Europe's Rail

Europe's Rail Joint Undertaking Multiannual Work Programme

Version 4.0
24 June 2025

Manuscript completed in 2025.

Luxembourg: Publications Office of the European Union, 2025

PRINT	ISBN 978-92-95215-30-6	doi:10.2881/5825182	HI-01-25-000-EN-C
PDF	ISBN 978-92-95215-29-0	doi:10.2881/8930141	HI-01-25-000-EN-N

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Table of Contents

Abbreviations

AC	alternating current
ACS	adaptable communication system
AGTU	Air Generation And Treatment Unit
AI	artificial intelligence
ASO	automated shunting operations
ASTP	advanced safe train positioning
ATC	automatic train control
ATO	automatic train operation
ATO-TS	automatic train operation – trackside
ATP	automatic train protection
ATS	automatic train supervision
AWP	Annual Work Plan
B2B	business-to-business
BEMU	batteries electric multi-unit
BIM	building information modelling
CAPEX	capital expenditure
CBO	common business objective
CCS	control, command and signalling
C-DAS	connected driver advisory systems
CDM	conceptual data model
CEN	Comité Européen de Normalisation [European Committee for Standardisation]
CENELEC	Comité Européen de Normalisation Électrotechnique [European Committee for Electrotechnical Standardisation]
CEN/CLC/JTC 20	CEN-CENELEC Joint Technical Committee
CER	Community of European Railway and Infrastructure
COP	coefficient of performance
CR	change request
CS	control system
CTC	centralised traffic control
DAC	digital automatic coupling
DATO	digital automated up to autonomous train operation
DC	direct current
DCM	Digital Capacity Management
DT	digital twin
ED	executive director
EDDP	European DAC delivery programme
EMB	electro-mechanical brake
ENE	Energy
ENISA	European Union Agency for Cybersecurity
ERA	European Union Agency For Railways
ERRAC	European Rail Research Advisory Council
ERTMS	European rail traffic management system
ESA	European Space Agency
ESO	European Standardisation Organisation
ETCS	European train control system
EU	European Union
EU Rail JU	Europe's Rail Joint Undertaking
EUG	ERTMS Users Group
EU-Rail JU	Europe's Rail Joint Undertaking
EUSPA	European Union Agency for the Space Programme
FA	flagship area
FC	fuel cell

FFFIS	form fit function interface specification
FIS	functional interface specification
FMU	Functional mock-up unit
FOC	Functional Open Coupling
FRMCS	future railway mobile communication system
FS	Ferrovie dello Stato Italiane [Italian State Railways]
GB	governing board
GHG	greenhouse gas
GNSS	global navigation satellite system
GoA	grade of automation
H2020	Horizon 2020
HDV	heavy duty vehicle
HIL	Hardware In the Loop
HMI	human–machine interface
HOF	Human and Organisational Factors
HPC	High Performance Computing
HVAC	heating, ventilation and air conditioning
I2M	integrated mobility management
IAM	Intelligent Asset Management
iCCTV	Closed-Circuit Television
IDS	International Data Space
IFC	Industry Foundation Classes
IM	infrastructure manager
IoT	internet of things
IP	Innovation Pillar
IRIS²	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ISO	International Organization for Standardization
IT	information technology
JU	joint undertaking
KPI	key performance indicator
LCC	life cycle cost
MaaS	Mobility As A Service
MAWP	multiannual work programme
ML	machine learning
MS	Member State
NS	Nederlandse Spoorwegen [Dutch Railways]
OD	obstacle detection
OPE	operations
OPEX	operational expenditure
OSI Model	Open Systems Interconnection Model
PEM	Polymer Electrolyte Membrane
PIS	passenger information system
PoC	proof of concept
PRAMS	performance, reliability, availability, maintainability and safety
PRM	persons with reduced mobility
PTO	public transport operator
R & D	research and development
R & I	research and innovation
RAMS	reliability, availability, maintainability and safety
RBC	radio block centre
RES	renewable energy sources
RFC	rail freight corridor
RFF	Rail Freight Forwarder
RST	Rolling Stock
RTM	Railtopomodel
RU	railway undertaking

S2R	Shift2Rail
SBA	Single Basic Act
SC	Scientific Committee
SEMP	system engineering management plan
SERA	single European railways area
SFR	Sector Forum Rail
SOFC	Solid Oxide Fuel Cells
SME	small and medium-sized enterprise
SNCF	Société nationale des chemins de fer français [National Company of the French Railways]
SP	System Pillar
SRG	States' Representatives Group
SRIA	*Rail Strategic Research and Innovation Agenda*
SRS	software requirement specification
STIP	Standardisation and TSI input plan
STP	safe train positioning
SWOC	smart wayside object controllers
TCMS	train control monitoring system
TCO	total cost of ownership
TD	technical demonstrator
TE	technical enabler
TIMS	train integrity monitoring system
TMS	traffic management system
TRL	technology readiness level
TSI	technical specification for interoperability
TT	transversal topic
TTD	trackside train detection
TTR	timetable redesign
UI	user interface
UIC	International Union of Railways
UIC	International Union of Railways
UIP	International Union of Wagon Keepers
UITP	International Association of Public Transport
UNIFE	Union des Industries Ferroviaires Européennes [European Rail Supply Industry Association]
UNISIG	union of signalling industry (UNIFE committee)
UNITEL	union of telecom industry (UNIFE committee)
V & V	verification and validation
V2	version 2
V3	version 3
V2X	vehicle-to-everything

1. About the Europe's Rail Joint Undertaking multiannual work programme

The Europe's Rail (EU-Rail) Joint Undertaking (JU) is the universal successor of the Shift2Rail (S2R) Joint Undertaking and it is established by Council Regulation (EU) 2021/2085 of 19 November 2021 (hereinafter the Single Basic Act (SBA)) ([1]).

In accordance with the SBA, EU-Rail has defined in its master plan ([2]) its priority research and innovation (R & I) activities, overall system architecture and harmonised operational approach, including large-scale demonstration activities and flagship areas (FAs). These are required to accelerate the implementation of integrated, interoperable and standardised technological innovations necessary to support the single European railways area (SERA). The master plan provides an overview of the ambitions and the objectives of EU-Rail and defines a systemic, long-term and result-oriented strategy for implementing R & I in the railway sector.

EU-Rail works towards the EU's twin green and digital transitions.

The objective of the European Green Deal is to reach climate neutrality by 2050, the fit for 55 package sets medium-term greenhouse gas (GHG) emission reduction targets, and the Digital Decade establishes a policy framework to bring Europe to the forefront of digitalisation and automation.

The sustainable and smart mobility strategy lays out the pathways towards digitalising and greening the transport sector and sets specific milestones for the railway sector. The industrial strategy aims at enhancing Europe's industrial competitiveness, including in sectors at the forefront of the twin transitions, such as the rail supply industry.

These EU policy goals are a major reason for the railway sector to undergo a significant transformation – increasing its capacity for the transport of passengers and goods, enabling an increase in the use of rail transport, and achieving additional reductions in the railway sector's GHG emissions. To achieve this change, the sector must address the following challenges.

- Changing customer requirements. Demographic, technological, market and political trends are changing the needs of passenger and freight customers. These shifts, along with disruptive events like the COVID-19 pandemic, require the railway sector to be more flexible than in the past.
- Need for improved performance and capacity. In order to achieve an overall more sustainable transport mix, the railway sector must be able to accommodate increased demand.
- High cost. Rail is currently often more expensive than other transport modes. To be more competitive and support future increased usage, the railway sector must provide more cost-efficient solutions and services than it does today.

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(1) Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe and repealing Regulations (EC) No 219/2007, (EU) No 557/2014, (EU) No 558/2014, (EU) No 559/2014, (EU) No 560/2014, (EU) No 561/2014 and (EU) No 642/2014 (OJ L 427, 30.11.2021, p. 17, ELI: http://data.europa.eu/eli/reg/2021/2085/oj).

(2) Adopted by the European Commission on xx/02/2022 and by the EU-Rail governing board on 1 March 2022.

- Climate change. Rail is the most sustainable motorised mode of transport, as indicated in a recent European Environmental Agency report. Increasing the use of rail transport is necessary to fulfil European climate objectives, and rail assets must be made climate resilient.
- Legacy systems and obsolescence. Rail system assets are procured on the assumption that they will have very long life cycles and are based on national approaches, which makes fast and interoperable transformation difficult.
- Interaction with other modes. Rail networks and the services associated with them in some contexts integrate well with other transport modes, but this must be improved to better serve the needs of customers and make rail more attractive and central to future mobility.
- Increased competition. The European rail supply industry is world leading. However, it faces many challenges at the global level.

This multiannual work plan defines how the EU-Rail JU has designed its activities and structure to achieve the general and specific objectives set out in the SBA, as detailed in the following sections.

In this respect, during the period of its existence, 2021–2031, EU-Rail must do the following.

- Bring to completion and implement the ongoing S2R programme and projects that will also set the baseline for the new programme, including fostering the market uptake of mature solutions, for example those being part of the 2022 technical specification for interoperability (TSI) package. These activities will continue to be performed under the Horizon 2020 (H2020) regulatory framework. In order to ensure projects are monitored at the JU level, the S2R innovation programme steering committees will be convened on a regular basis.
- Implement the EU-Rail R & I programme, established in its master plan and detailed in the following sections, under the Horizon Europe legal framework and the SBA.
- Perform operational activities in relation to its programme, such as outreach and international cooperation in support of EU policy objectives and international commitments.
- Set up an internal management and control system (CS) to ensure the sound financial management, legality and regulation of its transaction to fulfil its corporate, operational, administrative, legal and financial obligations.

Article 5 of the SBA, complemented by the specific provisions of Title IV of the SBA, details the tasks to be performed by EU-Rail to deliver on its objectives.

2. The vision and mission statement of the Europe's Rail Joint Undertaking

The vision of EU-Rail is:

To deliver, via an integrated system approach, a high capacity, flexible, multi-modal, sustainable and reliable integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, for European citizens and cargo.

The mission statement of EU-Rail is:

Rail research and innovation to make rail the everyday mobility.

3. Objectives of the Europe's Rail Joint Undertaking

In addition to the general and specific objectives established in Chapter 1 of the SBA, EU-Rail is entrusted with the following.

General objectives

- Contribute to the achievement of the SERA.
- 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.
- Support the development of a strong and globally competitive European rail industry.

Specific objectives

- Facilitate R & I activities to deliver an integrated European railway network by design, eliminating barriers to interoperability and providing solutions for full integration, covering traffic management, vehicles and infrastructure, including integration with non-standard national railway gauges, such as 1 520, 1 000 or 1 668 mm, and services, and providing the best responses to the needs of passengers and businesses, accelerating the uptake of innovative solutions to support the SERA, while increasing capacity and reliability and decreasing the cost of railway transport.
- Create a sustainable and resilient rail system by developing a zero-emission, silent rail system and climate-resilient infrastructure, applying a 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 for guided surface transport.
- Develop through its System Pillar (SP) a unified operational concept and a functional, safe and secure system architecture, taking cybersecurity aspects into account, focused on the European railway network to which Directive 2016/797 ([3]) applies, for integrated European rail traffic management, control, command and signalling (CCS) systems and automated train operation, which shall ensure that R & I targets on commonly agreed and shared customer requirements and operational needs, and is open to evolution.
- Facilitate R & I activities related to rail freight and intermodal transport services to create a competitive green rail freight system fully integrated into the logistic value chain, with automation and digitalisation at its core.
- Develop demonstration projects in interested Member States.
- Contribute to the development of a strong and globally competitive European rail industry.
- Enable, promote and exploit synergies with other EU policies, programmes, initiatives, instruments and funds in order to maximise impact and added value.

In carrying out its activities, the EU-Rail JU shall seek a geographically balanced involvement of members and partners in its activities. It shall also establish the necessary international connections in relation to rail R & I, in line with European Commission priorities.

([3]) Directive 2016/797 of the European Parliament and of the Council on the interoperability of the rail system within the European Union (OJ L 138, 26.5.2016, p. 44, ELI: http://data.europa.eu/eli/dir/2016/797/oj).

Additional tasks

In addition to the tasks set out in Article 5, the EU-Rail JU, together with the Commission, shall also prepare and, after consultation with the States' Representatives Group (SRG), submit for adoption by the governing board the master plan, developed in consultation with all relevant stakeholders in the railway system and rail supply industry.

4. Legal framework and governance

The legal framework of the EU-Rail JU is described in the SBA and its operational aspects and targets are detailed in the master plan, complemented by the multiannual work programme (MAWP).

This section is not exhaustive and highlights the relevant elements of the legal framework and governance of the JU in relation to programme management.

4.1. Single Basic Act

The SBA sets out the legal basis of EU-Rail and its programmes. The private members of the EU-Rail JU have expressed in writing their agreement and acceptance of the SBA through a letter of commitment. They shall make or arrange for their constituent or affiliated entities to make a collective contribution, defined in Article 87 of the SBA. In this respect, they shall agree to the management principles put in place by EU-Rail in order to execute the programme.

4.1.1. Private members' letter of commitment

The letter of commitment details the scope of the membership in terms of content, activities and their duration, and the members' contributions to the JU, including an indication of the envisaged additional activities referred to in Article 11(1)(b) of the SBA. The letter of commitment does not contain conditions regarding its accession other than those set out in the SBA. Hence, the private members shall contribute to the proper implementation of the EU-Rail programme in accordance with the objectives and requirements set out in the SBA.

4.2. The governing board and their decisions

The governing board (GB) is the decision-making body of the JU. It shall have overall responsibility for the JU's strategic orientation, its operations and its commitment to the relevant EU objectives and policies, and shall supervise the implementation of its activities. In accordance with Article 17 of the SBA, the GB shall, among other things:

- take measures to implement the JU's general, specific and operational objectives, assess their effectiveness and impact, ensure close and timely monitoring of the progress of the JU's R & I programme and individual actions in relation to the priorities of the EU and the Strategic Research and Innovation Agenda, and complementarity with regional or national programmes, and take corrective measures where needed to ensure that the JU meets its objectives;
- assess, accept or reject applications for membership;
- assess, accept or reject applications of prospective contributing partners;
- decide on the termination of the JU membership of any member that does not fulfil its obligations;
- adopt the financial rules of the JU;
- adopt the annual budget and the staff establishment plan;
- decide on the distribution of administrative costs among the non-EU members;

- exercise, in accordance with paragraph 4 and with regard to the staff of the JU, the powers conferred by the Staff Regulations of Officials of the European Union (the 'Staff Regulations');
- appoint, dismiss, extend the term of office of, provide guidance to and monitor the performance of the executive director (ED);
- adopt the Strategic Research and Innovation Agenda at the beginning of the JU and update it throughout the duration of Horizon Europe, where necessary;
- adopt the work programme and corresponding expenditure estimates as proposed by the ED, after taking the SRG's opinion into consideration, to implement the Strategic Research and Innovation Agenda, including the administrative activities and the content of the calls for proposals, and adopt measures for attracting newcomers, in particular small and medium-sized enterprises (SMEs), higher education institutions and research organisations, into the activities and actions of the JU;
- approve the annual additional activities plan;
- provide strategic orientation as regards the collaboration with other European partnerships in accordance with the Strategic Research and Innovation Agenda;
- assess and approve the consolidated annual activity report;
- deliver an opinion on the JU's final accounts;
- make arrangements, as appropriate, for the establishment of an internal audit capability for the JU;
- approve the organisational structure of the programme office, based on the ED's recommendations;
- approve the JU's communication policy;
- unless specified otherwise, approve the list of actions selected for funding;
- adopt implementing rules giving effect to the Staff Regulations in accordance with Article 110(2) of the Staff Regulations;
- adopt rules on the secondment of national experts to the joint undertakings and on the use of trainees;
- set up, as required, advisory or working groups, including in collaboration with other JUs, in addition to the JU bodies referred to in Article 13;
- submit to the Commission, where appropriate, requests to amend this regulation;
- request scientific advice or analysis on specific issues from the JU's scientific advisory body or its members, including as regards developments in adjacent sectors;
- adopt by the end of 2023 a plan for the phasing-out of the JU from Horizon Europe funding;
- ensure the completion of any task that is not specifically assigned to a particular body of a JU, subject to the possibility that the governing board may assign such a task to another body of the JU concerned.

Articles 92, 93 and 94 of the SBA set out the specific composition and functioning of the EU-Rail JU and the additional tasks of its GB.

To be noted that, in accordance with Article 86(5) of the SBA, the EU-Rail master plan constitutes the Strategic Research and Innovation Agenda (SRIA) of the JU. As a consequence, any reference to the SRIA shall be interpreted to the master plan.

In addition to the documents already mentioned, with particular regard to the decision-making process and the programme implementation, the following two GB decisions should be considered:

- rules of procedure of the Governing Board of the Europe's Rail Joint Undertaking ([4]);
- decision of the governing board adopting the revised financial rules of the Europe's Rail Joint Undertaking ([5]).

([4]) https://rail-research.europa.eu/wp-content/uploads/2022/01/GB-Decision-01-2021.pdf
([5]) https://rail-research.europa.eu/wp-content/uploads/2020/01/GB-Decision_11-2019_Revised-Financial-Rules.pdf

4.3. The executive director and their decisions

The ED is the chief executive responsible for the day-to-day management of the EU-Rail JU in accordance with the decisions of the GB. The ED is the legal representative of the EU-Rail JU and has the power to make ED decisions, the purpose of which is to implement the strategic plan and budget of the programme. The ED is accountable to the GB and shall provide the GB with all the information necessary for the performance of its functions.

In accordance with Article 19. 4 of the SBA, the ED shall, among other things:

- ensure the sustainable and efficient management of the JU and efficient implementation of the work programme;
- prepare and submit for adoption to the GB the draft annual budget and the staff establishment plan;
- prepare and, after having taken into account the opinion of the SRG or the public authorities board, as appropriate, submit for adoption to the governing board the work programme and the corresponding expenditure estimates for the JU, to implement the Strategic Research and Innovation Agenda;
- prepare and submit for assessment and approval to the GB the consolidated annual activity report, including information on the corresponding expenditure and contributions from non-EU members referred to in Article 11(1);
- monitor the contributions referred to in Article 11(1), report to the GB regularly on the progress in achieving the targets and propose remedial or corrective measures where necessary;
- monitor the implementation of measures for attracting newcomers, in particular SMEs, higher education institutions and research organisations;
- establish a formal and regular collaboration with the European partnerships identified in the Strategic Research and Innovation Agenda and in accordance with the strategic orientation provided by the GB;
- submit for approval to the GB or to the public authorities board, as appropriate, the list of actions to be selected for funding by the JU;
- assess applications for associated JU members following an open call for expressions of interest, and submit proposals for associated GB members;
- regularly inform the other bodies of the JU on all matters relevant to their role;
- sign individual grant agreements and decisions in his or her remit on behalf of the JU;
- sign procurement contracts on behalf of the JU;
- ensure the programme's monitoring and the assessment of the progress in relation to relevant impact indicators and the JU's specific objectives as defined in Part Two, under the supervision of the GB, in coordination with advisory bodies, where relevant, and in accordance with Article 171;
- establish and ensure the functioning of an effective and efficient internal control system and report any significant changes it undergoes to the GB;
- protect the financial interests of the EU and private members by applying preventive measures against fraud, corruption and any other illegal activities, by means of effective checks and, if irregularities are detected, by recovering amounts that were wrongly paid and, where appropriate, imposing effective, proportionate and dissuasive administrative and financial penalties;
- ensure the carrying out of risk assessments and risk management for the JU;
- take any other measures necessary for assessing the JU's progress towards achieving its objectives.

For a complete description of the functions of the ED, refer to Article 18 of the SBA.

4.3.1. The System and Innovation Pillar Programme Board

The ED is also supported by a System and Innovation Pillar Programme Board (SIPB), which is responsible for providing advice on resources, planning and synchronisation, implementation, change management and monitoring the progress of the programme, and for providing strategic guidance and making recommendations with regard to its management.

The SIPB shall be responsible for providing advice to the ED on:

- resources, implementation and monitoring the progress of the programme (SP and Innovation Pillar);
- identifying risks and opportunities and related mitigating actions;
- providing strategic guidance and making recommendations on the management of the programme;
- solving issues escalated to his attention (e.g. potential resourcing conflicts between the SP and the Innovation Pillar) in accordance with the EU-Rail regulation on programme implementation, and proposing a way forward;
- advise the ED on the need to complement the programme with specific expertise to be contracted as needed;
- assist and advise the ED in any matter of relevance.

The composition of the SIPB shall be:

- chair: EU-Rail ED;
- members:
  a. one representative of the European Commission,
  b. the other founding members,
  c. two representatives of the SP Core Group,
  d. observers who may be invited to attend the meetings on the basis of the agenda points.

The meetings of the SIPB will have dedicated sessions attended solely by the listed other founding members, in particular to address Innovation Pillar programme management or change management aspects.

