities are considered in this Flagship initiative based on the R&I and harmonisation activities conducted in Flagship Initiative 1, becoming the vehicle that ensures the fast adaptation, validation and integration of automated operations, modular onboard and full trackside CCS system solution in the highly innovated, competitive and visible context of European High-Speed operations. It is of utmost importance to ensure interoperability, safety, operational harmonisation, and compatibility with existing and future signalling and communication systems, including the evolution of the European Rail Traffic Management System (ERTMS).

b. Objective

By 2036, following the completion of the planned pre-deployment activities:

- There will be ATO GoA3 in at least four cross-border high-speed European corridors using harmonised specifications and operational processes, and safety frameworks, as well as relying on equipment from different suppliers
- There will be a fully tested and validated modular on-board system including full Advanced Safe Train Positioning and perception systems enabling reliable and interoperable automated train operations on the high-speed rail network.

- There will be a fully validated end-to-end CCS trackside (with ETCS Level 2) implementation using simplified and harmonised specifications and processes on high-speed rail network

c. Pre-deployment activities

Pre-deployment activity 1: ATO GoA 3

- Pre-deployment and operation of ATO GoA 3 systems on high-speed European corridors across at least 4 Member States, including trans-border high-speed operations by 2036.
- Test and validate at high-speed, including:
 - The definition and application of harmonised operational rules
 - The consolidation of mature ATO specifications
- Revision of processes and associated training/upskilling for staff, with focus on human factors and cultural aspects, in at least five Member States.

Pre-deployment activity 2: future CCS onboard

- Pre-deployment of modular on-board system including full Advanced Safe Train Positioning in High-Speed Train across at least four Member States, including cross-border high-speed operations by 2036.
- Test and validate at high-speed, including:
 - The consolidation of mature specifications supporting modular onboard architectures and advanced positioning functions.

Pre-deployment activity 3: CCS trackside system ETCS L2 based installation

- Pre-deployment of an end-to-end CCS trackside (with ETCS Level 2) implementation using simplified and harmonised specifications and processes on high-speed rail network by 2036
- Test and validate at high-speed , including:
 - Harmonised operational rules and L2 engineering rules together, including degraded mode

d. EU-Rail activities

This work will indirectly build on the ongoing work carried out in EU-RAIL through the EU-Rail input into Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS) R&I and harmonisation activities and will aim at translating these results into pre-deployment and operational implementation in the high-speed railway network.

e. R&I and harmonisation activities

The efforts on High Speed R&I and associated harmonisation activities will be corresponding to the ones identified within the scope of Flagship Initiative 1 - European Simplified and Integrated Railway System (ESIRS) as well as any specific activities for High Speed.

2) Future rail radio communications in high-speed operation

a. Context

As indicated in the Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS), the development of FRMCS Edition 2 will improve the reliability and performance of high-speed rail operation. It will provide new communication capabilities supporting advanced digital railway applications, including higher levels of automation such as ATO, as well as other data-intensive operational and safety services. Reliable, high-capacity and low-latency communication systems are essential for ensuring safe and efficient railway operations at very high-speeds.

Consequently, specific pre-deployment activities shall be considered in Flagship Initiative 4 based on the R&I and harmonisation activities conducted in Flagship Initiative 1 to ensure that European high-speed rail network swiftly benefit from FRMCS next generation.

b. Objective

By 2036, following pre-deployment activities

- There will be a tested and validated solution for high-speed rail operations available for the future rail radio communication system in Europe based on an extended use case set compared to the FRMCS Edition 1.

c. Pre-deployment activities

Pre-deployment activity : FRMCS Edition 2

- Extend the pre-deployment campaign for the FRMCS Edition 2 in high-speed rail operation across at least four Member States, including trans-border high speed operations by 2036.
- Test and validate at high-speed:
 - Consolidation of mature specifications for FRMCS Edition 2
 - Confirm in an ambitious high-speed operational setup both the Satellite Navigation for Safety-Critical Applications as well as the European Satellite Communication for strategic resilience

d. EU-Rail activities

This work will indirectly build on the ongoing work carried out in EU-RAIL through the EU-Rail input into Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS) R&I and harmonisation activities and will aim at translating these results into pre-deployment and operational implementation in the high-speed railway network.

e. R&I and harmonisation activities:

The efforts on High Speed R&I and associated harmonisation activities will be limited corresponding to the ones identified within the scope of Flagship Initiative 1 - European Simplified and Integrated Railway System (ESIRS) as well as any specific activities for High Speed.