The SIPB shall meet indicatively monthly.

The ED shall be established by an ED decision and the SIPB after having consulted the GB; he or she shall report at each GB meeting about the work performed by the SIPB.

4.4. The System Pillar

The SP will establish a unified operational concept and a functional, safe and secure system architecture, taking cybersecurity aspects into account, focused on the European railway network to which Directive (EU) 2016/797 of the European Parliament and of the Council applies, for integrated European rail traffic management, CCS systems and automated train operation, which shall ensure that R & I targets commonly agreed and shared customer requirements and operational needs, and is open to evolution.

The main governance bodies involved in the SP are:

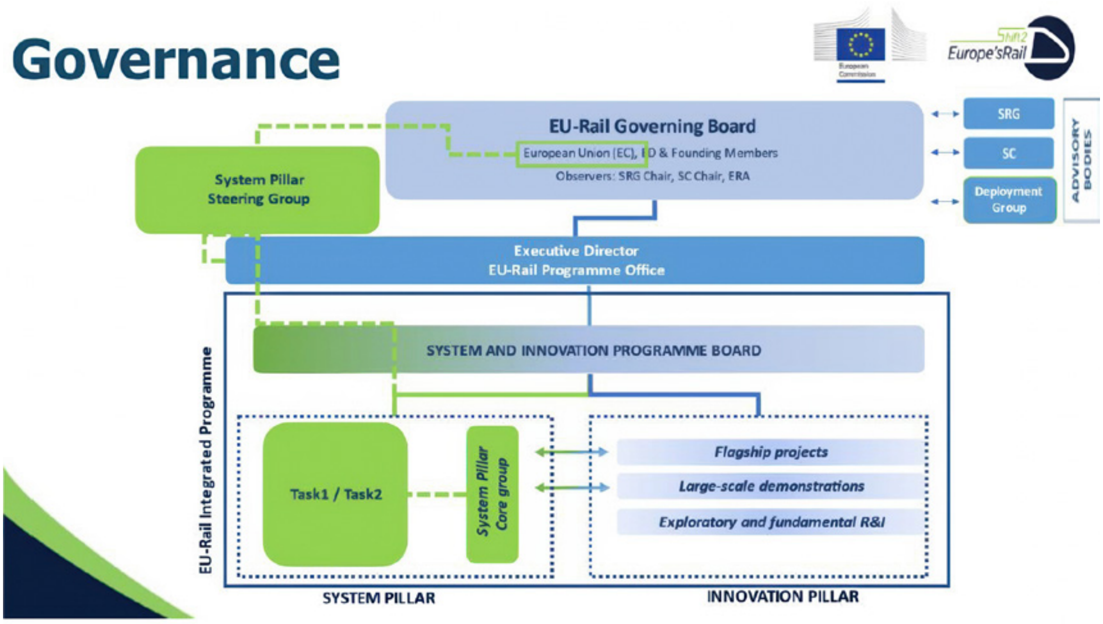
- the EU-Rail GB;
- the SP Steering Group:
  a. oversees the architectural governance, with the support of the core group,

b. decides on:
   » the proposals of the core group, including the overall vision of the SERA system architecture and operational concepts that support it,
   » the SP outputs;

- the SP Core Group:
  a. provides the competent leadership and expertise of the development of the functional layered railway system architecture, specification models and operational concepts that enable safe, secure and efficient implementation of the new systems,
  b. manages the common business objectives and deliverables from the tasks;

- the SIPB, which advises the ED, specifically, on:
  a. the coordination of resources, budgets and timescales of the SP and the Innovation Pillar,
  b. supported by the SP Core Group, project and programme management of the JU, including interaction between the two pillars, and change management and conflicts.

FIGURE 1. **Governance of the JU**



4.4.1. The governing board

The GB shall oversee activities performed under the SP according to the arrangements set out in Article 93(4) of the SBA.

4.4.2. The System Pillar Steering Group

Article 96 of the SBA sets out the following in relation to the SP Steering Group.

- The SP steering group shall be an advisory body of the EU-Rail JU in charge of providing advice on SP issues.
- The SP Steering Group shall be composed of representatives of the Commission, representatives of the rail and mobility sectors and of relevant organisations, the ED of

the EU-Rail JU, the Chairperson of the SRG and representatives of the European Union Agency for Railways (ERA) and of the European Rail Research Advisory Council (ERRAC). The Commission shall take the final decision on the composition of the group. When justified, the Commission may invite additional relevant experts and stakeholders to attend the meetings of the SP Steering Group as observers. The SP Steering Group shall regularly report to the SRG on its activities.

- The SP Steering Group shall be chaired by the Commission.
- The recommendations of the SP Steering Group shall be adopted by consensus. Where no consensus is reached, the ED of the EU-Rail JU shall prepare a report for the GB, in consultation with the ERA and the Commission, outlining the key common points and diverging views, and the SRG shall also prepare an opinion for the GB.
- The SP Steering Group shall adopt its own rules of procedure.
- The SP Steering Group shall be responsible for providing advice to the executive director and GB on any of the following:
  a. the approach to operational harmonisation and the development of system architecture, including on the relevant part of the master plan;
  b. delivering on the specific objective set out in Article 85(2)(c), namely:
     » to develop through its SP a unified operational concept and a functional, safe and secure system architecture, with due consideration of cybersecurity aspects, focused on the European railway network to which Directive (EU) 2016/797 of the European Parliament and of the Council applies, for integrated European rail traffic management, CCS systems, including automated train operation, which shall ensure that R & I is targeted on commonly agreed and shared customer requirements and operational needs and is open to evolution;
  c. carrying out the tasks set out in Article 86(5)(a), namely:
     » to develop in its SP a system view – reflecting the needs of the rail manufacturing industry, the rail operating community, Member States and other private and public stakeholders in the rail sector, including bodies representing customers, such as passengers, freight customers and others, along with relevant stakeholders outside the traditional rail sector – encompassing:
       – the development of the operational concept and system architecture, including the definition of the services, functional blocks, and interfaces that form the basis of rail system operations,
       – the development of associated specifications including interfaces, functional requirement specifications and system requirement specifications to feed into TSI established pursuant to Directive (EU) 2016/797 or standardisation processes to lead to higher levels of digitalisation and automation,
       – ensuring the system is maintained, error-corrected and able to adapt over time and ensure migration considerations from current architectures,
       – 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;
  d. the detailed annual implementation plan for the SP in line with the work programmes adopted by the GB in accordance with Article 94(b);
  e. monitoring the progress of the SP.

In effect, it is the SP's decision-making body, ratifying the SP's deliverables and providing a mechanism to reach consensus, or issue decisions/recommendations where this is not possible.

The composition of the SP Steering Group shall be:

- chair – European Commission;
- Members: CER, EIM, UNIFE, UITP, UIP, chairperson of the States' Representative Group, Executive Director EU-Rail, ERA, ERRAC
- Technical bodies (provide advice to Members): EUG, UIC, UNISIG, UNITEL

- observers – European rail traffic management system (ERTMS) coordinator, European Union Agency for the Space Programme (EUSPA), European Space Agency (ESA), other representative bodies to be considered.

The composition of the SP Steering Group may be changed by the Commission, in line with the requirements of Article 96 of the SBA.

Meeting inputs shall be provided primarily by the SP Core Group, via the ED of the EU-Rail JU.

4.4.3. The System Pillar Core Group

The SP Core Group is essential for leading the day-to-day work of the fulfilment of the SP by managing tasks and supporting the SP Steering Group in its decision-making. This will include:

- providing guidance on the work of the SP:
  a. assessment of outputs,
  b. technical management supporting decision-making within the remit set by the SP Steering Group,
  c. ensuring sector alignment,
  d. supporting SP and Innovation Pillar coordination;

- programme management of the SP;
  a. day-to-day management and fulfilment of SP objectives,
  b. liaising with the SIPB on progress and resource allocation,
  c. continuous monitoring and management of progress,
  d. management of budget and administration;

- managing inputs:
  a. integrating relevant inputs from the Innovation Pillar and sources outside the JU;

- managing outputs:
  a. production and day-to-day management of the standardisation and TSI input plan (STIP);
  b. monitoring that the relevant EU-Rail outputs to the TSI and standardisation process are in line with the overall operational concept and system architecture, and associated principles, and are completed on time and within scope;
  c. reports to the SIPB and SP Steering Group on SP outputs;
  d. day-to-day liaison with ERA, including the ERA Extended Core Team and working group representation, concerning the handling of change requests to TSIs;
  e. handling of standardisation requests.

The SP Core Group will have the resources necessary to be competent in leading the SP's development of the system architecture and operational concept, setting the objectives and checking the quality of the outputs, and validating the proposed inputs for TSI enhancements and harmonised standards.

The core group will work with the Innovation Pillar, subject to the final structure of the latter, to enable, when relevant, the alignment and integration of the flagship projects (FPs) at the railway system level and vice versa.

The core group will also need to manage the resources within the contracts and programmes associated with the SP.

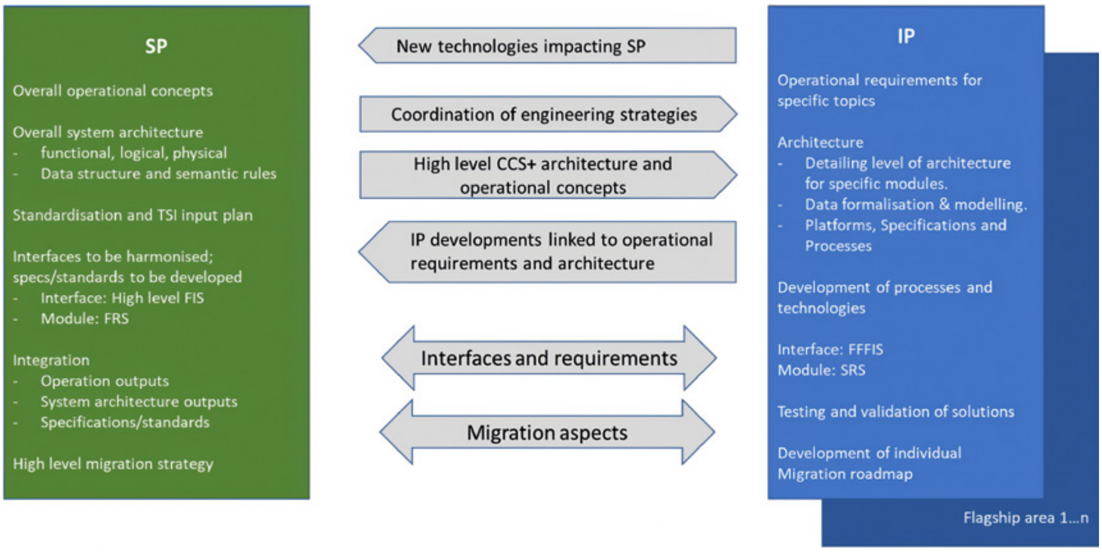
4.5. System Pillar and Innovation Pillar interaction

The SP and the Innovation Pillar of EU-Rail will work together to deliver a coherent output from EU-Rail.

The SP aims to, when relevant, guide, support and secure the work of the Innovation Pillar (i.e. to ensure that research is targeted on commonly agreed and shared customer requirements and operational needs, compatible and aligned with the system architecture), and the Innovation Pillar will impact the scope of the SP where new technologies or processes mean that innovations can drive a change in approach, and deliver detailed specifications and requirements.

The high-level principles of the working arrangements and the relationship between the pillars are set out in Figure 2.

FIGURE 2. **Relationship between the SP and the Innovation Pillar**



The principle of interaction is that the SP proposes the architecture and operational concept and describes this at a high-level FRS&FIS specification level. The Innovation Pillar will develop the technologies and innovation solutions including, when relevant, more detailed form fit function interface specifications (FFFIS) and software requirement specifications (SRS) for the specific systems. The detailed specifications will be verified by the SP to ensure consistency with the overall architecture and operational concept. This will enable integration of the FPs both with each other and within the overall proposed system architecture.

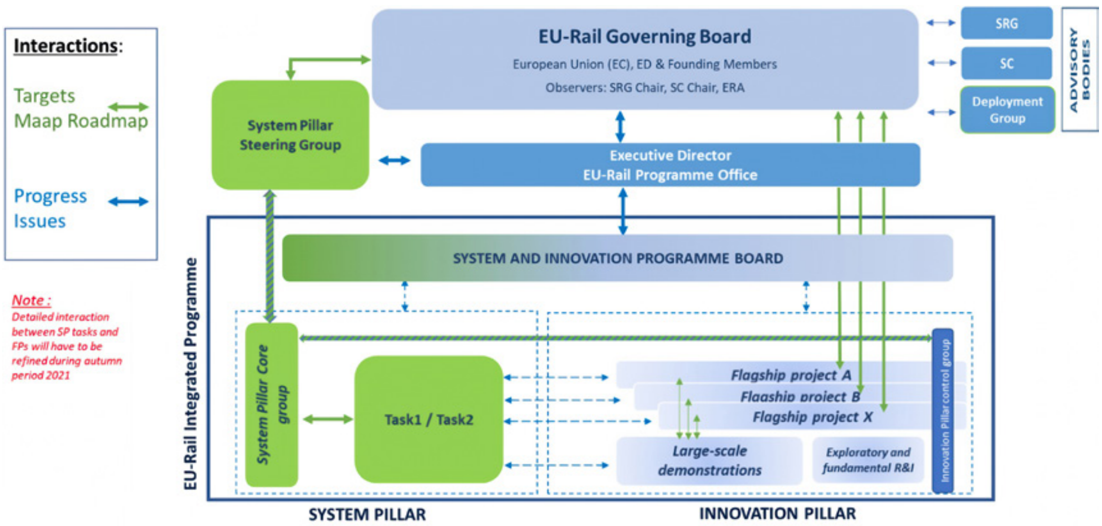
From the results of this joint work, the SP will update the standards and TSI input plan with those draft specifications FRS, SRS, FIS, FFFIS that will allow the next iteration of the future rail system through the ERA process to achieve EU-Rail's goals.

There is a need for an agile and iterative interaction between the SP and the IP:

- the evolution of the EU-Rail JU will produce innovation and new technologies that will require further development of the system architecture, and proposals from the IP will need to be considered and included;

- in case of misalignment between the two pillars or new proposals to consider for the evolution of the SP system architecture, an integrated change management process should be designed (i.e. potential decision affecting grant agreement or reference architecture).

FIGURE 3. **Interactions between pillars**



4.6. High-level Deployment Group

The High-level Deployment Group is a stakeholder group, established in accordance with Article 22 of the SBA, which advises the GB on the market uptake of rail innovation developed by the EU-Rail JU and supporting the deployment of the innovative solutions.

5. The Europe's Rail Joint Undertaking integrated programme

The EU-Rail JU is entrusted to manage and deliver one integrated rail R & I programme, built around two main pillars that are interdependent on each other and on the deployment group.

The SP contributes defining the concept of operations for rail, through a system-of-systems, service-oriented approach, providing the overall framework for the delivery of R & I, taking into account interfaces within different rail segments and other transport modes. These activities should ensure a common approach and efficient use of resources. EU-Rail is the platform for and provides the coordination and resources to enable sector convergence on common solutions at the European level. EU-Rail shall, therefore, coordinate and consolidate all relevant sector initiatives, noting the importance of unified railway requirements. This complements and underpins focusing R & I on impact-oriented solutions. Indeed, the work to define and then maintain the operational concept and functional system architecture will be the framework within which R & I work progresses with logical interactions.

The R & I activities to deliver the concept of operations, addressing the specific segments' interfaces, are structured within the Innovation Pillar and established around the full lifecycle of R & I, from exploratory research, via applied research to large scale demonstrations.

EU-Rail's focus is on key priorities while also addressing the subsystems of the various rail market segments and, where relevant and cost-effective, standardisation or commonly agreed harmonised specifications needed to deliver them. Automation will require converging on digital solutions, artificial intelligence (AI), imaging, robotics, etc., but also addressing sub-components, for example, mechanical, that otherwise would jeopardise the achievement of this transformation. In order to achieve these goals, EU-Rail acts as a single coordinating body to ensure the convergence of the sector towards the aforementioned new concept of operations and the related reference functional system architecture, both addressing different segments. This would allow the right conditions to be set for modular (standard interfaces), scalable, plug-and-play, etc. solutions in view of large-scale market introduction and their evolution.

R & I large-scale operational demos will be one of the major game changers in the impact to be achieved by EU-Rail. Rather than being about coordinating the funding, it concerns integrated R & I large-scale demonstration activities, i.e. moving from small-scale demonstrators (prototypes) in one specific network or lab, to Europe-wide, live, operational, network-scale demonstrations of solutions in a different environment, reaching technology readiness level (TRL) 8/9 ([6]), and showing the benefits of the European deployment of new solutions. This will also be a key component for the inclusiveness of these areas of Europe, and consequently, Member States, which are under-represented in the current rail R & I activities, since they will be capable to contribute to the definition of specifications and demonstrate the benefits of the

([6]) In accordance with Council Decision (EU) 2021/764 of 10 May 2021 establishing the Specific Programme implementing Horizon Europe, all activities in EU-Rail up to TRL 8 can be eligible for EU funding from Horizon Europe. In accordance with recital 31, 'grants should not be awarded for actions where activities go above TRL 8. It should be possible for the work programme to allow grants for large-scale product validation and market replication for a given call under the pillar "Global Challenges and European Industrial Competitiveness"'. Notwithstanding the provisions of recital 31, activities at the level of TRL 9 can be part of the in-kind contribution for additional activities (Article 2(10) of the SBA).

proposed partnership or ongoing programmes, solutions in their operational network and services offered to their customers.

This activity will also support the necessary steps for the regulatory or standards changes needed to bring solutions to the market, completing the virtuous cycle that started with the definition of concepts within the SP, before industrialisation and deployment.

The deployment group will tackle the transition from R & I to coordinated and consistent deployment at the European level, to avoid creating new barriers to a single European network.

6. The System Pillar activities

6.1. System Pillar rationale and outputs

Most railway systems in Europe have been developed at the national level or even at the regional level, leading to a heterogeneous system at the European level.

National markets for rail infrastructure and vehicles continue to operate in a way that has been overcome in other transport modes or sectors. This is typically the case for complex innovation (e.g. implementation of digital automatic coupling (DAC) throughout EU). A common EU railway system architecture has been lacking.

The problem with this is that innovation and changes to the system are very difficult and costly to achieve. Ultimately this undermines the performance and competitiveness of rail.

The EU-Rail SP aims to converge to a more harmonised concept of operations for rail and a functional rail system architecture for the future to support a consistent and coordinated approach to the evolution of the European rail system according to the EU policy goals.

The outputs of the SP are primarily:

- specifications and standards, concerning, among other things, cybersecurity, CCS systems, the traffic management system (TMS) and DAC, to support the Europe-wide deployment of digital systems;
- through the STIP, a coordinated and transparent view of all the harmonisation elements from EU-Rail in order to define a clear and agreed plan for the evolution of the CCS/TMS system, TSI enhancements, and standards, which will support interoperability, modular interchangeability, system integration, robustness, harmonisation and implementation of the SERA, and the role of EU-Rail (both the SP and the Innovation Pillar) in delivery.

6.2. Working method and system architecture considerations

As set out in the SBA ([7]) and the EU-Rail master plan ([8]), the SP considers the overall EU Rail system architecture but with a deeper focus on an integrated ERTMS and CCS.

It considers the properties of the integrated railway system by developing a system view, based on an overall system architecture approach to speed up standardisation, innovation and deployment.

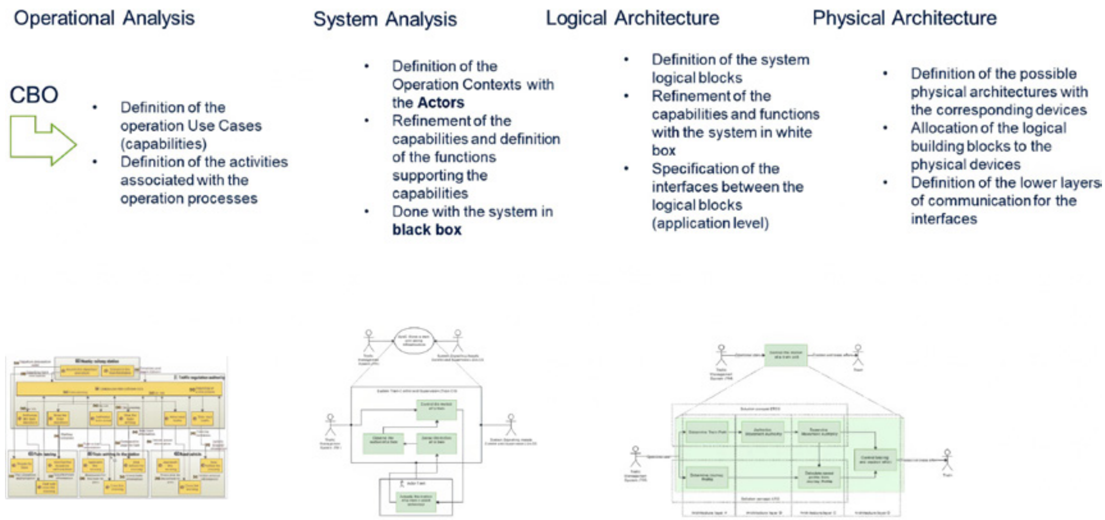
The aim is to harmonise processes, standardise architecture and solutions, and allow continuous (digital) development, contributing to our shared objective: the SERA.