3) Future rail traffic and capacity management for enhanced high-speed operations

a. Context

As indicated in the EC High Speed Plan, one of the main obstacles to boosting long-distance and cross-border passenger services is the difficulty in obtaining attractive cross-border train paths. Building on the developments initiated in the Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS), as well as on regulatory aspect on the use of railway infrastructure capacity³, this pre-deployment activity will implement the first commercial solution addressing in a systemic way capacity planning, allocation and traffic management with a strong focus on cross-border coordination and digitalisation. By adapting fragmented national or regional traffic and capacity management systems, not designed for a truly European High Speed network, and integrating them into a standardised, distributed and interoperable platform, high-speed trains can seamlessly cross borders, reducing delays caused by incompatible scheduling, capacity allocation and operational procedures. This streamlines train path requests and optimises network use, enhancing punctuality and service efficiency.

The shift to dynamic, real-time capacity allocation is especially valuable for high-speed rail and a European rail traffic and capacity management approach will be paramount to maximise networks efficiency, ultimately creating a more resilient, user-centric, and environmentally friendly European High Speed rail network.

b. Objective

By 2035, and in parallel to the pre-deployment activities conducted in Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS), Flagship Initiative 4 will ensure that a significant part of the high-speed traffic in Europe benefit from the implementation of advanced Capacity Management Systems (CMS) and Traffic Management Systems (TMS) innovations.

This will be achieved through targeted high-speed pre-deployment activities and, where relevant, the integration of customised high-speed features designed to further enhance the seamless operation of the high-speed rail network and its interface with conventional lines. The outcome will be a more efficient, reliable, and interoperable high-speed rail network, supporting real-time operational optimisation, improved capacity utilisation, and better service quality for passengers across Europe.

c. Pre-deployment activities

Extending the activities foreseen in Flagship Initiative 1, the following pre-deployment activities will be conducted:

- Pre-deployment and validation of digital systems supporting existing European framework across at least four Member States, covering a significant part of the European high-speed traffic by 2036. It will include:
 - improved planning and regulation algorithms
 - implementation of TMS to ATO link for optimised high-speed operations
 - digital operational communication systems
 - pioneering AI-supported traffic management
 - Multi-network capability to enabling seamless operation across national and regional networks.
 - Multimodal integration with airports

³ Proposal for a Regulation of the European Parliament and of the Council on the use of railway infrastructure capacity in the single European railway area, amending Directive 2012/34/EU and repealing Regulation (EU) No 913/2010 (COM(2023) 443 final)

d. EU-Rail activities

This work will indirectly build on the ongoing work carried out in EU-RAIL through the EU-Rail input into Flagship Initiative 1 European Simplified and Integrated Railway System (ESIRS) R&I and harmonisation activities and will aim at translating these results into pre-deployment and operational implementation in the high-speed railway network.

e. R&I and harmonisation activities:

The Flagship Initiative 4 will develop adaptor solutions to enable the integration of harmonised specific trans-European high-speed traffic management functionalities without requiring immediate full-scale system redesign in each country or regions. These adaptors will support interoperability, rapid deployment, and tailored solutions for complex cross-border operational scenarios. At the same time they will ensure future readiness for migration into new standardised and commercially validated European solutions.

Additional efforts on High Speed R&I and associated harmonisation activities will be focusing on specific activities for High Speed not covered within the scope of Flagship Initiative 1 - European Simplified and Integrated Railway System (ESIRS).

4) A cyber secured high-speed railway network

a. Context

The growing digitalization and connectivity of Europe's rail networks made the sector more exposed to cyber threats and vulnerabilities. Additionally, with the creation of a connected European Network of High Speed services, new digital exchanges will be established across countries making the subject of particular relevance in this Flagship Initiative for research and pre-deployment activities. Consequently, the need for harmonised cybersecurity strategy as expressed in Flagship Initiative 3- Resilient Railway (Re²Rail) is also essential for high-speed rail networks across all EU countries.

b. Objective

By 2038, and in line with the objective of cybersecurity pre-deployment activities in Flagship Initiative 3, the most relevant cybersecurity solutions shall be pre-deployed on European high-speed rail network ensuring robust protection, operational continuity and resilience across Member States.

c. Pre-deployment activities

- Develop, test, and validate cybersecurity-by-design architectures for rail systems and demonstrate in high-speed rail operational context.
- Pre-deployment of AI-enabled threat detection systems on high-speed rail network
- Pre-deployment of interoperable incident response mechanisms for rail-specific assets on high-speed network.
- Enable remote traffic operations (RTO) on high-speed network for seamless handover between control centres during cyber or physical disruptions.
- Integrate cyber-physical protection systems for high-speed critical infrastructure, with AI-driven surveillance and anti-drone technologies.

d. EU-Rail activities

This work will indirectly build on the ongoing work carried out in EU-RAIL through the EU-Rail input into Flagship Initiative 3 Resilient Railway (Re²Rail) R&I and harmonisation activities and will aim at translating these results into pre-deployment and operational implementation in the high-speed railway network.

e. R&I and harmonisation activities:

The efforts on high-speed R&I and associated harmonisation activities will be limited corresponding to the ones identified within the scope of Flagship Initiative 3- Resilient Railway (Re²Rail) as well as any specific activities for High Speed.