([7]) Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe and repealing Regulations (EC) No 219/2007, (EU) No 557/2014, (EU) No 558/2014, (EU) No 559/2014, (EU) No 560/2014, (EU) No 561/2014 and (EU) No 642/2014 (OJ L 427, 30.11.2021, p. 17, ELI: http://data.europa.eu/eli/reg/2021/2085/oj).

([8]) https://rail-research.europa.eu/wp-content/uploads/2022/03/EURAIL_Master-Plan.pdf.

To achieve an architecture that offers the demanded functional improvements concerning production performance, reliability, quality and cost, and the required architecture quality, the SP follows the defined process, based on the principles of model-based system engineering.

FIGURE 4. **Model-based system engineering process used by the SP to develop the overall architecture**



To achieve the SP common business objectives (CBO) ([9]), reduce costs and create a robust, future-proof railway, the focus is on designing a system based on digitalised and radio-based ERTMS without lineside signalling. This development will be complemented by improvements such as DAC and full digital freight train operations (FDFTO), automatic train operation (ATO), the future railway mobile communication system (FRMCS), improved TMS and other innovations.

The system-of-systems approach is used inside the SP to recursively refine the structure of the architecture down to the level of subsystems. Figure 5 shows the decomposition of a system of systems on one consistent example spanning five levels of refinement. Level 5 is the actual subsystem layer and is visually integrated into the bottom layer in the figure to show its relationship to logical components.

The SP has identified a need to implement a viewpoint-driven approach, emphasising a clear separation between needs analysis, requirement engineering and architecture building. This viewpoint-driven approach complies with some technical processes (stakeholders requirements definition process, requirements analysis process, architecture design process) of the ISO/IEC/IEEE 15288:2015 standard by deriving four generic phases of architecture development: operational analysis, system requirements analysis, logical architecture and physical architecture.

The workflows supporting the described model-based system engineering approach for developing the railway system architecture have been launched. The work comprises both the top-down system engineering approach, starting from the CBOs and operation use cases, and the bottom-up integration of the existing outcomes of previous S2R work or other sector initiatives (such as the open CCS on-board reference architecture and EULYNX). The process steps of the implemented model-based system engineering approach have been elaborated in

([9]) https://rail-research.europa.eu/wp-content/uploads/2022/10/SP-Common-Business-Objectives.pdf.

the system engineering management plan (SEMP) and applied to a first set of operational capabilities.

FIGURE 5. **System levels 1–5, the content is based on indicative CCS/TMS**

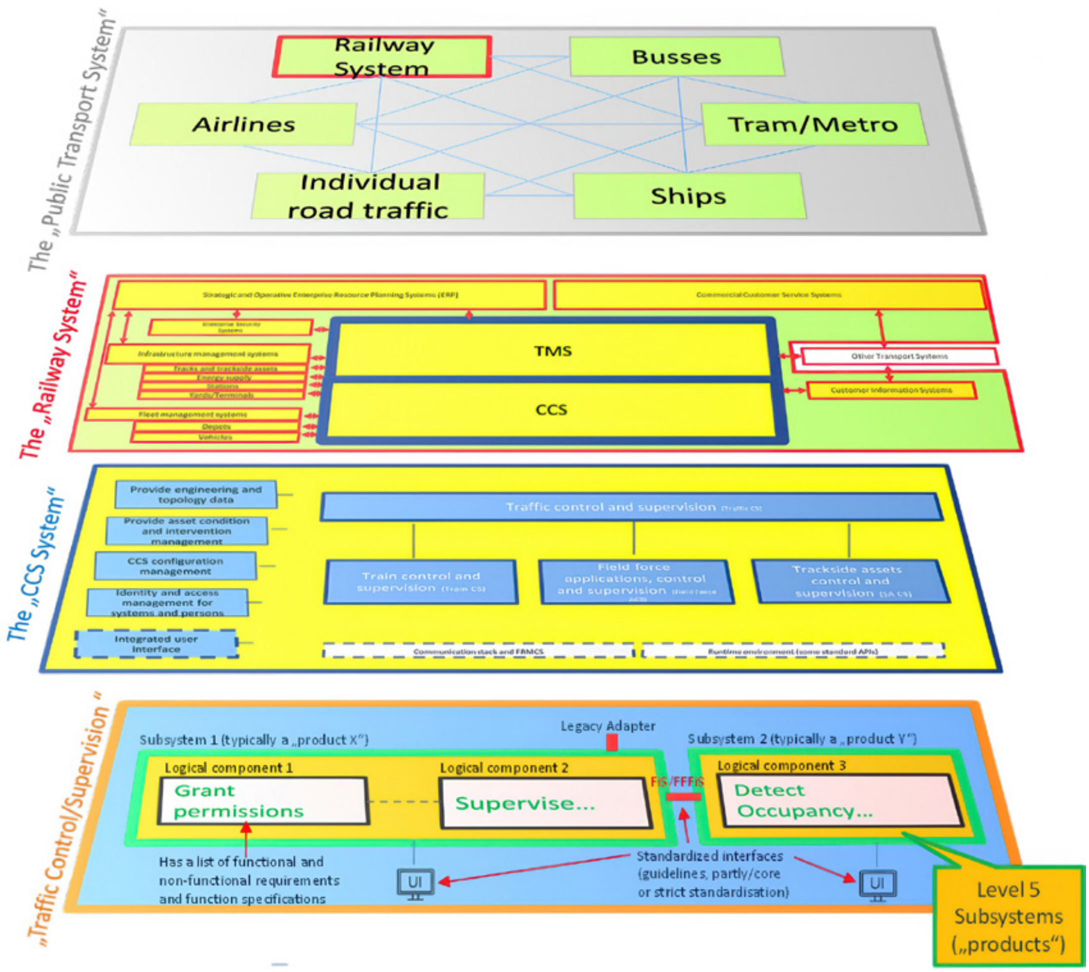
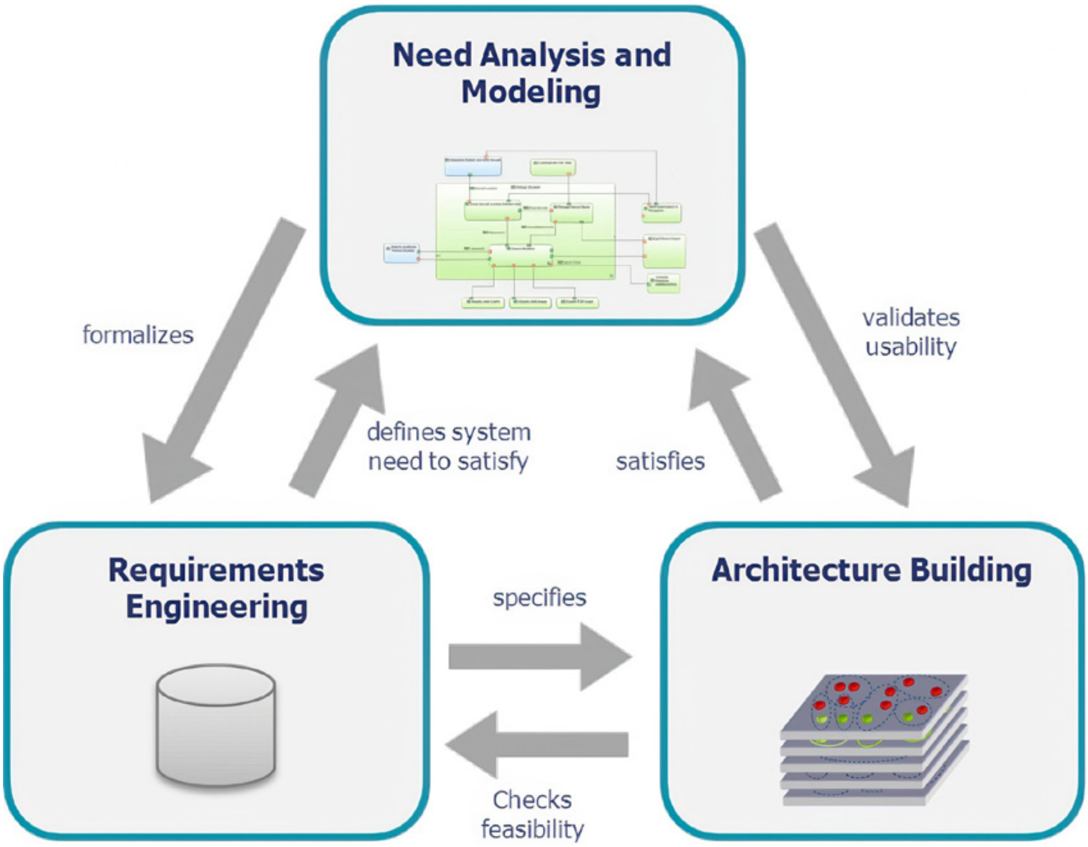


FIGURE 6. **Viewpoint-driven approach (augmenting requirements with models to improve the articulation between system engineering levels and optimise verification and validation (V & V) practices, INCOSE International Symposium, 29: 1018-1033)**



In order to recursively refine the structure of the architecture down to the subsystem level, the SP implements control loops. 'Control loops' refers to the concept of 'control/command' widely used in the railway sector. The control loops provide feedback once an order of action has been sent from a controller to an actuator and are paramount to railway safety (from the overall railway system to smaller electronic boards).

A process control loop is composed of:

- **feedback** for making a review of the document, including quality management (e.g. conformity to the SEMP);
- **controllers** for providing the templates/guidelines to apply and perform spot checking on artefacts provided by each SP domain;
- **actuators** for using the set of documents shared by the controllers;
- **communication of artefacts** to ease the transmission of requirements and documents.

The two types of control loops shall be pushed in SP activities.

Technical control loops aim to:

- define a safety architecture within an SP domain;
- identify the potential interactions with other domains (not exhaustive):
- control actions coming from another domain,
- feedback loops going outside the scope of the SP domain;

- ensure that interconnections of control loops are deeply analysed by all concerned SP domains to avoid a cut in a control loop (e.g. the feedback data provided by SP domain 1 is not consumed by SP domain 2, whereas it should).

Process control loops aim to reinforce the safety and quality management system of the SP:

- the PRAMS (performance, reliability, availability, maintainability and safety) Team gets feedback on how its artefacts are used in SP activities;
- the Engineering Environment Team gets feedback on the deployment of the SEMP in each SP domain;
- the PRAMS Team and Engineering Environment Team are interconnected to avoid any conflicts between system analysis and safety activities.

6.2.1. Why a focus on CCS/TMS?

The regulation and implementation of European rail CCS is of central importance in the running of a safe, efficient, interoperable, robust, cost-efficient and reliable rail service in Europe. CCS deals with all the on-board and trackside equipment required to ensure safety and to plan, command and control movements of trains authorised to travel on the network as well as the efficient integration of maintenance processes that occupy tracks.

Historically, the automatic train protection (ATP) systems developed over time allowed drivers' operation to be monitored (continuous speed monitoring and avoidance of signals passed at red) in each specific EU Member State. Meaning, ATP / Class B (legacy) systems are substantially different in each national railway network, and thus a major barrier to operate one European network.

A central focus at the European level has been the implementation of ERTMS, a major industrial programme to harmonise the automatic train control (ATC) and communication system and underpin interoperability throughout the rail system in Europe. The deployment of ERTMS provides the backbone for a digital, connected SERA. Despite a very slow start, there are now coherent and ambitious plans across the EU to deploy ERTMS and create an interoperable corridor across EU Member States in the upcoming years.

The current harmonisation at the European level, through the CCS TSI, addresses the safety and interoperability requirements, the on-board functions, and the interfaces between trackside and on-board systems related to train protection, signalling the permission to move the train and radio communication. Hence, not the full CCS system.

For trackside CCS beyond that specified in the CCS TSI, there are currently network- or deployment-specific approaches to trackside engineering, operational concept, signalling rules and their interfaces.

The current typical CCS on-board configuration includes multiple proprietary train control and monitoring systems (TCMSs) and Class B driven interfaces between the main train on-board building blocks, which are currently not harmonised. This induces low on-board upgradeability and dependency on the initial suppliers when on-board upgrades are necessary and, consequently, increased cost and complexity.

As a result, even if ERTMS as it stands is implemented in full across the EU, national systems for significant parts of the CCS system would continue, along with national operational rules driving customisation, and a continued overall fragmented CCS market of signalling configurations and rail business models.

This situation significantly increases CCS complexity and reduces the opportunity for more open and competitive markets across Europe. It also creates a system that is not conducive to harmonised evolution and innovation, and induces errors and incompatibilities in the implementation of the TSI-regulated interfaces. Finally, it undermines the performance of the rail system in favour of clients opting for other mobility and transport solutions.

This emphasis on CCS and on ERTMS-only operation is important, as it is in line with the shift to ERTMS across Europe but highlighting that with ERTMS-only operations there is the opportunity for a deeper harmonisation of operational approaches and rules, a simplification of the wider CCS architecture, and the link and integration with TMS.

On this basis, a converging shared vision on future rail operations based on ERTMS-alone Level 2 combined with ATO will set up the baseline for the operational and technological solutions to ensure and continue evolutions of rail.

The focus of the operational and architecture design of the SP is based on a purely radio-based system, including harmonisation of all operational CCS processes in all detailed steps and user–system interactions, down to one single way of using European train control system (ETCS) L2 modes or features, including degraded modes:

- harmonise the engineering rules of ETCS-relevant assets (like balises, boards);
- harmonise all relevant interfaces in the CCS architecture;
- take consideration of links to other expected improvements of the system, for example, for DAC and TMS.

The transition towards a new architecture encompasses more than just an engineering challenge; it signifies a comprehensive transformation that affects operational processes, design, construction and the introduction of new information technology (IT) systems.

In addition, there is the opportunity to develop a modernised and adaptive ETCS L2 safety logic. This approach has significant potential benefits, including increasing the speed of implementation.

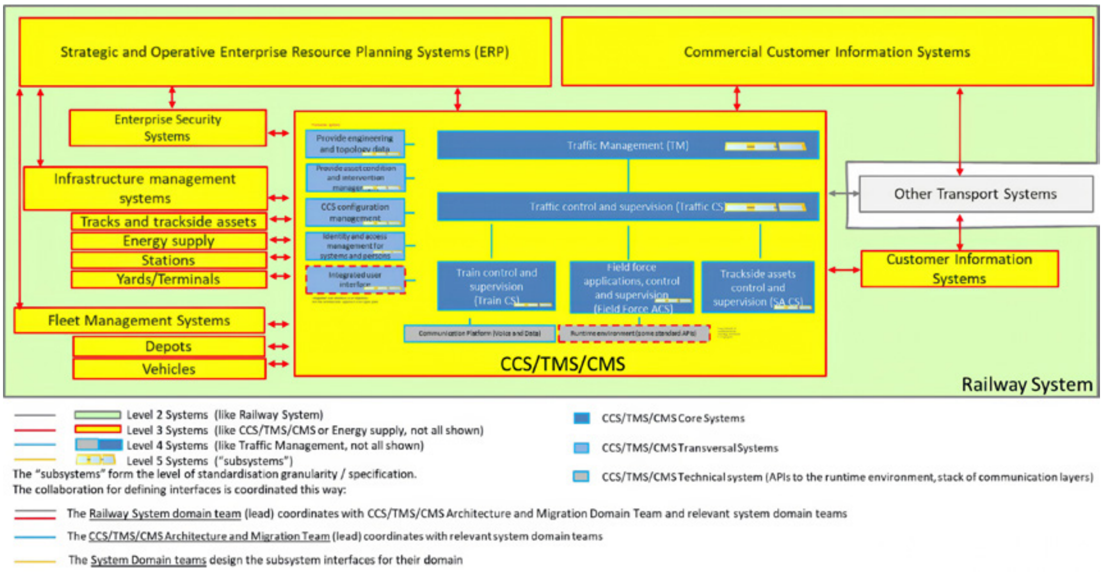
The rollout and design program allows for the introduction of pivotal shifts for the railway sector and its associated industries, including:

- transitioning from a track-based rollout to national and European implementation strategies;
- supporting the move from an operational technology framework to a data-driven IT approach; and
- shifting from isolated national efforts to a collaborative model of joint performance improvements.

These changes are expected to necessitate major adjustments in organisational structures and a re-evaluation of the skills and behaviours of the people involved.

Considering the intrinsic nature of rail as one integrated, complex system of systems, a harmonised, functional and technical CCS/TMS architecture on a systems level is a prerequisite to master complexity and ensure enduring coherence. Managing the complexity requires a common, harmonised and functional CCS/TMS approach between the different CCS and TMS components, with a clear separation between safety-related and non-safety-related layers, where appropriate. In terms of interfaces and dependencies throughout the lifecycle (with designers, operators, maintainers), specific attention must be paid to human and organisational factors.

FIGURE 7. **System of systems, CCS/TMS/CMS architecture**



The role of railways and infrastructure managers is to define the services, performances, and operational needs of the CCS/TMS system to meet passenger and freight requirements. The role of the supplier is to conceive, design and develop the technological and operational solutions of the functional system architecture. The SP shall develop the definition of CCS/TMS architecture requirements and specifications in a joint approach involving the whole sector.

In the case of CCS/TMS system architecture, there is a significant overhaul of the existing architecture. This needs to be done in a manner consistent with the defined operational principles, and bearing in mind the deployment and migration challenges. The goal is general harmonisation at the EU level, enabling integrated European traffic and capacity management.

To achieve this, the SP will coordinate, connect and combine different domains, including operation of the railways (e.g. traffic management planning and execution or driver operational rules), control and command (e.g. ERTMS, ATO, localisation, data preparation), systems engineering (e.g. architecture, specification models, migration strategies, harmonised datasets), assets, human resources, security and safety (e.g. reliability, availability, maintainability and safety (RAMS) and assessment).

No 7 - Figure 7 comprises some initial high-level system architecture diagrams that suggest the direction of the scope of the CCS/TMS architecture, and hence the scope of CCS/TMS.

The control and command train activities can however only be understood within the global control and command process, which can be roughly divided into four successive types of activities:

- strategic activities resulting in strategic decisions and regulatory controls, based on operational information, with the aim of anticipating the future behaviour of the railway system;
- operational activities that lead to operational decisions implementing the strategic decisions, based on control and command information;
- control and command activities leading to control and command decisions that respond to operational decisions while taking into account train-level information and local train-level activities, initiated by control and command decisions, that result in local train-level decisions, integrating local observations and having an impact on the field.

The SP shall therefore also integrate all the upstream anticipating and operating activities driving the control and command trains actions at global control and command and train levels. As a consequence, the technical scope proposed for the SP shall cover the two following interconnected functional domains:

- CCS – control and command of trains (both infrastructure and trains),
- TMS – operating the railway system.

The targeted CCS/TMS system is specified in a modular way with standardised interface specifications between CCS/TMS components and the various off-board and on-board systems with which they are interfaced. In other words, the CCS/TMS shall be divided in a harmonised way, according to a unified European architecture, into a series of modules with standard functions and standard interfaces. This is key for ensuring interoperability and the capacity for system integration, and mastering the evolvability of the railway control and command system.

Functional standardisation is not enough to achieve the interoperability and modularity objective of the SP. Its scope shall therefore also integrate all the safety, security, performance and physical requirements (e.g. technical performances and geometrical constraints) into the various railway components that are key for achieving its goals.

6.3. System Pillar structure of tasks

The SP is managed and led by the SP Unit of EU-Rail, under the responsibility of the ED, within the governance established by the SBA.

It is necessary to define the whole rail system in order to determine the areas of priority and focus. The following two structures co-exist within the SP's organisation of activities.

- **The content structure** describes the work items that need to be built in a certain sequence to create the deliverables. Content structures have many levels of details and are connected in all directions by the 'flow of requirements'.
- **The organisational structure**, built to be as simple (top-down), efficient and effective as possible, defines the team structure and the flow of control.

Regarding the difference between the content structure and the organisational structure, a 'design team' for the business architecture of the railway system cannot be the 'leading' team for all SP projects. Design work and program management is not the same. The task 1 analysis and design team contributes important requirements to the SP projects, but the progress management of the SP is done by the SP Core Group / JU.

FIGURE 8. **First and second level operational breakdown of the structure of the system**

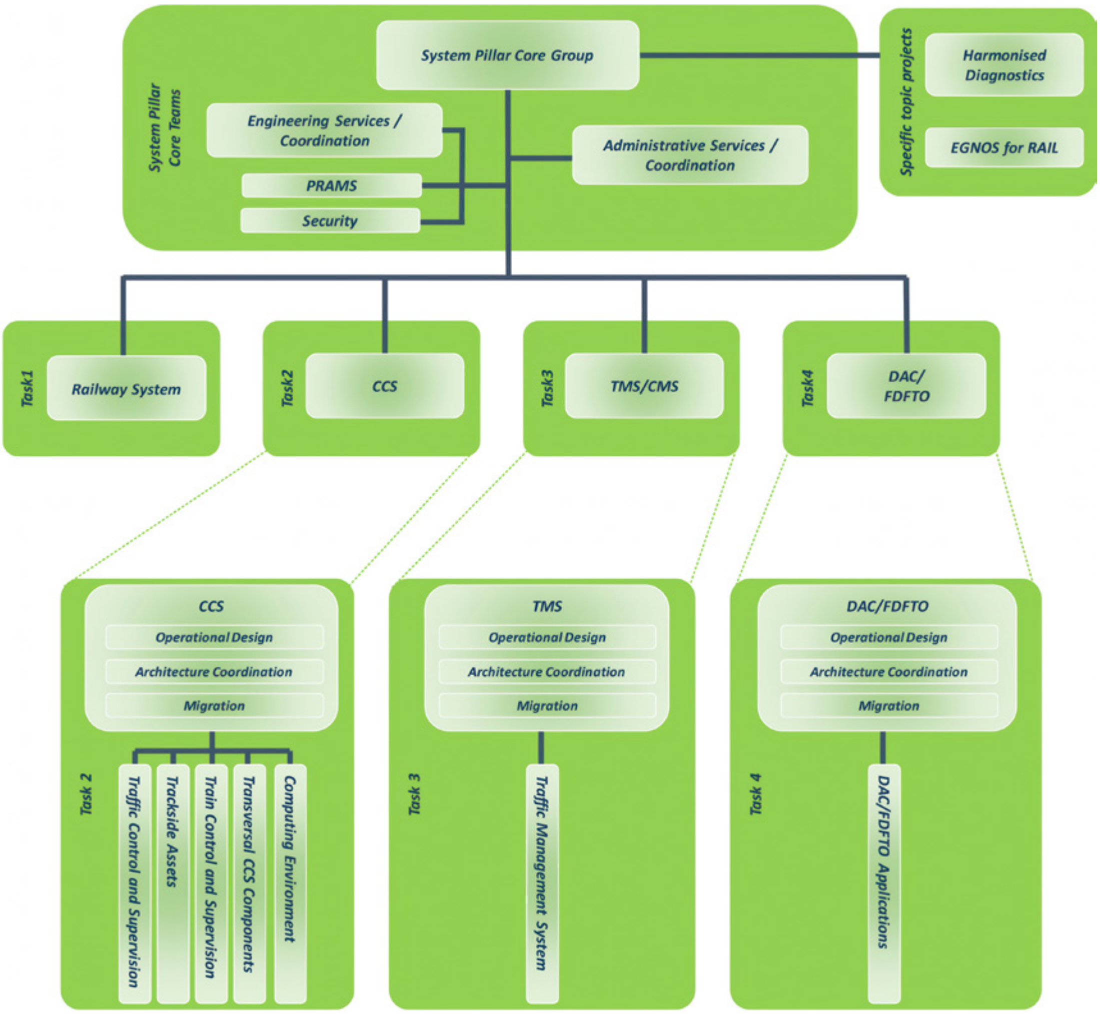


Figure 8. includes the first and second level operational structure of the SP as of 2024. Additional specific projects may be added in the upcoming years as the development identifies new lines of work to fulfil the CBOs.

The roles and responsibilities of the following SP groups are given in the *Europe's Rail Joint Undertaking Governance and Process Handbook* as a summary.

6.3.1. System Pillar core teams

6.3.1.1. SP Core Group

The SP Core Group provides competent leadership and expertise in the development of the functional layered railway system architecture, specification models and operational concepts that enable the safe, secure and efficient delivery of the new systems. Moreover, the SP Core Group manages the common business objectives and deliverables from the various SP tasks.

This SP Core Group has the following responsibilities:

- managing the SP programme;
- handling content and guidance;
- integrating relevant inputs from the Innovation Pillar and/or taking into account input from outside the EU-Rail programme;
- preparing and maintaining the STIP, ensuring alignment with the JU at the rail stakeholder's level and with European standardisation organisations and the International Organization for Standardization (ISO);
- monitoring whether the relevant EU-Rail outputs to the TSI and standardisation process are in line with the overall operational concept and system architecture and whether the associated principles are being delivered on time, in scope and incorporating the successful R & I outputs of the Innovation Pillar's activities (or from S2R programme);
- determining with the JU the liaison with ERA, the ERA Extended Core Team and working group representation, concerning the handling of change requests to TSIs;
- handling harmonisation requests.

6.3.1.2. Engineering Environment Team

The Engineering Environment Team is in charge of the definition of methods (SEMP) and the provision of tools and training (Polarion, Capella, SysML specification environment) for the whole SP.

The Engineering Environment Team monitors the formal quality of the work items, their correct allocation to the tasks and domains, and the consistency, traceability and integrity of the specification. This refers to all work items described in the SEMP, but in particular to the work items of the requirements management, glossary, ontologies, centralised reference lists to external sources, the elements of the models from Capella and the SysML modelling environment, and the structure and consistency of the deliverable templates and documents. This supports the automated model checking/proving process (basic model checks to ensure quality, no fully formal model) for system level 5 specifications by providing the environment and methods.

6.3.1.3. PRAMS Team

The PRAMS Team is in charge of defining the strategy, policies, methods and principles to be followed by the other tasks and domains during the design activities, along with coaching and supporting implementation. The PRAMS Team does not produce PRAMS Analysis, Hazard and Risk Analysis, for system components or system parts; these activities are delegated to a related domain which must include members with PRAMS skills. The PRAMS team is in place to ensure proper coordination and synchronisation.

6.3.1.4. Security Team

Security requirements are coordinated centrally. This includes top-level design and assurance of the security strategies and requirement implementation in the SP tasks, and the specification of the subsystems for monitoring and the system control access.

6.3.2. System Pillar task 1: railway system

The SP task 1 will focus on the European railway network to which Directive (EU) 2016/797 applies.

The system architecture used by the SP needs to be structurally and logically consistent, and reflect the structural reality that, currently, there is no single European railway system.

The scope of task 1 should be ambitious and flexible, to account for the impact of new technologies and processes in the rail sector (e.g. from the Innovation Pillar). This may require a substantial revision of, among other things, safety concepts and the regulatory framework underpinning operations, with the clear goal to harmonise activities across Europe.

Best practice from other industries shows that successful integration of system architecture approaches, especially when moving from current engrained systems like in rail, is to take the opportunity when systems are in any case evolving to put in place the correct system architecture processes and principles.

6.3.3. System Pillar task 2: CCS

The targeted CCS system is indeed to be specified in a modular way with standardised interface specifications between CCS components and the various off-board and on-board systems with which they are interfaced. In other words, the CCS shall be divided in a harmonised way according to a unified European architecture into a series of modules with standard functions and standard interfaces. This is key for ensuring interoperability and the capacity for system integration, and mastering the evolvability of the railway control and command system.

The CCS's task is to develop a harmonised operational concept and functional system architecture for a genuine integrated European CCS system, supported by a model-based systems architecting and engineering approach, beyond the current specifications of the CCS TSI, with much greater standardisation and much less variation than at present. Differences in operation are one of the key root causes for complexity and product diversity and are therefore a major driver of cost. The harmonisation of operational principles where economically possible – in particular under cab signalling and radio-based ETCS – is key to achieve generic CCS solutions, minimise national requirements, reduce life cycle cost (LCC) and achieve operational interoperability. This integrated CCS system shall on the one hand deliver unrestricted movement of trains and on the other hand create a single market for rail components.

CCS – both on board and trackside – shall be based on a standardised modular system architecture using standardised interfaces. In order to preserve investments made, the SP should not only create an adequate interface but also care about migration feasibility (i.e. clear and affordable transition steps) and find paths for moving beyond the current system to one with proprietary interfaces and modular components.

The need for the CCS task comes, as explained in Section 6.2.1, from digitalisation technologies being ready for use in rail, with huge potential to improve passenger and freight services. Digitalisation coupled with automation is one effective way to increase performance and capacity with less investment in new infrastructure. Without high quality architecture, adding new technologies such as these and maintaining compatibility will not be possible.

Task 2 consists of domain teams for cross-cutting activities and (sub)system design activities that need to be managed and coordinated.

- Cross-cutting activities:
- Operational Design Team
- Architecture and Release Coordination Team
- Migration and Roadmap Team
- (Sub)system design activities:
- Traffic Control and Supervision Team
- Trackside Assets Control & Supervision Team
- Train Control and Supervision Team
- Transversal CCS Components Team
- Computing Environment Team

6.3.4. System Pillar task 3: TMS/CMS

Traffic management / capacity management aims to create a long-term to short-term operational plan (production plan) that fulfils customer needs in an optimised way, to prepare and execute the plan, and to predict and react to deviations and events with adapted planning or initiated interventions to solve production problems. The operational plan describes in great detail all types of track usage (train movements, stabling, construction sites, usage restriction areas, etc.).

The task 3 aim for traffic management is to reach a high level of smart and flexible automation and cooperation for its long- or short-term simulation, planning, forecasting and coordination processes (cross-company and across countries) in a way that allows work to be done with an integrated and rolling high-quality plan in near-real-time, based on automated information exchange between all involved planning partners.

The harmonisation of operational processes is a key driver towards a deep and seamless integration of the new services and capabilities, with a specific focus on national borders; this is fundamental for the evolution of the Traffic and Capacity Management System to get an effective Single European Railway Area (SERA).

The basic vision will also include a highly digitalised tactical short-term plan, with the relevant cost-efficient approach to address risks and opportunities.

This will allow task 3 of the SP to achieve the objectives of:

- strengthening the ability to sustain a given service quality, punctuality and safe operation, by completeness of planning, adequate level of information, rapid responses to capacity requests and planning changes, and reducing the impact of disturbances;
- leveraging real-time information and data sharing to get accurate status updates and provide customers rapid alerts regarding traffic congestion and, in general, gather and share valuable data and information;
- enabling more efficient infrastructure usage and improving the prediction of infrastructure capacity needs.

6.3.5. System Pillar task 4: DAC/FDFTO

Coupling is done manually by a worker who must climb between wagons to hook and un-hook them, requiring physically exhausting manual labour in a hazardous environment. A more efficient, sustainable and competitive rail freight system is essential to meet the needs of both climate protection and rising transport volumes. DAC can help create a modern and digital European railway freight transport. It will not only increase efficiency thanks to automation processes, but it will also ensure sufficient energy supply for telematics applications and safe data communication throughout the entire train.

Through the work in task 4, mainly regarding the high-level specifications and providing the system view, the SP will support the improvement of freight train composition, operation and capacity allocations of paths, stabling tracks (e.g. waiting for terminal slots) and shunting (yard) work.

6.3.6. System Pillar specific topics

6.3.6.1. Harmonised diagnostics

The ambitious plans of the EU and railway undertakings are targeting a significant increase in rail usage. This increase means that there will be a need for a higher availability of railway infrastructure and rolling stock but also shortens the time for maintenance for both infrastructure and rolling stock. Thus, fast, harmonised and accurate data sharing among different stakeholders is key for better maintenance.

Previous and ongoing projects have already developed approaches and concepts for standardised data exchange. However, a harmonised European approach for exchanging maintenance data has not yet been established and data which is currently produced by different technologies (e.g. checkpoints) are not harmonised and cannot be exchanged across Europe, hindering the development of the railway sector and blocking business cases.

The initial remit is to select a limited number of examples to demonstrate proof of concept (PoC) European harmonisation on the approach, based on the SP data model. The procedure methodology and proposed solution should be worked out using simple, non-critical and useful examples, keeping the complexity of the task within manageable limits. Therefore, existing and proven systems should be considered, as far as possible, and feasibility demonstrated using non-critical, useful applications and applying a system-wide view.

6.4. Deliverables

The SP is the 'generic system integrator' for EU-Rail and performs the role of architect of the planned railway system. This means that the SP is already preparing and proposing the concept of operations, system architecture, associated standards and specifications, and migration strategies.

As stated above, the general target is to provide specifications – for the whole CCS system and the link to improved TMS – to support a harmonised, digitalised and radio-based ERTMS without lineside signalling. This development will be complemented by known systems, such as DAC/FDFTO, ATO and FRMCS, and unknown potential new customer demands and innovations.

6.4.1. System Pillar core teams

There are defined groups/teams that will develop and provide cohesion within the SP (see Figure 8.). The SP Core Group, the engineering services, the PRAMS Team and the Security Team are responsible for providing the following deliverables.

- **The SEMP**, which is the foundation document for the technical and engineering activities conducted during the project. The Engineering Environment Team has a central and active role in guiding and supporting other teams. Modelling and specification (including

integration of external input) is done in the tasks and domains. The Engineering Environment Team does not contribute to the specification or modelling work itself but actively supports where needed and makes sure that the work of the tasks and domain can be done in an efficient way and with the needed quality.
- **PRAMS targets, requirements and standards** (most of the non-functional requirements) are coordinated centrally. This includes top-level design and assurance of the implementation of requirements in the SP tasks.
- **Security targets, requirements and standards** are coordinated centrally. This includes top-level design and assurance of the implementation of requirements in the SP tasks and the specification of the subsystems for monitoring and for system control access.

6.4.2. Task 1: railway system

The railway system is expected to deliver operational capabilities using many resources and entities. These resources interact throughout the whole life cycle, from design to operation and maintenance. The integration of new technology and new concepts or innovation is usually a complicated effort.

In SP task 1, the business process architecture and operational design (organisational needs, generic automation needs, etc.) for the railway system will be specified, based on and reflecting the common business objectives and the expected future performance, up to system level 2 of the railway system architecture (see Figure 8).

More specifically, the main ambition of the task 1 system levels is to get a list of the needed and important improvements in selected interaction processes. A preliminary analysis should highlight differences in the selected interaction processes between countries represented in task 1 to assess migration issues. For prioritised capabilities, full operational analysis and system analysis should be finalised using the SEMP.

The system view will allow a common understanding in the area of European railway systems the stakeholders' needs, resources and capability to deliver beyond the existing implementation of railway subsystem or products. It will support tackling harmonisation, enable innovation and build capability in the railway system.

These improved business and technical process solutions will, to the extent needed, describe the rationale behind the requirements of the planned target business process architecture and operational design. The design work for task 1 is not intended to describe all process and improvement aspects of the full railway system in full detail, especially when no need for harmonisation inside of the SP is identified.

Specifically, the planned deliverables for task 1 include the following.

Railway system architecture and operational design. Specify the railway system business process architecture and operational design (organisational needs, generic automation needs, etc.) for the (planned) railway system, based on pain points and expected future performance.

The rail system functional architecture will support overall coherence and the coherent evolution of the EU-Rail target system(s), including:

- CBOs, deployment, economic assessment and key performance indicators (KPIs);
- deployment and migratory strategies;
- compatibility, modularity, capacity for system integration;
- conformity assessment strategies, supported by strategic partnerships across EU industrial sectors, and sector strategies aimed at the acceptance of global standards.

Identify high-level input requirements for lower-level tasks from operational interactions. The high-level business process architecture and operational design for the planned railway system should ultimately include:

- consideration of system level 2 railway system architecture of all main railway subsystems, including infrastructure (infrastructure, energy, telecom, civil works), rolling stock, railways operation, maintenance and services.
- consideration and description of important outputs from EU-Rail, such as DAC/FDFTO, within the planned architecture.
- Analysis of concept candidates for target performance and a description of the functional and performance requirements for the planned system.
- identification of the main system concepts (concept of operations and operations concept) that define the capability, quality and performance needed in the system.

6.4.3. Task 2: CCS

Task 2 will focus on the next iteration of the railway system evolution that is focused on the CCS scope, as described above.

The following deliverables are planned to be provided in the upcoming years by task 2.

- **Operational harmonisation**. The work of the operational harmonisation domain connects the needs of the stakeholders to the design process of the operational processes of the future, including the definition of all performance, safety and efficiency targets.
  Therefore, operational harmonisation will include defining the operational target concept as part of the system design process evaluating the root cause of different operational concepts: planning, projecting and implementation engineering rules of radio-based ETCS and their timely harmonisation at the EU level, the translation of CBOs into operational target processes (business re-engineering), the analysis of principles for operational legacy/diversity trade-offs to find a harmonised operational solution design, and the derivation and maintenance of standardised operational requirements.
  The operational processes that are designed will be used to derive the functionality by the architecture domain. They will also be used to check the completeness and correctness of already existing technical specifications that were created from the bottom up. Task 2, led by the OD (operational domain), will ensure the integration of the stakeholder needs of the railway undertaking (RU) and the infrastructure manager (IM) into the operational design in a way that allows CCS procedures to be harmonised in the interoperable interactions and CCS products to be harmonised according to the harmonisation scope of the SP.
- **System analysis**. Task 2, led by the architecture domain and supported by train CS, traffic CS, the computing environment and trackside assets CS, will provide the system architecture, which will include the derivation of system actors from operational actors, the derivation of system capabilities from operational capabilities, the derivation of functional chains and their functions from operational scenarios and processes (based on the operational harmonisation input), the bundling and allocation of functions (perhaps by splitting into logical functions) to logical components (thereby clarifying the system border), the derivation and bundling of the corresponding logical functional exchanges in the logical architecture, the coordination of the work per logical functional exchange, and the derivation of system requirements from the operational design, the system analysis and the logical architecture.
  The operational design, included in the operational harmonisation, will be used to verify the completeness and correctness when it is finalised. Completing these core tasks has a high priority since these form the functional allocation that is needed in all system domains and is a basis for them.

- **Logical architecture**. Task 2, led by traffic CS and train CS, supported by ARC (architecture demain), will refine the technology-agnostic functions from the system analysis into solution-specific logical functions. Besides, the system of interest is no longer treated as a black box: logical functions are grouped into logical components, forming the structural basis of the logical architecture. Logical interfaces between components are defined based on the functional exchanges previously identified.
- **Physical/subsystem architecture**. Task 2, led by Traffic CS and Train CS, supported by ARC, will provide the definition of subsystem architecture that fulfils the generic solution of the logical layer with this one very specific architecture.
  In the subsystem architecture, all technical constraints to the solution are to be added to the core business functionality defined in the logical architecture.
- **Migration and roadmap definition**. Task 2, led by the migration domain, will analyse national situations and product and deployment constraints, design standard architectural migration roadmaps and principles, derive system requirements, design an operational process migration roadmap and its principles and process requirements (including initial intermediate scenarios), propose interface forward and backward compatibility for migration and safe investments, and define migration concepts for existing vehicle designs.
- **Risk evaluation and assessment**. Based on the PRAMS Team and Security Team's new requirements, assessment processes and standards, task 2 will implement and perform, through the development of requirements, a risk management process.

Additionally, task 2 shall coordinate end-to-end issues, especially work for the use of lineside signal ATO, absolute train positioning – including support of the EGNOS projects in EU-Rail – data sharing and management, computing environment definition, engineering and asset data, and ETCS change requests (CR). The target of the coordination is the organisation of the design fragments into different teams, domains and Innovation Pillar FAs. The deliverables provided above shall enhance CCS topics such as the following.

- **Operational harmonisation**. The recommended amendment for TSI operations (OPE) includes operational rules now also described as detailed situation and configuration specific processes for all actors (including signaller), for all degraded modes, and with a binding time-ordered sequence of actor and system actions with defined input and output. The result shall be introduced in three steps: in 2027, as a TSI guideline for using ETCS L2 in a specific harmonised way with ATO grade of automation (GoA) 1/2 and linked to a specific technical implementation; this guideline is recommended to become mandatory in 2030 for those lines that implement the SP target architecture; a guideline for the completed operational rules including ATO GoA3/4 and RTO is planned for 2031.
- **ATO GoA2**. Provide complete system requirements specifications for subsystem 'ATO trackside' (ATO-TS). The focus will be the interface between ATO-TS and the execution/adaptation layer or TMS. Requirements for track-train interface ATO existing FFFIS might be adjusted and/or extended according to the needs of the traffic CS design in the SP.
- **ATO GoA3 and GoA4**. CCS on-board functionality ATO up to GoA4, including degraded mode, provide requirements for interface from ATO-TS to the execution layer, provide complete system requirements specification for subsystem 'ATO trackside' and provide requirements for track-train interface ATO Existing FFFIS might be adjusted and/or extended according to the needs of the Traffic CS design in the SP and a new subset for testing, validation, certification. Upgrade from GoA2 to GoA3/4.
- **Advanced safe train positioning (ASTP)**. With ASTP, an independent CCS component will be specified, allowing for an improved safe localisation of the train independent from the ETCS functionality in the EVC (European vital computer). In a first step (basic ASTP 2027 timeframe), the interface between an ASTP component and the EVC will be specified to prepare for future upgrades, and the odometry performance targets for new on-board CCS shall be considered and may be updated to the state of the art of

available and proven technologies. In the second step (full ASTP timeframe 2032) the functionality of the ASTP will be specified.