5) Sustainable, resilient and harmonised high-speed assets

a) Context

Infrastructure is one of the main cost drivers of the rail system. Construction, renewal and maintenance are expensive, and the Letta⁴ and Draghi⁵ reports both highlight this as a structural challenge. This challenge is even more acute for high-speed development, where new civil works and new alignments are unavoidable.

A coordinated European effort in innovation and pre-deployment activities in this Flagship Initiative aims at reducing the cost of upgrading existing lines, renewing ageing components and building new infrastructure.

Additionally, to offer passengers a seamless high-speed journey and an attractive service, both rolling stock and infrastructure assets must be capable of operating under extreme mechanical and thermal stresses, requiring sophisticated maintenance strategies to ensure safety, reliability, and cost-effectiveness. Traditional time-based maintenance approaches result in over-maintenance of some components and under-maintenance of others, increasing lifecycle costs and reducing availability.

The European high-speed rail network is a critical infrastructure that may be affected by external disruptions. It is therefore essential also to preventively ensure that the system is protected against such disruptions. While cyber security aspect is addressed in the previous pre-deployment activity, this activity will focus on enhancing climate resilience.

b) Objective

The objective is to create a European wide approach to developing cost effective and climate resilient infrastructure and maintainable high-speed assets.

For infrastructure, this includes standardised families of core asset types, modular and automated construction methods and harmonised engineering solutions that can be deployed in multiple Member States. The goals are to reduce lifecycle costs, shorten construction and renewal time, improve safety and ergonomics and ensure long term maintainability.

An additional objective is to create economies of scale. When infrastructure components and construction methods are shared across Europe, costs fall and industrial capacity can grow. This avoids the current situation in which each project develops its own methods and interfaces, often without considering long term maintenance or cross border reusability.

Ensuring the availability of the high-speed network under all climate conditions and addressing future climate change challenges is another key objective for providing a reliable and resilient transport service.

Predictive maintenance enabled by digital twins, AI analytics, and comprehensive sensor networks offers the opportunity to optimise maintenance scheduling, reduce unplanned failures, extend asset lifecycles,

⁴ <https://www.consilium.europa.eu/media/ny3j24sm/much-more-than-a-market-report-by-enrico-letta.pdf>

⁵ https://commission.europa.eu/topics/competitiveness/draghi-report_en

and significantly reduce operational costs while contributing to the overall safety of the future European high-speed network. This applies to both for rolling stock and infrastructure, building on the groundwork already conducted by EU-Rail. Through this Flagship Initiative, harmonised maintenance approaches for high-speed rail can be validated across diverse European countries, paving the way for industrial-scale and European-wide future implementation.

c) Pre deployment activities

Pre deployment activities 1 : harmonised infrastructure assets

Pre deployment activities will initially focus on several core infrastructure domains where standardisation and industrialisation would have immediate effect. The following areas remain open for expansion:

- I. **Track and civil assets**
Turnouts are among the most expensive and sensitive assets of high-speed rail network. A small set of European reference families can reduce fragmentation and enable seamless cross-border high-speed operation. Slab track systems, with long life and high capital cost, will benefit from interoperable platforms, while transition modules between slab and ballast (widely used) are vulnerable to accelerated degradation when inconsistent.
- II. **Power and overhead line systems**
Masts, foundations and structural elements vary significantly across countries, complicating high-speed train operation and maintenance. A shared set of structural types will reduce cost and simplify spare management of the future European High-Speed Network. Neutral sections and switching modules should not be project specific.
- III. **Lineside components**
Cable routes, troughing and chambers are installed on every high-speed line and involve substantial labour, making them strong candidates for modularisation and automation. Lineside cabinets and equipment bases are repetitive and suited to consistent physical and spatial interfaces.
- IV. **Structures and drainage**
Bridge and culvert typologies are major cost drivers in high-speed rail construction. Reference designs will avoid repeated engineering efforts and promote cross-border standardisation. Drainage systems, earthworks and soil protection measures are widely used, maintenance intensive and vary considerably between Member States. Standardisation and best-practice design will enhance network reliability and reduce long-term maintenance costs.
- V. **Access and inspection**
Trackside walkways and access solutions appear in thousands of locations on high-speed lines. A small number of shared modules will simplify design, installation and future upgrades while maintaining safety for high-speed operations. Improved access supports logistics, routine maintenance, and rapid intervention, all essential for safe, efficient, and reliable high-speed service.

These domains will form the basis for innovation on which pre-deployment activities can validate a European standardised approach.

Defined pre-deployment will consist in installing, running and validating those assets across at least four Member States by 2035.