- **On board**. By 2027, the modularity will be improved by fully specifying the Ethernet CCS consist of network (one common bus). Additionally, the CCS interface for train length / overall consist length and train integrity will be fully specified for freight and passenger trains. Besides the enhancement of the CCS train interface providing additional information to be used in the vehicle, the interface between EVC and the train display will be harmonised.
- **Trackside assets**. Comprises the specification of the subsystems controlling the trackside objects like points, track vacancy detection, level crossings and others. With this, a unified interface between the Traffic CS system and the object controller should ensure interchangeability between both components.
- **Traffic CS**. Trackside CCS covers the functioning of current interlockings, radio block centres (RBC) and centralised traffic control (CTC) / plan execution (PE) systems. The enhancement of traffic CS comprises specifications for the interaction of the three systems of traffic CS: the PE system, the advanced protection system and ATO-TS. Traffic CS offers the functionality to combine various on-board or trackside sensors to detect train occupation (also known as 'hybrid train detection'), place ETCS movement authorities at fixed (also known as 'fixed (virtual) block') or flexible (also known as 'moving block') positions, and perform supervised manoeuvres.
- **ETCS CR enhancements**. Proposals for TSI CR emerging from the EU-Rail activities (SP and IP) will be identified in the STIP. These can potentially apply to any TSI. The ERA may request support from the SP for TSI CR submitted from outside EU-Rail.
- **Digital asset management, data spaces and models**. Focuses on additions to the data schema and reference data to further support the infrastructure domains, particularly for bridges, roads, rails, ports and waterways, and common foundations, such as alignment, terrain, strata and earthworks. The requested standard should be based on and should at least be compatible with the CCS/TMS data model of the SP and promote the engineering rules for ETCS-only for enabling data preparation for ETCS-only implementation. Resources for this task are partially SP external.
- **Diagnosis and monitoring**. Defines a coherent and comprehensive diagnostic and monitoring system at the CCS level. Subsystem(s) may be introduced that connect via standardised diagnostic interfaces to the CCS and relevant non-CCS components to ensure a dynamic diagnostic and monitoring oversight at the CCS level.
- **CCS interfaces to TMS/CMS**. Consists of splitting the features of a supervision system between the two systems (TMS/CMS and TCS) which implement the former and finalisation of the specification of the interface between TMS and TCS, based on SCI-OP (Standard Communicaiton Interface - Operational Plan).

The obtained results will be integrated through the evolution of the CCS/TMS system, TSI enhancements, and standards, as defined in the STIP.

6.4.4. Task 3: TMS/CMS

TMS and CMS carry out the coordination and execution of the detailed design work for the lower system levels 3, 4 and 5 for the TMS/CMS (see Figure 8), and define detailed operational processes and requirements, functional system analysis and technical architecture.

The planned deliverables of task 3 are as follows.

- **TMS/CMS operational design**, including the activities to define the operational target concept as part of the system design process, translate business objectives into operational target processes (business re-engineering), analyse operational legacy/

diversity/migration trade, design operational solutions, and derive and maintain standardised operational requirements.

- **TMS/CMS architecture and release**, including the activities to define the strategy to be followed to design and release the fully integrated system architecture, collect and evaluate all the existing work (research projects, state-of-the-art documents) as input to design the system architecture, coordinate the work and inputs of the task-architecture-linked domain teams and cross-cutting teams, and the continuous interaction with the IP and the SP Core Group and SP domains to provide and receive inputs and mediate conflicts, design/develop/maintain the system architecture according to the defined principles, the existing work and to the operational concept into functional and logical architecture and verify architecture consistency on a functional and logical level
- **TMS interfaces standardisation** (internal-external interfaces), including standard interfaces from telematics applications for freight (TAF) / TSI modelling new standard interfaces.
- **TMS/CMS architecture and requirements** (allocated to TMS/CMS), TMS/CMS logical architecture and requirements management/maintenance, TMS/CMS physical architecture and requirements management/maintenance, TMS/CMS data sharing management/maintenance, all while ensuring alignment and close cooperation with Innovation Pillar FA1.
- **TMS/CMS migration and roadmap**, including the analysis of national situations and product and deployment constraints, the designing of standard operational process and architectural migration roadmaps and principles, and deriving system requirements. Additionally, the roadmap shall define interface forward and backward compatibility for migration and safe investments.

The obtained results will be integrated through the evolution of the CCS/TMS system, TSI enhancements, and standards, as defined in the STIP.

6.4.5. Task 4: DAC/FDFTO

Task 4 is responsible for managing all cross-cutting activities related to DAC/FDFTO (e.g. regarding operational procedures, architecture and interfaces embedding the on-board system, developed by FP5, into the overall railway system), managing the input to the STIP for DAC/FTDFTO and supporting FP5 regarding the authorisation strategy.

The foreseen deliverables of task 4 are as follows.

- **DAC/FDFTO operational harmonisation**. Review input from the European DAC delivery programme (EDDP) and FP5 on the operational concept, ensuring consistency and including the results in the overall operational concept, including for CCS-related processes in collaboration with task 2, with a focus on the harmonisation of operational procedures controlled by ERTMS (mainly CCS and TMS). Detailed operational procedures in shunting yards are to be developed within FP5.
- **DAC/FDFTO architecture and requirements**. Provide the overall architecture to level 3/4, and associated requirements, within which detailed specifications and architecture (to level 5) are to be developed by FP5. Task 4 shall ensure consistency and take responsibility for the overall architecture coherence of any architecture output from FP5 and the EDDP and embed it into the overall rail system architecture (task 1).
- **Central instance management of data and software (updates)**. The software versions and updates of the DAC system need stringent control to avoid incompatibilities between wagons and locos. Also, access to the DAC data needs to be regulated wayside. Task 4 should analyse the existing solutions in the field of freight wagon management about suitability to be extended for such additional tasks. Task 4 aims to develop a

concept regarding how to share the data generated by the DAC system by locos and wagons with the stakeholders considering data ownership and confidentiality topics.

The obtained results will be integrated through the evolution of the railway system, TSI enhancements, and standards, as defined in the STIP.

6.4.6. System Pillar specific topics

NB: Additional deliverables and/or tasks / specific teams may be added as required if the SP work development identifies the need for it.

6.4.6.1. Harmonised diagnostics

The harmonised European approach for exchanging maintenance data has not yet been established and data which is currently produced by different technologies (e.g. checkpoints) cannot be exchanged across Europe, which hinders development in the railway sector and blocks business cases.

The HERD Team is expected to provide the following deliverable.

- **Harmonised diagnostics concept**. Preparation of a technical concept (requirements for technology and processes; interfaces; embedding in and consistency with planned European structures) for the integration of existing monitoring activities with simultaneous openness for expansion through new use cases or new technological developments. This deliverable includes the detailed elaboration of selected use cases (demonstrators) to describe the added value (technology, (meta-)data, information, framework conditions).

6.5. Europe's Rail Joint Undertaking and harmonisation

As described in the *Europe's Rail Joint Undertaking Governance and Process Handbook*, an important task of the SP is to promote the harmonisation process and removal of national rules ([10]).

The transfer of R & I results of EU-Rail to the EU standardisation and regulation process is a crucial goal for EU-Rail. Such harmonisation plays a crucial role in providing a future-oriented legal framework and ensuring a consistent standardisation system, especially via the introduction of European rail innovations, thus further supporting interoperability, safety and competitiveness.

The SP will coordinate the harmonisation outputs and needs of the EU-Rail programme in the STIP and support the interaction of the related activities of EU-Rail with the ERA and the standardisation bodies (including Sector Forum Rail and RASCOP).

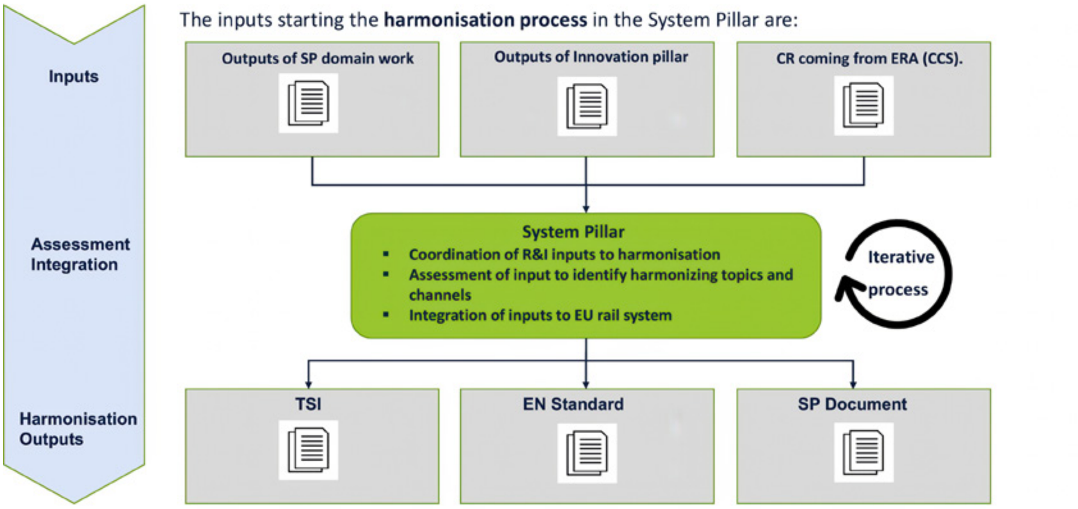
The process aims to support the delivery of mature input to harmonisation channels, respecting existing processes and their ownership and legal status.

([10]) EU-Rail, *Europe's Rail Joint Undertaking Governance and Process Handbook*, Version 2.7, 2025.

In general, the following main harmonisation channels are envisaged (Figure 9) ([11]):

- TSIs and associated documents (e.g. subsets or application guides),
- European standardisation,
- SP documents.

FIGURE 9. **Process for harmonisation of standardisation and regulation activities driven by innovations**



Source: EU-Rail.

The specific harmonisation topics for EU-Rail as a whole will be integrated and delivered in the STIP.

In addition, it is proposed that the SP will support the ERA in its role as ERTMS system authority through an assessment of CCS TSI CRs external to EU-Rail. The support is delivered case-by-case, subject to the availability of SP resources, and does not replace the ERA's responsibilities with regard to the CCM process.

Through the approval of the STIP by the SP Steering Group ([12]), a validated and complete view of the harmonisation outputs linked to EU-Rail will be provided, endorsed by the European Commission, the ERA, the European standardisation bodies and the sector as a whole. This should enable a more strategic alignment of the outputs of EU-Rail with the TSI revision process and the European standardisation process, and the associated Commission request.

The integration of EU-Rail outputs, interfaces and assessment processes into the TSI and standardisation processes is aligned with and does not replace existing Directorate-General for Mobility and Transport, ERA and Sector Forum Rail / RASCOP processes ([13]).

The TSIs define the technical and operational rules which must be met by each subsystem or parts of a subsystem in order to meet the overall essential requirements and ensure the

([11]) Exceptional harmonisation channels can be considered if requested.
([12]) The SP Steering Group is composed of representatives of the Commission, representatives of the rail and mobility sectors and of relevant organisations, the Executive Director of the Europe's Rail Joint Undertaking, the Chairperson of the SRG and representatives of the European Union Agency for Railways and of the ERRAC.
([13]) To note, a revision of the CCM process by ERA is expected, and the processes outlined will feed into this revision process. Once concluded, it may be adapted based on the final agreed CCM process.

interoperability of the EU railway system [14]. This implies the reduction and removal of national rules. Directive (EU) 2016/797 defines the subsystems, either structural or functional, forming part of the EU railway system [15].

For each of those subsystems, the essential requirements are specified and the technical specifications determined, particularly in respect of constituent parts and interfaces, in order to meet those essential requirements. The essential requirements can be summarised as safety, reliability and availability, health, environmental protection, technical compatibility, and accessibility. Additional requirements are interoperability and security (including cybersecurity). Significant amendments to the TSIs are expected from EU-Rail activities, for example linked to DAC, ATO and advanced train positioning.

Standards and standardisation have been highlighted under the Europe 2020 strategy as pivotal in driving EU R & I activities, reaffirming the important role of standards for innovation as sources of competitiveness and in underpinning smart, sustainable and inclusive growth. European projects are now expected to stimulate pre-normative and standardisation activities.

6.5.1. Standardisation and TSI input plan

The SP will develop a strategic STIP of the main changes to be introduced within TSIs (mainly CCS and OPE TSIs) and the Commission's standardisation request. This will include, among other things, new functionalities and rules. This plan will also be made on the basis of migration considerations and alignment with Innovation Pillar FPs, giving rise to an agreed plan and timeline for the evolution of the CCS/TMS system, consistent with the agreed operational concept and system architecture and a clear picture of the role of the EU-Rail JU in delivery, including the allocation of those elements that will be delivered by the Innovation Pillar and the SP.

The proposed categories are outlined in Table 1.

TABLE 1. **Categories for harmonisation [16]**

Category for topic classification		
Category		**Description**
Main section		
C1	Operational harmonisation	Topics related to operational processes and rules
C2	Evolvability and maintainability	Topics aiming at enhanced compatibility between versions and easy maintainability
C3	TMS and CMS	Topics related to enhanced European TMS and CMS
C4	ATO GoA2	Topics related to ATO until GoA2
C5	ATO GoA3/4	Topics related to ATO until GoA3/4
C6	Remote supervision and control	RTO as application independent from ATO GoA3/4 (can come earlier) specific applications (e.g. shunting yards)
C7	ASTP	Topics related to enhanced odometry and localisation systems

[14] ERA, Technical Specifications for Interoperability, 2023.
[15] Directive (EU) 2016/797 of the European Parliament and of the Council on the interoperability of the rail system within the European Union (OJ L 138, 26.5.2016, p. 44, ELI: http://data.europa.eu/eli/dir/2016/797/oj).
[16] Please consider that the list of topics may change/evolve as the project progresses.

Category for topic classification		
Category		**Description**
C8	FDFTO	Topics related to enhanced freight traffic, including DAC
C9	FRMCS	Topics related to the new radio system
C10	On board	Topics related to CCS on-board systems
C11	Cybersecurity	Topics for cybersecurity in CCS systems
C12	Safety management	Topics related to safety in CCS
C13	PRAM	PRAM topics
C14	Trackside assets	Topics related to CCS trackside assets
C15	Traffic CS	Topics related to enhanced traffic CS and interfaces to TMS/CMS
C16	Driving control, adhesion management	Topics related to adhesion management and driving control
C17	Energy management and supply	Topics related to energy management and operational measures
C18	Bridge dynamics	Topics related to vehicle–bridge dynamic interaction
C19	Alternative propulsion, traction energy	Topics related to battery and hydrogen trains
C20	TCMS	Topics related to TCMS
C21	Subsystem components	Topics considering braking, environmental conditions, etc.
C22	Reduction of environmental impact	Topics considering noise, air quality and climate change
C23	Composite materials	Use of composite materials for lightweight design
C24	ETCS CR enhancement	ETCS CR enhancements from the ERA assessed by the SP
Additional topics ([17])		
C25	Digital asset management, data spaces and models	Topics related to data spaces, data models and asset engineering
C26	Digital twin	Topics related to digital twin modelling and the digital register
C27	Virtual certification	Methods for virtual certification and implementation
C28	Zero-Onsite-Testing	Use of simulations and lab testing procedures
C29	Drones	Topics related to the use of drones in railway applications
C30	Field force applications	Topics related to field forces (maintenance staff and machines)
C31	Diagnosis, monitoring	Topics related to diagnoses and condition-based maintenance in railway applications

([17]) The section 'Additional Topics' includes topics with one or more of the following characteristics.
Topics which do not yet have a defined time planning due to the early state and uncertainty in the development process.
Topics which are very innovative and disruptive compared to established technical solutions. Acceptance and uptake by the sector might therefore require additional alignment and coordination.
Topics for which the state of maturity does not allow a scheduled input to harmonisation channels in the short/medium term. Development and specification work is still ongoing, aiming at a higher maturity and the inclusion in one of the next STIP versions.

Through the STIP, the SP will define a clear and agreed plan for the evolution of the CCS/TMS system, TSI enhancements, and standards, which will support interoperability, the capacity for modular interchangeability, the capacity for system integration, robustness, harmonisation and the implementation of the SERA, and the role of EU-Rail (both the SP and the Innovation Pillar) in delivery.

The STIP does not include an explicit prioritisation of the topics. The implementation of the topics depends on the defined expected timeline, considering harmonisation needs and dependencies with related specification documents. The STIP key input will be obtained from the different tasks that conform the SP and from the FPs in the Innovation Pillar, with the aim of forming a cohesive multiannual plan.

Europe's Rail

7. The Innovation Pillar activities

7.1. Flagship area 1 – Network management, planning and control, and mobility management in a multimodal environment

7.1.1. Objective and level of ambition

The main objective of the FA on network management, planning and control, and mobility management in a multimodal environment is to dramatically improve the flexibility, efficiency, resilience and capacity adaptation of the European rail network – supporting the development and operation of the SERA.

The objective is to develop the functional requirements, associated specifications, and operational and technological solutions to enable future European traffic management. This will include the requirements to make common train operations and ticketing possible and enable the design of future network management, planning and control. Such requirements shall be consistent with the layered structure of the target railway system, ensuring clear delineation between standardised and SMS-based (Safety Management System) components. This consistency shall enable seamless integration into the regulatory framework and shall support risk-based operational implementation by RUs and IMs.

In order to achieve an acceleration in the European approach, R & I in FA1 will also consider early implementation of these common functions and approaches starting from existing national TMS. This dynamic network and traffic management at the European scale, built on a harmonised functional system architecture to ensure agile, borderless and mixed-traffic operations, is the target solution that the various legacy TMS should migrate towards.

This extends the capacity planning at the European level and enables the automatic management of cross-border rail traffic. Improved service offers, operations and capacity utilisation reduce the inefficiencies of the door-to door services and enhance the competitiveness of rail-based mobility chains.

7.1.1.1. Targeted objective, new opportunities and associated risks

To achieve the overall objective of dynamic European traffic management, the following streams of improvement have been identified.

- Rail must move away from services with a long planning horizon to a much more dynamic approach that meets the needs of passengers and freight customers. Operators need to be able to adapt quickly to possible deviations or disruptions and last minutes changes in demand.
- Increased flexibility paves the way for smarter and tailored door-to-door services and offers, where mobility solutions meet the expectations of passengers and logistics.
- Maintaining the reliability of rail traffic almost continuously is a challenge. It requires all subsystems that influence the traffic to be connected to the TMS, in order to collect information in real time. Capacity improvements delivered by ERTMS and ATO and other

improvements can be used. Resilience can be improved by closely monitoring any deviations to anticipate problems, and generating the best alternatives using digital technologies.
- This enhanced integration opens the door to a shift towards a more unified European network, contributing to delivering the SERA. Better connection of the rail networks will allow capacity planning and operation to be extended at the European level, enabling capacity optimisation and automatic management of cross-border traffic by predicting and controlling the routes of cross-border trains in European networks and corridors.

The interconnection of rail networks and long-distance corridors (e.g. freight corridors) and the integration of stations and yards will make it possible to optimise capacity, enhance dynamic scheduling and improve the resilience of the connected rail network.

Information related to real-time forecasts of punctuality, available capacity and transport demand makes it possible to adapt the supply to the real-time demand. This ensures that rail remains the central element for the orchestration of sustainable mobility in the future. Additionally, a door-to-door mobility approach is improving the accessibility of rail.

The main risk preventing or delaying the delivery of this ambitious objective remains the lack of coordination and interaction between the various stakeholders, an organisational framework and deployment strategy which is not well defined or not implemented, and potentially the lack of European regulations to enforce it.

7.1.1.2. Innovation beyond the state of the art, including the integration of S2R results

Several innovation streams are proposed for the EU-Rail JU to achieve its overall objectives. A variety of Shift2Rail activities is taken into account.

TABLE 2. **Shift2Rail activities and EU-Rail innovations**

Topic	State of the art, including S2R	EU-Rail JU innovation
Methods and algorithms for capacity planning and management	Advanced algorithmic approaches based on historical data, first AI implementations.	Based on real-time information of the EU-wide TMS, based on AI, machine learning, and statistical or other algorithmic approaches.
Set of external data connected to traffic management	Asset management, external resources (crew, rolling stock), X2R4, S2R integrated mobility management (I2M), Optima using a conceptual data model (CDM) data format.	Extended with energy aspect, yard resources, ATO, other rail networks, but also other transport modes, real-time speed profiles, construction and maintenance plans.
Target scope for planning and operation	National.	European.
Traffic management	Partial automatic algorithms at the national level, X2R4-WP8 enhanced TMS concepts.	Train prediction, smart conflict resolution, decision support.
Planning versus Operation	Iterations at the local/national level, not real time.	Real-time feedback loop between planning and operation.

Topic	State of the art, including S2R	EU-Rail JU innovation
Real-time punctuality and capacity forecasts	National punctuality and capacity simulations (Plasa).	European networks punctuality and capacity simulations.
Capacity interaction nodes and network	Simple functions with a human–machine interface (HMI) (technical demonstrator (TD) 5.2).	Node capacity and departure time prediction, conflict resolution, decision support.
Demand forecast	Preliminary (business analytics in TD4.6).	Activity-based or AI-based models for the whole transport chain.
Overall mobility approach	End-user perspective (IP4).	Offer perspective with rail integration in door-to-door, end-user benefit at connections (information, persons with reduced mobility (PRM)).
Mobility orchestration, with adapted rail as the backbone of the system coping with the mobility demand	None.	Developing orchestration between rail sub-networks in order to move to a more unified European network, and developing open interfaces with other modes so that rail can adapt its traffic operations to the mobility demand.
TMS scalability	None.	Architectural, operational and functional design in cooperation with the SP that allows the same system architecture to be used for both simple regional TMS applications with low effort and more sophisticated solutions for higher traffic densities and complex network topologies.

The interoperability framework from S2R I2M activities will be used as the baseline for all TMS developments.

7.1.1.3. System integration, interactions with the SP and with other FAs

One of the main enablers to drastically improve the rail traffic management in the planning and operational phases is to connect the TMS in Europe with the most relevant resources that have an impact on the traffic, including across borders. This will be developed in close cooperation with sector organisations like UNIFE, UIC, RNE and European rail freight corridors (RFCs).

The targeted traffic management approach and the migratory steps for a successful integration need further in-depth assessment and evaluation for the sector to come to a final decision.

The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initially identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.

- Annex A already identifies certain relevant elements of the interaction, such as specifications (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar's future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

The following interactions with the other FAs were identified.

- Collaboration with FA2 will centre on achieving an overarching system solution by jointly designing interfaces, with SP involvement, focusing on specifications for TMS-CDAS-ATO planning/execution functionality and interfaces. These interfaces will facilitate the exchange of additional information according to project activity results (e.g. train position and speed information, as planned for the safe train positioning (STP) system in FA2, and precise speed control information for movement permissions). FA1 will share concepts, procedures and techniques for traffic management for different types of traffic (e.g. high and low density) and mission profile (e.g. short or long distance) with FA2. FA2 will provide parameters for planning and simulation tools to calculate the capacity benefits of applied digital automated up to autonomous train operation (DATO) technology on corridors, nodes and lines. Results will be shown in joint demonstrations, for example together with FA6, for the provision of the 'simplified TMS' demonstrator platform.
- Interaction with FA3 (asset) will secure the exchange of information between TMS and the intelligent asset management (IAM) system, enabling the sharing of data such as maintenance plans, predicted disturbances, asset status following, topics initiated in the Shift2Rail I2M workstream. Both FAs will be aligned to feed cooperative planning tools in FA3 with train planning and operation information to balance the impact on train service and asset management, including possession planning and possession management tools.
- FA4 (energy) will interact with the TMS to optimise the timetables and reduce the fleet's energy consumption. Consideration will be given to leveraging slack periods in the real-time timetable to send targets to the trains, enabling energy-savings and transmitting information about the on-board system's confidence in meeting the punctuality target.
- FA5 (freight) will benefit from cross-border planning and the connection of TMS with automated yards and ports, and the management of the yards themselves in the seamless freight corridor showcase. Cooperation is planned for demonstrator-related activities, such as interfaces with yards, with real-time data exchanges between various resource management systems. Cooperation will also exist in the area of DAC, with real-time data exchanges concerning, for example, train composition information and train integrity.
- TMS will support the **regional rail services (FA6)** by considering FA6 requirements for TMS to provide a simplified TMS and on-demand passenger services requesting flexible timetabling.
- With respect to **FA7**, cooperation regarding the introduction of specific capabilities provided by the FA7 innovative systems in the TMS is envisaged.

Details of the exchange between the FAs can be found in Annex B.

Regarding the transversal topics (TTs), the asset models behind traffic management and planning will need to be linked to digital twins of the future rail network and related operations. Other aspects, such as demand forecasts, capacity optimisation and real-time disruption impact analyses, will also benefit from digital twins.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the functionality and data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT for:

- the CDM,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

7.1.1.4. Roles and responsibilities by stakeholder group

IMs and RUs define the main challenges, use cases and functional needs. Together with system suppliers and academia, they specify, prioritise and cluster demonstrators to ensure that a wide range of improved processes and state-of-the-art technological developments are covered. IMs and RUs host the demonstrations and provide test facilities.

Suppliers and technology providers propose solutions for identified use cases and functional needs. They define the technical requirements and interface specifications, in line with the SP architecture, develop the solutions and contribute to designing adequate demonstrations. They deliver products and systems, and support the integration within the demonstrations.

Research institutions and universities plan, develop, study and evaluate demonstrators together with IMs, RUs and system suppliers, and coordinate dissemination activities. They contribute to the process of innovation, and to the procedural aspects for validation, certification and homologation.

The SP will have a close connection with FA1, as TMS interacts with many subsystems within CCS+ (combination of ATP systems, automatic train supervision (ATS) and ATO, which together represent an evolution of the current CCS subsystem)or at the rail system level. To achieve dynamic traffic management, new operational concepts will have to be developed and many specifications and processes will need to be defined or modified.

7.1.1.5. Interaction with other programmes, European and/or national

The FA on network management, planning and control, and mobility management in a multimodal environment is connected with other programmes, projects and initiatives, developing complementary aspects or implementing respective solutions.

The work of EU-Rail will define the future European approach to traffic management, including the capacity planning and timetable redesign (TTR) process. Other related programmes should align their work with the overall future approach.

Other related programmes (e.g. RNE, Forum Train Europe) have a close connection with FA1 to ensure alignment with IMs' requests regarding capacity management and traffic management, and to ensure the integration of RNE/sector initiatives/projects into the SP and propose recommendations on demonstrations.

The RFCs, along with others, such as public transport operators, should be considered for a role in the demonstration activities.

Additionally, there are some national R & D programmes with which any direct overlap will be coordinated to prevent double funding.

7.1.2. Results/outcomes

7.1.2.1. Operational solutions outcome

Improving strategic and tactical planning of the rail network

The objective of FA1 activities will be to overcome the main pain points that the railways are facing (mainly lack of flexibility, efficiency and resilience in planning and capacity adaptation, and handling a cross-border train as two or more trains rather than one) and to ensure an enhanced, interoperable planning and management of Europe-wide railway timetables, improving the quality of planning, which is the systemic fulfilment and balance of all related requirements, including efficiency, robustness, efficient reserves and fair trade-offs.

The improved functionalities and performance of planning and simulation software enable the automation in decision support systems (e.g. for supporting the management of short-term path requests), enhance conflict resolution and optimise the deployment of resources such as network, crew, rolling stock and energy, thus boosting the efficiency of the rail network and its operations.

An important component often envisaged in future planning processes, i.e. coherence with external services and operational technologies, will be ensured by already taking into account the related driving modes and on-board technologies at the planning stage. This specifically addresses the areas of cross-border planning, yard and station processes, traffic management and ETCS or ATO engineering.

The innovations will be integrated/connected and used with state-of-the-art systems, to demonstrate the functionalities and the capability to be implemented for production use.

Such activities will lead to increased punctuality, along with reductions in energy consumption and CO_2 emissions.

Increasing the resilience of a connected real-time rail network

Another output of the activities carried out in FA1 will be the improvement of real-time railway traffic management and operations with the goal of providing a more agile, optimised and automated response to unplanned situations, such as disturbances and dynamic demand, especially in cross-border traffic situations. This will lead to significantly enhanced TMS technology capable of supporting interoperable traffic management at the European level, which will increase the resilience of a connected real-time rail network in Europe.

This outcome will be achieved by deploying the latest available methodologies and technologies based on best practices and operations research, new signalling technologies (for example ATO, ETCS level 2 and hybrid level 2) and software/algorithms, or developing improvements thereof. The resulting capacity gain will be enabled by the new TMS technology feeding field or on-board train control components with optimal timing and routing requirements.

In order to support a Europe-wide traffic management approach, it is essential to address the customer requirements concerning a simplified, efficient and performant cross-border traffic system. This includes requirements like the optimisation of the quality of cross-border train paths in the scheduling process (e.g. resource negotiation with subsystems), and the corresponding real-time management of deviations. An optimised overall system architecture and operational workflows have to be developed together with the SP.

The mentioned activities allow for a more accurate modelling of operations and train behaviour and thus, a more effective operational use of network capacity (including resources, yards, terminals). The resulting international and national train flow optimisation and improved flow of information lead to a reduction in delays and a higher level of comfort.

The standardisation of interfaces and processes will facilitate this objective and will also reduce the expenditures and the operational cost of the resulting technology, supporting the future EU traffic management approach.

Integrated rail traffic within door-to-door mobility

To achieve the target of rail becoming the backbone of door-to-door mobility, it is essential that the offer is attractive and reliable, and therefore competitive with private cars and purely road-based truck transport. At the same time, the offer and the operation of the services need to be improved in terms of cost-effectiveness for all the involved operating companies, to allow them to increase the service offer step by step. Functional definitions of planning, timetable redesign and multimodal synchronisation processes, including standardised interfaces, will be structured for future integration into the existing harmonised operational references. This would enable improvements at the operational level and allow harmonisation to be broadened, where feasible.

This will be achieved by a number of enablers for an improved real-time door-to-door offer planning and management. It includes a better information exchange between operators (for operational issues), long-term and short-term demand predictions for all parts and stretches of the chain, and systems for dynamic best offers (including real-time availability of resources and network constraints). Additional enablers are improved accessibility and attractiveness at the interconnection, specifically for PRM.

This operational enhancement aiming at a more reliable and flexible door-to-door mobility ecosystem, in combination with a more effective use of vehicle/train capacity, will result in a reduction in CO_2 emissions. Furthermore, it will support the public transport market and ensure that rail remains the central component of sustainable mobility.

7.1.2.2. Technical enablers: capabilities to achieve the desired operational outcomes

To achieve the operational outcomes targeted in this FA, several technical capabilities were identified. To develop flagship demonstrations, some functions must be delivered with enough maturity, indicatively above TRL 7. An estimation of the TRL of the capabilities for 2026, 2028 and 2030 is provided in Table 3.

TABLE 3. **Technical readiness of the capabilities in FA1**

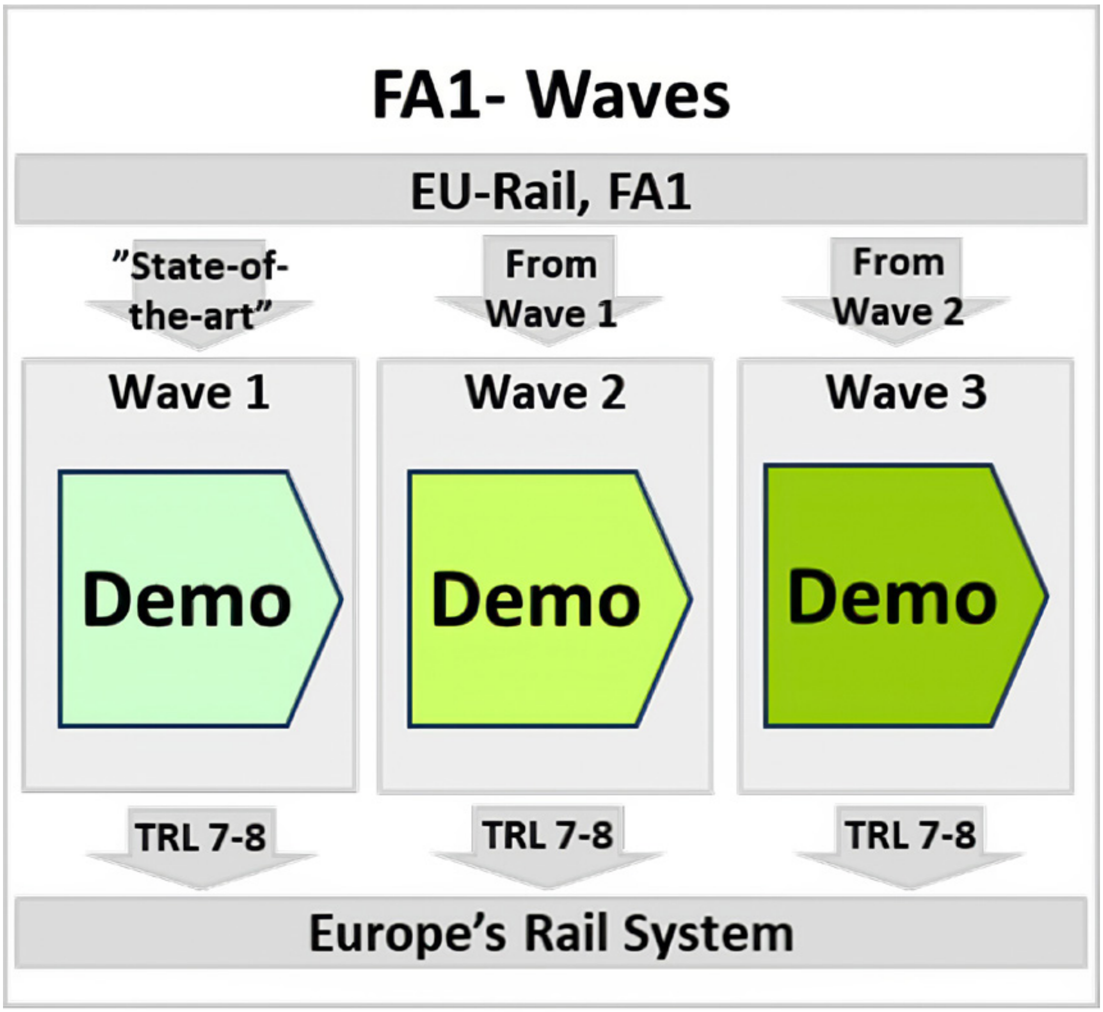
Capabilities (functions/services) enabling operational objectives	Up to TRL		
	By 2026	By 2028	By 2030
Improving the strategic and tactical planning of the rail network	**D1**	**D4**	**D7**
1. European cross-border scheduling with international train path planning and improved capacity allocation using rolling planning and TTR.	6	7	7/8
2. Decision support for short-term planning.	6	7	7/8
3. Train path and schedule optimisation methods and strategies for capacity efficiency, punctuality and energy efficiency for various parts of the network and various traffic situations (level of punctuality).	6	7	7/8
4. Improved rail traffic simulation models for selected use cases to forecast punctuality in the network (e.g. simulating proportion primary and secondary delays, simulations drivers versus ATO over ETCS).	7	7	8
5. Integration of planning systems and TMS with yard capacity planning and station capacity planning.	6	7	7/8
6. New planning and operational processes using feedback loops from ERTMS ATO and the connected driver advisory system (C-DAS).	6	7	–
Increasing resilience for a connected real-time rail network	**D2**	**D5**	**D8**
7. Real-time connection of rail networks as managed by TMSs and involved stakeholders, and modelling and decision support for cross-border traffic management.	6	7	7/8
8. Integration of TMS with the yard management system and processes, the station management system and processes, energy management (electric traction system) and real-time crew / rolling stock dispatching.	6	7	7/8
9. HMI for TMS based on user experience design and user input.	8	–	–
10. Real-time convergence between planning and feedback loop from operations (TRL 4/5).	5	6	7
11. Cooperative planning multi-actors within rail.	5	6	7
12. Integration of incident management and customer information, with IM and RU interaction and decision support for disruption management.	5	7	7/8
13. TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables.	5	7	7/8
14. Automation of very-short-term train control decisions and real-time conflict detection and resolution for main line and optimisation.	5	7	7/8

Capabilities (functions/services) enabling operational objectives	Up to TRL		
	By 2026	By 2028	By 2030
Integrated rail traffic within door-to-door mobility	**D3**	**D6**	**D9**
15. Improved rail integration using business-to-business (B2B) intermodal services leveraging existing European standards. This covers aspects of cross-operator information sharing, for example regarding sales and distribution, traffic information and the end-user experience.	7	8	8
16. PRM information sharing between rail operators and other transport modes (e.g. information on connections) for assistive digital tools (including harmonised interfaces between rail operators and other transport modes, leveraging existing European standards to enhance collaboration between mobility providers and support B2B integration, including the objective to deliver an enhanced end-user experience).	6	7	–
17. Dedicated to delivering a hands-free experience for travellers using rail services and transferring between rail operators and other transport modes, and developing a Wi-Fi roaming setup, which will allow travellers using different rail operators to seamlessly stay online.	8	–	–
18. Innovative platform-based passenger guidance solution; measurement and guidance of customer flows to and on the platform.	5	7	7/8
19. Short-term demand forecast calculation using run-time data (e.g. ticketing data, short-term weather forecasting and passenger density).	7	8	
20. Long-term demand forecasting focusing on data analytics stemming from a variety of sources (e.g. public events and the holiday calendar), operators' data (e.g. fare and passenger density data) and historical information for predictive models related to passenger clustering.	5	7	7/8
21. Integrated traffic simulation and demand forecasting in a digital twin to optimise offers, passenger occupancy, connection times and other service-related elements.	5	7	7/8
22. Disruption management across various mobility modes, enabling operators to collaboratively solve the disruption and properly inform passengers.	7	8	

7.1.2.3. Demonstration implementations

The innovation actions to be demonstrated involve the development of new systems/modules and/or the adaptation of existing ones in order to achieve the targeted results. This includes activities to set up integrated/joined multinational demonstrators stepwise. The FA1 strategy is to jointly use available state-of-the-art and R & I solutions to compose demonstrators with the required capabilities. A harmonised interoperability for planning, methods and system specifications will be the starting point for all common activities.

FIGURE 10. **Schematic of planned FA1 demonstrators**



The activities of FA1 are organised around three streams improving the planning, operation and integration of European rail traffic. The demonstrations will focus on these three streams.

Wave 1. The first wave of demonstrators is based on regional and local activities, integrating available state-of-the-art solutions and functions, along with results from R & I. There will be three demonstrators (D1–D3) in 2026, one for each stream.

From the first wave, some results will be deployed with TRL 7/8, other results, even with lower TRL, will function as input for the second wave's demonstrations. The composition of each demonstrator is crucial and requires well-structured cooperative planning and preparation to reach harmonised interoperability.

Wave 2. The second wave of demonstrators is planned to use validated results from relevant activities within FA1 and other FAs together with available R & I solutions. Most results will already be delivered in accordance with TRL 7/8, other results will function as input to the third wave. Three demonstrators are planned for the second wave (D4–D6). The experiences with demonstrators from wave 1 may have identified open challenges at lower TRLs. These lower TRL challenges can be addressed in wave 2, while also working up the (positive) results to higher TRLs.

Wave 3. The third wave of demonstrators will be used to validate results and finalise the remaining technical enablers (TEs), which will reach up to TRL 7/8. The outputs will be consolidated and validated in combination with the results of previous demonstrators by including them in larger systems, for example. For the third wave, harmonised interoperability is necessary.

Up to three demonstrators are planned for the last wave, depending on the results and other framework conditions, with the aim of having one demonstrator during the last FA wave.

Improving strategic and tactical planning of the rail network

In **wave 1**, activities will focus on tactical and short-term timetable planning, including across borders with improved models and functions, and supporting capacity planning and operations for yards, stations and terminals.

In summary, the following activities will be included.

- 'Tactical and short-term timetable' will focus on tactical and short-term timetable planning, including across borders with improved models and functions.
- 'Nodes and rail network planning' will demonstrate the use of decision support to support capacity planning and operations for yards, stations, terminals and the rail network.

The demonstrations will focus on showcasing the following capabilities (see Table 3):

- European cross-border scheduling;
- decision support for short-term planning;
- integration with yard and station capacity planning.

Demonstrations in **wave 2** will cover activities related to the support of strategic and short-term planning considering ERTMS and ATO evolution and their effects on capacity. In addition, integration with ATS will be considered.

The following activity will be included in this demonstrator.

- 'Effects of ERTMS and ATO capacity, "time-keeping" and working methods' for demonstrating a functional system for strategic, tactical and short-term planning considering ERTMS and ATO evolution and integration with ATS.

The demonstrators will focus on showcasing the following capabilities:

- planning using feedback loops from operations;
- integration of feedback loop with ATO/TMS for higher capacity;
- using ATO journey profiles for timetabling;
- operational technology railway cloud cybersecurity.