Pre deployment activities 2 : Predictive maintenance for high-speed assets

Validation and pre-deployment of:

- Unmanned monitoring vehicles fleet (including drones) for the monitoring of High-Speed rail assets, including enhanced sensors for climate-related deterioration detection.
- Modular Robotic units supported by AI technologies for maintenance/construction/renewal intervention on high-speed lines
- Harmonised railway checkpoints, including high-speed relevant Intelligent Video Gates features for the daily monitoring of critical HS Rolling Stock components.
- Structural Health Monitoring (bridges, tunnels, track) and environmental sensors integrated into the twin; anomaly detection and remaining-useful-life models.

- Centralized Intelligent Asset Management System integrated with Traffic Management Systems for all critical high-speed assets monitoring, from rolling stock to infrastructure, including energy and signalling, so asset condition drives high-speed traffic decisions (speed restrictions, re-routing, maintenance windows, energy savings, etc.) in a safe manner.
- Harmonised onboard condition monitoring standards for high-speed assets.
- Cross-border high-speed maintenance depot interoperability pilots, validating harmonised inspection procedures, certification frameworks enabling high-speed trains to receive scheduled and unscheduled maintenance at qualified facilities.

Defined pre-deployment across at least eight Member States by 2035.

Pre deployment activities 3 : Resilient and Recovering enhanced high-speed infrastructure

Deploy high-speed tailor-made modular and precast infrastructure solutions featuring plug-and-play high-speed trackside equipment designed for rapid replacement during extreme weather events, to restore thermally affected rail tracks, damaged lines or bridges within hours or days.

Pilot wind-resistant high-speed infrastructure standards including enhanced structure design specifications for sustained winds up to 150 km/h and active wind monitoring systems with automatic speed restriction protocols

Deploy Energy Railway Smart Grid in High Speed Lines, integrated with trackside infrastructure and operational monitoring, to optimize the traction network performance, enable real-time power flow control and support efficient energy billing, complementing resilience measures and ensuring reliable high-speed operations under extreme conditions.

Secure power supply resilience for signalling and telecom systems via decentralised, autonomous energy sources (renewables, batteries, fuel cells, hydrogen).

Defined pre-deployment across at least four Member States by 2035.

d) EU Rail activities

This work will build on ongoing work already within Europe's Rail Flagship Area 3 (FA3):

- Assets monitoring technology developments, testing and demonstration activities carried out in FA3, including wayside, onboard and unmanned vehicles
- Outcomes from the Robotics platform demonstrators
- European checkpoints demonstrators developed for mix-traffic operations
- Results from the Wayside Monitoring and TMS link demonstrators
-

This work will also build on the Shift2Rail outcome (IN2TRACK3 project) and Europe's Rail Flagship Area 3 for the validation of enhanced infrastructure asset components.

e) R&I and harmonisation activities

R&I activities should address both design, execution and maintenance solutions. This includes modular and standardised components, automated and robotised construction, maintenance and renewal processes, data driven asset design, lifecycle modelling and harmonised engineering specifications. Additionally, outcome of the FI3- Resilient Railway (Re²Rail) R&I and associated harmonisation activities will be exploited and adapted to pave the way of specific High Speed pre-deployment activities not covered within the scope of FI3.

Impacts

The impacts of Flagship Initiative 4 represent a transformational advancement for European high-speed mobility, delivering enhanced service quality, cost-effectiveness, system optimization, and environmental performance while strengthening European industrial leadership.

Service Quality Enhancement

Reduced travel times between major European urban nodes through optimized operations and higher operational speeds, enhanced reliability and punctuality through predictive maintenance and advanced traffic management, and seamless multimodal integration with regional networks and airports enabling convenient door-to-door journeys.

Cost-effective Solutions:

Reductions in lifecycle costs via predictive maintenance and optimized rolling stock and infrastructure assets utilization, simplified ETCS Level 2-only infrastructure reducing deployment and maintenance costs, standardised European designs enabling economies of scale for manufacturers, and energy efficiency improvements reducing operational expenses while supporting climate objectives.

System Optimisation:

Increases through AI-supported traffic management, harmonised operational rules enabling seamless cross-border operations without delays, validated migration pathways from current systems to simplified future architectures, and enhanced integration between high-speed and conventional networks maximizing overall system efficiency.

Resilience and Improved Security:

Strengthen European mobility through climate-resilient infrastructure designed to withstand extreme weather conditions, ensuring reliable operations despite increasingly frequent climate events. Cybersecure digital systems protect critical high-speed operations from cyber threats. Ensure equitable accessibility across all EU regions through integrated planning that prevents territorial exclusion and improves connectivity for peripheral regions. Strategic autonomy is reinforced through European technological sovereignty in critical high-speed systems—eliminating dependence on non-EU suppliers for essential technologies including traffic management, and cybersecurity solutions.