In the demonstrations for **wave 3**, automated solutions for improved strategic and tactical planning will support cross-border scheduling and TTR planning processes, based on harmonised methods for capacity planning and intelligent functions with optimisation and simulation support.

The following activity will be included in this demonstrator.

- ‘Capacity planning methods including cross-border operations’, demonstrating automated solutions for improved strategic and tactical planning.

The demonstration will focus on showcasing the following capabilities:

- improved capacity allocation using rolling planning and TTR;
- optimisation methods for timetabling and railway planning;
- improvement of rail simulation models for selected use cases.

Increasing the resilience of a connected ‘real-time’ rail network

The following activity will be included in **wave 1**.

- ‘TMS and human factor’ is planned to be concluded in 2025 and will focus on the use of simulation supporting future TMS, including capabilities, best practices and needs for future TMS. There will be a special focus on human factors, automation and visualisation. This activity will provide the input needed for the continuation of the activities below.

The demonstrations will focus on showcasing the following capabilities:

- TMS and human factors.

For **wave 2** demonstrations, all topics covered by the first wave will be continued in the second wave; some of them will be concluded and demonstrated. The focus will be on TMS at the regional and global levels. The demonstrations will cover decision support and interaction between stakeholders, including incident management and handling of maintenance, cross-border operations and asset conditions for rolling stock and infrastructure in real-time. Large-scale demonstrations of decision support and automation and overall real-time traffic planning will cover several EU Member States, nodes and networks, with feedback loops from planning to operation.

The following activities will be included in this demonstrator.

- ‘Regional mixed traffic including rolling stock and infrastructure maintenance’ will focus on TMS for the regional area (mixed traffic). This activity will be concluded in 2027, providing input for wave 3 demonstration activities.
- ‘Decision support and automation for national and international rail networks’ will focus on global area TMS (mixed traffic). This activity will be concluded in 2027, providing input for wave 3 demonstration activities.

The demonstrations will focus on showcasing the following capabilities:

- real-time connection of the networks;
- improved modelling of cross-border operations;
- integration of energy management (electric traction system);
- integration of real-time crew / rolling stock dispatching information;
- cooperative planning multi-actors;
- dispatching, incident management and customer information;
- disruption management;
- increased automation in decision support;
- conflict detection and resolution.

For **wave 3**, TMS will include the real-time effect of ATO and the resulting service quality, and feedback loops with effects on the planning process of feeding operational observations into improved train timetables. Moreover, TMS connecting stations/yards and other rail networks will be shown. Another focus of the demonstration activities will be the decision support for the improved control of nodes, yards and stations, the improved connection to industry sidings and ports, and the interaction with other rail networks.

The following activities will be included in this demonstrator.

- 'Connecting nodes with rail network passengers/freight' (wave 3) will focus on TMS connecting stations/yards and other rail networks.
- 'Decision support ATO/ERTMS and digitalisation' (wave 3) will focus on TMS including ATO line(s) and feedback loops with the planning process.

The demonstration will focus on showcasing the following capabilities:

- real-time convergence between planning and operations;
- connection between TMS and CTC, and automated yards;
- integration with yard and station management;
- speed regulation, precise routes and target times for ATO and dynamic timetables.

Integrated rail traffic within door-to-door mobility

Wave 1 covers demand-driven predictions to improve the operations and service offers of operators. An important data source for these predictions is the disruption information across mobility modes. This will show how cross-regional, multimodal travel, in combination with demand forecasting and disruption handling, improve daily operations in the mobility sector and also benefit customers. Furthermore, additional features improving customer accessibility and attractiveness are implemented and allow for a modern and interactive travel experience.

The demonstrations will focus on showcasing the following capabilities:

- short-term demand forecasting based on various data sources (e.g. real-time, CRM);
- manage/communicate disruptions across different transport modes with real-time data;
- B2B service platform ensuring cross-operator information transfer;
- cross-regional multimodal travel, including in the first and last mile and in demand-responsive transport.
- hands-free travel experience and smooth transfers between transport modes;
- walking in/out without barriers, access gate interaction and automatic payments;
- standardised interfaces and data formats.

In **wave 2**, more challenging long-term demand-driven predictions will be used, taking into account the results of short-term demand forecasting and disruption management. Digital twins are needed for the visualisations and modelling of movements at train stations. The ongoing challenge of cross-border travel within Europe and the connection of rural areas via an inclusive mobility network are also tackled here, with a focus on PRM guidance based on real-time data.

The demonstrations will focus on showcasing the following capabilities:

- combination of short- and long-term demand forecasting with disruption data;
- integration of demand forecasting into digital twins;
- cross-border multimodal travel, including in the first and last mile;
- PRM automatic guidance and incident management based on real-time data.

Wave 3 will use the output from disruption management and demand-driven predictions (short term) and further integrate and adjust long-term predictions and the digital twin approach to improve rail capacities by applying AI-based techniques. This will give operators the advantage to be aligned with future demands. Furthermore, a B2B service platform will be available across Europe to move towards an inclusive mobility network.

The demonstration will focus on showcasing the following capabilities:

- AI-based optimisation of rail capacity;
- Europe-wide B2B service platform;
- general approach to platform-based guidance;
- digital twin usage for predictive support of operators (including short- and long-term demand).

7.1.3. Impacts

7.1.3.1. Description of the impacts on existing rail services

TABLE 4. **Descriptions of FA1 impacts in relation to the intended impacts laid out in the master plan**

	Meeting evolving customer requirements FA1 will support the delivery of much more flexible approaches to the planning and traffic management of rail services, allowing rail to better serve customer needs. The primary impact will be a driver for the migration to an overall cohesive EU rail system. To make this happen, the flagship will solve the rail system's pain points – lack of flexibility, lack of reliability, lack of capacity – and also improve the resilience, punctuality and reactivity between stakeholders.
	More sustainable and resilient transport FA1 will provide more robust traffic management processes by integrating dynamic forecasting for the status of assets in the decision process and improving the efficiency of maintenance operations through better scheduling following more precise traffic forecast information that will result in increased operational reliability (fewer service disruptions). Optimisation of the TMS and fewer disruptions of train services will enable better utilisation of available resources and improve energy efficiency.
	Harmonised approach to evolution and greater adaptability FA1 will contribute to the common evolution of the system and greater harmonisation of traffic management in order to facilitate the delivery of the SERA and improve the rate of deployment of new technologies. By developing a new approach for European traffic management with the SP, including operational and functional requirements that allows the same system architecture to be used for both simple regional TMS applications with low effort and more sophisticated solutions for higher traffic densities and complex network topologies, FA1 is strengthening the treatment of trains when different network and business models meet each other, such as in cross-border traffic and on main lines and regional lines.

	Reinforced role for rail in European transport and mobility FA1 is supporting a better integration of rail into a more sustainable mobility system, in order to deliver better services for passengers and freight, and to bring greater usage and larger passenger volumes. Connecting transportation modes and breaking the silos between public and private transportation industry stakeholders will enable door-to-door mobility. Developing the matching solutions for the special demands will incentivise people in their choice of mobility and hence support the promotion of rail, the optimisation of investments and the contribution to health and well-being.
	Improved EU rail supply industry competitiveness A successful introduction of FA1 results will make rail more attractive for present and future green transport systems and more competitive compared to the car industry, which will strengthen European rail industry. One of the main objectives of FA1 is to improve the integration of rail, and to preserve its role as the backbone of the mobility system. The evolution of the rail system will impact employees significantly. Persons dealing with capacity planning and operational processes will be supported by new tools and processes to improve rail operations. The quality of work and the attractiveness of the sector is increasing. By supporting the transformation of the current rail system into a central transport mode of tomorrow's European mobility, FA1 will build unique capabilities in the European rail industry, supporting its position in global markets.

7.1.3.2. Quantitative KPIs demonstrated in this FA

The listed KPIs are to be reached at the end of the project implementing activities and proven by demonstrations where appropriate. In order to track these KPIs throughout waves 1–3, it is recommended to create specific project KPIs that create a credible pathway towards these KPIs listed here.

Improving strategic and tactical planning of the rail network

- Increased number of possible trains on a given infrastructure on a reference day using improved processes and methods:
  a. baseline 2022, expected increase of 5 % to 20 %, depending on the line or area.

- Reduction in answering time between the short-term request of a cross-border train path and the answer with a firm offer:
  b. down to five minutes.

- Improved robustness of timetables and, hence, reduced impact of disturbances and disruptions:
  c. baseline 2022, expected decrease of 5 % to 15 % of delay minutes in a reference week, depending on the line or area.

Increasing resilience for a connected real-time rail network

- Prediction quality – less than 5 % of trains with more than five minutes mean deviation in a typical scenario of at least 100 trains in a two-hour interval running ahead of actual time.
- Prediction performance (including dynamic infrastructure restriction handling, train regulation and automated conflict resolution) – less than 120 seconds in a typical scenario of at least 100 trains in a two-hour interval running ahead of actual time.
- ATO journey profile / segment profile provision cycle time down to 30 seconds.

Integrated rail traffic within door-to-door mobility

- Demand forecast for improved service planning:
  a. achieve 65 % precision in the average forecast one week in advance;
  b. achieve 80 % precision in the forecast at one hour.

- Improved matching between demand and supply:
  a. achieve 75 % success rate in meeting the planned travel time of passengers.

7.1.3.3. Exploitation, deployment and migration considerations

Within FA1 it is expected to deliver solutions for the improvement of methods and processes that support an extended network management planning and control framework, while ensuring safety and availability and meeting environmental sustainability demands.

The overall goal of improving global performance within the railway system will be met by FA1's demonstrators in areas such as: new TTR process and rolling planning; improved planning and operational evaluation; decision support for TMS conflict resolution; improved resilience; coupling TMS with C-DAS/ATO and expand; demand forecasting for improved service planning; and improved matching between demand and supply global networks, EU freight corridors, and national, regional and urban/commuter networks.

These developments in technology, methods and processes imply very important investments from the organisations involved in the EU-Rail JU and from the European Commission. Since all investments are not included in the FA1 budget, they need to be budgeted within the rail sector and mobility providers when making the decision to use FA1 outcomes. The involvement of a large community from both the user side and the supplier side is a good start for a wide deployment. The following measures were established to ensure future exploitation.

- Integrated approach in the demonstration scenarios so the new product and services are not siloed, but integrated with others, further supporting a broader impact, including integration with systems from other layers, such as ATC systems.
- Tests in real environments in order to ensure feasibility.
- Development up to TRL 7/8, so that solutions are ready for commercial exploitation.
- Involvement of final users that can be considered as references for commercial exploitation.

Currently, the products and processes used in the design, manufacturing, operation, maintenance and decommissioning of assets in the railway system are not expected to operate with new ones. Consequently, an adequate migration must be ensured by taking the following points into account.

- Coordination with the SP to draft a set of standards for information exchange at different levels, for example, data from inspection results to holistic approach to strategic decisions. Functions, system and interfaces requirements.
- Proposals of specific European regulations to be adopted by the Member States for enforcing or enabling the adoption of new technologies, methods and processes.
- Plug and play industry standards and open-source architecture to enable a more interoperable, quicker and more cost-effective implementation of new methodologies and technology, and integration with other rail systems (e.g. ATC).
- New technologies such as highly automated traffic management and ATO have a large impact on operational staff within the rail system. Therefore, FA1's scope includes R & D of human factors strategy, training and deployment planning to ensure a successful migration of the nearly developed systems.

7.2. Flagship area 2 – Digital and automated up to autonomous train operations

7.2.1. Objective and level of ambition

Today, urbanisation and population growth are already leading to rail capacity problems on main lines across Europe. To increase the railway capacity there are two main options: building new infrastructure and/or operating the rail system in a way that takes advantage of new technological and operational solutions. The reduction of the cost of capacity is a major indirect catalyst for capacity optimisation, which is in this context dominated by CCS asset density, CCS asset performance and asset LCC.

Option one, building new infra/lines, is challenging because it requires decades. Furthermore, the areas with capacity problems are typically crowded areas where land is already in high demand. Hence, a major opportunity is offered by the digitalisation and automation of rail operations. DATO represents the most visible result of a major transformation of rail operations. It builds on the next generation of ATC, in addition to enhancements on the TCMS allowing for integration at the on-board level. ATC ([18]) is the combination of ATP systems, ATS and ATO, which together represent an evolution of the current CCS subsystem, termed CCS+. Such targets build on the specific set-up of the EU-Rail JU, where the SP, under the leadership of the European Commission, shall deliver the system architecture on which the rail community will converge in a collaborative manner. The Innovation Pillar (IP) supports and complements this through the underpinning concepts and detailed solution architectures, along with PoCs. It is a joint commitment to deliver it and without such commitment an unrealisable ambition.

In support of a unified operational framework, this FA shall deliver outputs that are compatible with the evolving operational architecture, notably by aligning ATO operational modes with harmonised use cases and procedures. Attention shall be given to ensure that degraded modes, human–machine interactions, and fallback strategies are functionally described in a way that can be adopted by IMs and RUs within their SMS, following a risk-based approach ([19]).

7.2.1.1. Targeted objective, new opportunities and associated risks

The targeted objective of FA2 is to take the major opportunity offered by the digitalisation and automation of rail operations and to develop the respective systems, including the following.

- Next-generation ATC, including ATO GoA4 and FRMCS, based on a European approach agreed in the SP under the leadership and commitment of the Commission services, building on harmonised, adaptable and scalable trackside and on-board CCS+ system architecture. This will build on radio-based ERTMS or above, representing the next evolution of the system and incorporating the latest technological advancements, with functionalities enabling full optimisation of performance in line with the traffic management improvements developed in FA1. This will be a major transformation of rail operations, and also a stepping stone setting the basis for the future evolution of the

([18]) The ATS is responsible for '[the] supervision of [the] train status, automatic routing selection, automatic schedule creation, automatic operations logging, statistics and report generation, and automatic system status monitoring'. The ATP system is designed as a fail-safe system. Its aim is to keep a safe distance between trains and make each individual train comply with the track speed limits. If the speed limit is exceeded, ATP will automatically slow down the train or even bring it to a complete stop. ATO is responsible for train operation – the traction and braking controls – but also for creating the train's speed profile, the communication with the wayside equipment, the opening and closing of the train doors, and automatic train reversal.

([19]) Consistent with CSM on SMS.

system, while making use of existing assets and investment done in, for example, Shift2Rail innovations or in solutions compliant with the TSIs, where applicable.
- Delivering scalable automation in train operations, up to GoA4, meaning that the rail system is ready for fully unattended train operations, including setting a train in motion, driving and stopping the train, opening and closing the doors, and remote train control and recovery operations in the event of disruptions.

The optimisation potential coming with a next-generation ATC, including ATO GoA4 harmonised across Europe, is very large. The benefits are not limited to increased capacity, but also comprise improved punctuality, reliability, flexibility (through real-time adaptation to demand) and productivity, and reduced operating costs, recovery times and energy consumption.

Improved trackside and on-board ATP and ATS systems will:

- reduce the cost of capacity, which is a major indirect catalyst for capacity optimisation;
- enable precise traffic flow management, supporting punctuality, reliability and productivity improvements;
- enable the control of much higher train densities, with a significantly reduced LCC of CCS components compared to today;
- deliver scalable solutions for high- and low-density lines, supporting the generation of large-scale component markets and standardisable industrial asset management processes, speeding up the deployment and ensuring the long-term evolvability of the system.

Such improvements will increase the capability of future ETCS systems, for example, enabling ETCS trains even in manual modes to have time management, timetable interaction and follow speed commands for energy management and other features provided from current TMSs and the future TMS developed in FA1. Development should advance sufficiently to secure ERA authorisations, enabling the system to be placed into service.

The current CCS TSI allows for on-board configurations with multiple proprietary TCMSs and legacy (i.e. non-ETCS) interfaces between the main on-board building blocks across Europe. As regards ERTMS trackside configurations, the current CCS TSI does not include the definition of the interfaces for the main trackside signalling assets. Therefore, the development of a dramatically improved next-generation ATC system is coupled with the opportunity, through the migration of systems, to eventually deliver a single European system based on European system architecture approaches. Success in such an approach begins with seeking the necessary convergence of the relevant actors within the SP and will significantly reduce the fragmentation currently observed in Europe, increasing the opportunity to achieve the single market for rail, while creating, and speeding up, the deployment of innovation across the system.

FA2 ‘Digital and automated up to autonomous train operations’ will develop a next-generation ATC system with the following objectives:

- lowering expenses for IMs and RUs;
- decreasing travelling times for passengers and freight;
- increasing the overall capacity of rail operations;
- improving punctuality;
- improving the quality of rail operations;
- improving operational reliability;
- improving recovery time after any interruption or intervention;
- improving reaction time;
- increasing flexibility in planning on existing infrastructure;
- reducing energy consumption.

Implementing next-generation ATC with DATO as the major visible impact will open up opportunities for the railway sector as a whole. It could offer a solution for increased demand, even more so because it will increase the competitiveness with other less sustainable transport modes. In addition, further adopting/optimising the timetables can again be done when a next-generation ATC is implemented, even more so because the railway systems throughout Europe can be seamlessly integrated. It will also offer the opportunity to better integrate the railway system with other modes of transport and first- and last-mile automation. Besides, it will diminish the challenges related to the future shortage of staff and housing, and lead to an improved and less risky working environment for employees.

It will require, on one hand, the exploration of new technologies and the acquisition of experience from early partial implementation, and on the other hand, the integration of a complete system that builds on the convergence achieved in the SP. A well-structured and committed collaboration process is essential for its successful delivery.

To the fullest extent, automation can reach a level of ‘autonomy’. Autonomy is understood as the capability of a vehicle to respond in real time, without human interaction, to changing conditions in the operational environment, when fulfilling a predefined mission. The FA will be open to considering such capabilities.

Furthermore, DATO has some associated risks. The willingness to travel with automated trains, and the acceptance of automated cargo trains with hazardous substances need to be considered. For migration purposes and to avoid extensive approval of DATO software and hardware, a clear functional separation between subsystems must be achieved to manage the risk of full infrastructure dependency. A clear interface with TMS is key for implementation. The migration risk is also linked to the difficulty of the long lead time of ETCS deployment, which shall be reduced by lowering the cost and agreeing on an effective EU deployment process, while R & I continues. Furthermore, the risk of not finding or agreeing on a ‘fit-for-all’ legal sector agreement that will allow for sharing and reallocating liabilities, risks, costs, and benefits across the stakeholder groups, might decelerate the implementation of digital and automated train operation technologies. The business case within the sector is a risk as well, since the benefits (e.g. capacity increase, mainly for governments) may not be reaped by the same organisations that will pay for the costs (IMs, RUs and industry), so governments could postpone, minimise or even avoid future investments. The SP plays an important role in anticipating such risks and delivering the necessary input to FA1. To avoid the risk of slow innovations on the one hand and vendor lock-in on the other, an adequate degree of separation between of hardware and software elements must be defined. To do this, the economic, legal, regulatory and organisational implications need to be assessed and jointly agreed on in the rail sector. This is, however, beyond the technical scope of FA2. Furthermore, freight automation is an important challenge within FA2, due to the complexity being greater for loco-hauled freight applications than for electrical multiple units (EMU), and there is not as much experience with this as with passenger trains in mass-transit, for example. Therefore, freight automation needs to be considered a very sensitive and important challenge within FA2. Finally, the human factor, such as the impact on staff of new technology like remote management or HMI for highly automated systems, needs to be taken into consideration.

7.2.1.2. Innovation beyond the state of the art, including the integration of S2R results

S2R has pushed research in many key fields that will serve as the starting point for the development of a new generation of DATO assets and ATC systems. The S2R TCMS technologies, with the new generation of on-board functional architecture, its hardware- and software-independent platform, and the new train communication network (TCN), will have to integrate the new ATC functions. Research into communication, cybersecurity, safe train localisation, (passenger) train integrity functions, obstacle detection (OD), data collection, incident handling, remote driving, virtual coupling, formal methods, virtual or moving blocks, braking- and adhesion-management systems, fleet digitalisation, a new functional system architecture for main-line railways, a certification procedure for safety-related functions based on artificial perception, a standardised interface for remote driving and command, and using AI for automation (e.g. in perception systems and door management) will be taken as a starting point in this FA.

Outside S2R, state-of-the-art research has been published in papers and several demonstrations have taken place. Demonstrations include results that can be helpful for the development of a next-generation ATC in this FA. As an example, in the Netherlands, NS (Nederlandse Spoorwegen [Dutch Railways]) and ProRail researched and executed several tests regarding ATO over ETCS, ATO over legacy systems and highly automated shunting activities. Another example is the ongoing research activity conducted by FS (Ferrovie dello Stato Italiane [Italian State Railways]) and several Italian universities aiming to design ATO over ETCS for autonomous railway infrastructure maintenance and surveillance vehicles. SNCF is also investigating GoA4 for freight and passenger trains over ETCS and line side signalling over ETCS L1. Remotely controlled solutions have been tested on the French network. Results and best practices of these developments and demonstrators will be available as input for FA2 collaborative aspects.

Table 5 gives an overview of the innovations covered by this FA, and the input from state-of-the-art research and Shift2Rail. The innovations will be discussed further in the rest of the document.

TABLE 5. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail**

State of the art	Shift2Rail	Further innovation needed and covered by FA2
Radio-based ERTMS based on ETCS level 2.	Moving block: line capacity improvement by decoupling the signalling from the physical infrastructure and removing trackside train detection (TTD).	Mixed operation for radio-based ERTMS on lines with/without (mixed situation trackside) TTD and with L2- or L3-capable vehicles of different system versions (mixed situation on the vehicle side), having different train integrity monitoring systems (TIMSs), cold movement detection and localisation capabilities.
Different ATC system structures for different line types.	–	Scalable ATC architecture for different line types and integration with TMS.
Construction of ETCS level 2 ATP infrastructure.	–	Fast industrial infrastructure change from Class B: minimal effort, minimal prerequisites and short duration (including simplified safety case effort, automated toolchain, for example, for changes).

State of the art	Shift2Rail	Further innovation needed and covered by FA2
Shunting and manoeuvres of yellow fleet based on line-side signalling.	—	Continuous use of ETCS in full supervision mode for all types of train movements (in undisrupted situations).
Isolated and special system architectures in marshalling yards, depots or terminals for the ATP process.	—	Interfaces and methods for integrating special load and train formation systems into the standard ATP architecture.
Individual upgrade processes and safety cases for upgrading trackside or on board the ATO/ ATP/ATC system.	—	Fast, simple and standardised upgrade and change processes based on modular functionalities. Reduced safety case effort (modular safety cases) and flexible modular spare part compatibility between old and new system versions.
Research on real-time, reliable wireless transmission of high-speed train control data.	Communication system and cybersecurity: the adaptable communication system (ACS) – integrated into FRMCS, which was developed outside S2R – and protection against any significant threat in the most economical way.	Enhanced communication systems that enable adequate latency, handling of the data volumes, safe computing (platforms), AI functions and a digital map infrastructure for integration with the TMS and ATP system. Testing and validation of FRMCS version 2 (V2) specifications and analysis of the use of public mobile network operators (MNOs) as principal bearers and as backup. Technical support for the further development of FRMCS (post version 3 (V3)): tasks not included in FRMCS V2 specifications (see the SP FRMCS report), use of other radio bearers (e.g. satcom – Infrastructure for Resilience, Interconnectivity and Security by Satellite ($IRIS^2$) – or local wireless – Wi-Fi) and (optional) monitoring systems. Use cases and concepts of future systems of reduced cost on regional lines or robust and resilient networks using satellite communication systems such as $IRIS^2$ or Low Earth Orbit satcom.

State of the art	Shift2Rail	Further innovation needed and covered by FA2
		Adaptation of wireless communications (ACS/FRMCS) for smart wayside object controllers (in cooperation with FA6). (Optional) finalisation and testing of the adaptation of existing ETCS equipment to be compatible with FRMCS.
Studies on ATO over ETCS for main-line and regional passengers.	ATO: development and validation of a standard ATO up to GoA3/4 over ETCS, including ATO for freight.	New DATO technology solutions for interoperable automated driving and decision-making, for all applications and segments, such as an improved traction system interface and new braking systems.
Studies on ATO over ETCS for freight.	Freight train operation (ATO): ATO demonstrator GoA2.	Freight-specific applications in, for example, brake blending, the mass-damper system, physical and dynamic models, continuously changing train configurations and freight driving rules, need further development and demonstrators.
Global navigation satellite system (GNSS) based multi-sensor positioning for railways, including safety and logistic applications.	Safe train positioning: fail-safe multi-sensor train positioning system for the current ERTMS/ ETCS and non-fail-safe positioning for freight wagons aiming at reducing overall costs and improving service quality.	Absolute STP, highly accurate and safe, incorporating new sensors.
Electro-mechanical brake (EMB) for railway applications, high safety level electronic solutions for brake control and a new generation of disk and friction materials.	New braking systems: higher brake rates and lower noise emissions, providing major capacity gains in terms of mass and volume in bogies, paving the way for a fresh revisit of bogie design.	Next generation of braking subsystems, to safely detect and manage low adhesion and reduce braking distances.
A new generation of TCMS and the digitalisation of freight wagons.	TCMS, fleet digitalisation and automation and smart freight wagon concepts: development of a new-generation TCMS for passenger trains and key technologies to enable a digital and automated rail freight system based on the digital freight wagon.	Automating functions, such as train preparation for both passenger and freight trains (e.g. incident handling, self-healing).

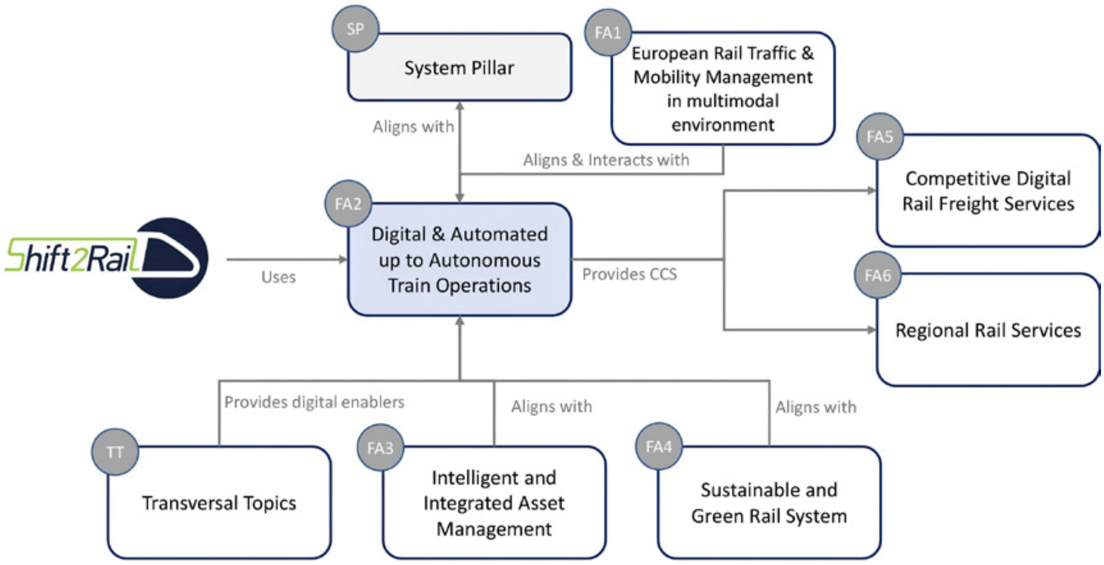
State of the art	Shift2Rail	Further innovation needed and covered by FA2
All-weather OD and track intrusion detection systems, and remote control for distributed power for long freight trains.	Fleet digitalisation and automation and new freight propulsion concepts: improvement of rail freight transport by developing all-weather OD and track intrusion detection systems and remote control for distributed power.	Safe environment perception, including signal reading and OD, supported by virtual certification. Remote driving and command, for depots, lines with low traffic and fallback operations, as well as for shunting.
Overall feasibility analysis that covers the technology, safety and business aspects of the virtual coupling train set deployment.	Virtual coupling: virtually coupled trains to operate much closer to one another and dynamically modify their own composition on the move while ensuring at least the same level of safety as is currently provided. PoC with tramways.	Development and deployment of the virtual coupling concept.
State-of-the-art survey of formal methods and taxonomy, including use cases for the use of formal methods for railway signalling systems.	Formal methods and standardisation for smart signalling systems: open standard interface and a functional ETCS description model, based on formal methods to facilitate verification and authorisation processes.	Modelling techniques to support the development, verification and validation solutions.

7.2.1.3. System integration, interactions with the SP and with other FAs

The Commission leadership in the SP will be essential in laying the foundation for a concept of operations and system architecture, which shall underpin innovation related to digitalisation and automation in train operations. FA2 will demonstrate innovations to be deployed for the next generation of railway systems to ensure a next-generation ATC system in relation with FA1 and other FAs. The focus of FA2 is ATO GoA4 and a next-generation ATC architecture as a critical core part to pave the way for a fully automated and, in selected specific cases, up to autonomous operation and a well-performing, cost-efficient and easy to migrate ATC system.

FA2 has several links to other workstreams of Europe's Rail, which are listed below. An overview of the relationships with other FAs, TTs and the SP is given in Figure 11.

FIGURE 11. **Overview of the relationships within the EU-Rail JU**



FA2 will interact closely with the SP to ensure a smooth takeover of the definitions delivered by the SP, such as the definition of the detailed architecture in accordance with the reference architecture. The process for the FA2 to adapt to the SP and vice versa is described in Annex A. As such, certain relevant specifications will be delivered by the FA2 partners, but the evaluation work done will be coordinated and shared with the SP. In common alignment within FA2 and with the SP, FA2 shall be able to execute its programme and deliver the missing details or maturity in a closely synchronised process. The resulting specifications (functional system requirements and interface requirements), detailed architecture, technologies and operational considerations developed in FA2 will be submitted to the SP for acceptance and integration.

The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initially identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

FA1 – European rail traffic and mobility management in a multimodal environment. The next-generation ATC will require other concepts, procedures and techniques for traffic management for different types of traffic (e.g. high- and low-density traffic) and mission profile (e.g. short- or long distance). FA2 ATO on-board (OB), trackside (TS) and train control and monitoring systems must interact with the FA1 TMS to achieve an overarching system solution. The joint design of interfaces between traffic management in FA1 and ATP systems in FA2 shall ensure that traffic management can make use of all ATP capabilities, especially the train position and speed information now available in the STP system or the precise speed control for movement permissions. Also, at the trackside, different next-generation ATC solutions need to be supported by FA1 with the provision of an interface for an operational TMS. FA2s demonstration results provide parameters for planning and simulation tools to calculate the capacity benefits of applied next-generation ATC technology on corridors, nodes and lines. These quantify the FA1 and FA2 jointly executed demonstrators' results into the TMS/ATO/ATC (both FA1 and FA2) business cases.

FA3 – Intelligent and integrated asset management. Specific trains or rail vehicles for diagnostic or inspection purposes and for the transfer of maintenance rail vehicles will be subject to automated train operation. FA2 will provide technologies from main-line ATO to support the automation of the yellow fleet while running under normal operational conditions.

FA4 – A sustainable and green rail system. One of the goals of the next-generation ATC system is to contribute to increasing the sustainability of the railway system. It must manage energy consumption, so interaction with both on-board and trackside energy management systems is required. FA2 delivers, in close cooperation with FA1, a methodology and model to quantify the benefits of ATO regarding reducing energy consumption.

FA5 – Sustainable competitive digital green rail freight services. Both digitalisation and next-generation ATC will give green rail freight transport a competitive edge. FA5 will provide new freight solutions, such as DAC. FA2 will develop ATO to automatically operate trains during commercial runs (i.e. on the track with, for example, a train ID) and will provide technologies within an ATC architecture, into which special technologies of shunting yards can be integrated by FA5. FA2 provides ATP functionality for TIMS to FA5 based on the current definition, with room for additional developments within FA5. All developments related to DAC in this respect are in FA5. FA2 incorporates the supervision of movements related to stabling (moving a train from the end of a train journey to the depot). The stabling function will be developed in FA2, while the shunting function will be developed in FA5 as an application-specific function. Special functions for the operation of automatic and autonomous shunting for freight will be developed in FA5, based on the generic ATO functions developed by FA2. These include the train protection system in yards (supported by enabling technologies such as environment perception systems), since the specification and use cases (push/pull functions) differ significantly from the main-line and stabling operations. FA2 also adapts the TCMS to cover the DAC requirements The dispatching software and train protection system for shunting will be defined in FA5, since yards and terminals are not equipped with ETCS. Yard automation equipment also differs from main-line automation equipment because yards operate under different safety requirements and therefore use more cost-efficient equipment. A specific cybersecurity management plan will be established within FA5.

FA6 – Regional and innovative rail services aimed at revitalising capillary lines. Next-generation ATC solutions for functions such as STP and safe environment perception will serve as the backbone for DATO rail services on lines with low numbers of passengers. FA2 will provide technologies to, among other things, automatically or remotely control the passenger trains during commercial runs or stabling, positioning solutions, safe environment perception technology and ATO technology solutions. It includes the integration of appropriate interfaces for the TMS for energy network management. Also, a digital register, acting as a data source for STP or planning and engineering, for example, will be discussed between FA6 and FA2.

Details of the exchange between the FAs can be found in Annex B.

TTs on digital enablers provide generic concepts and tools for the digital twins and models to be used in FA2. Close cooperation with the TTs will therefore be organised.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with the guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the CDM,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

7.2.1.4. Who does what by stakeholder group

IMs and RUs are responsible and accountable for the output of the railway system as a whole. They have a deep knowledge of the requirements for the operation, maintenance and evolution of the system. As future users of the next-generation ATC technologies, they need to establish functional and non-functional requirements for further solutions. They are at the forefront of demonstrations evaluating the feasibility and impact of (the cluster of) next-generation ATC technology components, including future radio. They can offer a train set, test sites and regular lines for tests, along with the related knowledge for proper validation. Engineering resources from IMs and RUs may also be involved in the detailed design and engineering process and rules for developing the next-generation ATC innovation.

Suppliers are experienced in the development, implementation, maintenance and certification of rail or related systems (e.g. telecommunication, cybersecurity) and their components and will thus be the main stakeholders providing innovative systems and their related specifications based on the next-generation ATC technologies developed and/or tested within the EU-Rail JU. Their experience is important in ensuring a smooth and sustainable roll-out of the new systems. As there are different suppliers for all the fields of FA2, multiple solutions and technologies can be developed to test and demonstrate next-generation ATC innovations.

Research centres are required to support this FA by means of the development of technologies, innovative concepts, tools and procedures. They contribute to the process of innovation, and to the procedural aspects for validation, certification and homologation.

The related specification for the next-generation ATC systems will be developed by all stakeholders in a collaborative process.

7.2.1.5. Interaction with other programmes, European and/or national

In addition to the links inside the EU-Rail JU described in Section 1.1.3 and the integration of the Shift2Rail results, FA2 also links to other national and international (innovation) programmes, such as FRMCS, the Single European Sky ATM Research (SESAR) 3 JU, the Connecting Europe Facility (CEF) and Horizon Europe. It will incorporate the outcomes of these developments into the work program in close coordination with- and under assessment by the SP. Specifically, with respect to satellite technologies to be used in FA2, such as IRIS[2] or local wireless solutions, an exchange with ESA, EUSPA and the European Union Agency for Cybersecurity is required.

7.2.2. Results/outcomes

7.2.2.1. Operational solutions outcome

To fully achieve the objectives described in Section 7.2.1.1, operational solutions will cover a wide range of applications for next-generation ATC technologies. Besides the application on main lines, the operational outcomes of this FA will be automated train preparation, automatic stabling, automatic maintenance inspection, and remote control. The application in more complex situations, such as mixed traffic, power supply transitions and ATP transitions (e.g. ETCS – undefined tracks), will also be part of FA2. The same goes for the application of next-generation ATC on commercial runs of freight trains, which are the most complex type of trains to control due to their difficult-to-predict dynamic behaviour. Furthermore, specific solutions for next-generation ATC on light-rail urban transport and regional lines in remote areas or with low-density traffic will be provided, as these systems need to be adapted to economic conditions, rural environments and complex situations, such as level crossings. The same goes for freight customer sites and maintenance workshops (non-ATP). The operational outcome of this FA also includes rail operation optimisation techniques. To support the functioning of next-generation ATC, a new radio system needs to be developed. This FA will support the development of a fully tested, complete, multi-bearer FRMCS (based on 5G and above, including alternative radio bearers such as satellite communications and/or Wi-Fi). FRMCS will also allow the use of public mobile network operators in conjunction with or without railway frequencies. For low-density traffic, the developed technologies will reduce the cost of communication (MNOs and satcom) and trackside CCS (radio connected smart wayside object controllers).

The implementation of these operational solutions will take place through demonstrators at TRL 7+ of the TEs. For next-generation ATC developments, principles of ATO over ETCS from S2R and the 2022 CCS TSI will be used and, where needed, further developed.

To secure investments and ensure a clear migration path, the next-generation ATC shall support backward compatibility with all automation levels. Furthermore, the overarching automation process 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. In addition to the modularisation of the functionality of the ATC systems, the decoupling of software from hardware will pave the way for a modular hardware platform. Upgradeability shall be a clear goal and special attention shall be given to the cost effectiveness of the solutions regarding maintainability and evolvability, while also taking into account retrofitting aspects where relevant.

The use of formal modelling techniques will ensure the quality, application and completeness of the specification and planning, while enabling evolution and controlling interoperability and interchangeability, and help to reduce field testing.

The following additional operational scenarios are considered to define the required TEs, services and functions below. Mixed operation for radio-based ERTMS on lines with/without (mixed situation) TTD and with L2- or L3-capable vehicles of different system versions, TIMS and localisation capabilities. This scenario is the next step to be developed in different target configurations: from low cost to high performance, different sensor mixes on-board and trackside (combined), different qualities of radio coverage, or lower grades of ATO/ATP automation, etc. To pave the way for an improved, faster infrastructure change from Class B to the previously mentioned scenarios: minimal effort, minimal prerequisites and short duration (including simplified safety case effort, for example, for changes), including integration with the modular ATC systems and the TMS. A further scenario is the 'fully mature ERTMS': full supervision (cab signalling) continuously in all normal modes, also for shunting or for yellow fleet movements. Finally, the same architecture is to be used for efficient processes for train stabling, formation and preparation, and in marshalling yards, depots or terminals in connection with their specialised technologies for passenger and freight trains.

Harmonised operational concepts and interface specifications for ATO (GoA1–GoA4), will be developed with the SP in functional layers to be embedded as operational updates. Focus will be given to degraded operations, supervision functions and interactions with ETCS, in support of interoperability.

The outputs from an operational perspective are listed in Table 6, along with a prediction of the TRL of the capabilities in 2026, 2028 and 2030.

TABLE 6. **Overview of the operational outcomes**

Activity			TRL 2026	TRL 2028	TRL 2030
ATP/ATS	Target ERTMS application with simplified migration, main line.	Mixed operation for radio-based ERTMS on lines with/without (mixed situation trackside) TTD and with L2- or L3-capable vehicles of different system versions (mixed situation on the vehicle side), having different TIMS, cold movement detection and localisation capabilities.		6 (L2, HTD) 6 (MB)	7 (L2, HTD) 7 (MB)
	Target ERTMS application, scaled to minimal cost.	Simplified sensor mixes, reduced radio coverage, etc.		6 (L2, HTD) 6 (MB)	7 (HTD) 7 (MB)
	Enabler for fast change of infrastructure.	Enabler for fast infrastructure change from Class B to target ERTMS configuration: minimal effort, minimal prerequisites and short duration (including simplified safety case effort, for example, for changes), including integration with the modular ATC systems and the TMS.		6/7 (HTD, MB) 5/6 (HTD, MB)	7 (HTD, MB) 7 (HTD, MB)

Activity			TRL 2026	TRL 2028	TRL 2030
ATP/ATS	Fully mature ERTMS.	Full supervision (cab signalling) continuously in all normal modes, also for shunting, or for yellow fleet movements.		6 (HTD, MB) 6 (MB)	7 (HTD, MB) 7 (MB)
ATO	Application on main lines.	GoA3/4.	5/6	6	7
		Application in mixed traffic.		6	7
		Power supply transitions.		6	7
		GoA2–4 on ATP transitions.		6	7
		Application on freight trains.	5/6	6	7
	Automatic processes.	Automated train formation and preparation (including coupling and uncoupling).		6	7
		Automatic stabling.		6	7
		Automated maintenance and inspection.		6	7
		Remote control.		6	7
	Regional lines.	GoA3/4.		6	7
	Application in light rail.	GoA2/3.	5/6	6	7
		Mixed road traffic.		6	7
FRMCS	Testing.	Testing and validation of FRMCS V2 specifications.	6	7	7/8
		Use of public MNO.	6	7	7/8
	Further development of the system.	Tasks excluded from FRMCS V2 specifications (after testing and validation project).		6	7

Activity			TRL 2026	TRL 2028	TRL 2030
Migration Strategies	Fast and simple vehicle upgrades, in particular for the existing fleet.	Adequate degree of separation of hardware and software elements, agreed on in the rail sector, to avoid the risk of slow innovations on the one hand and vendor lock-in on the other, facilitating migration. For this separation, the economical, legal, regulatory and organisational implications need to be assessed with the support of the SP, as this goes beyond the scope of FA2.			
	Smart, generic interface technologies: enhanced downwards and upwards compatibility.	Smart interface technologies for the secure connection of trackside protection components or for on-board components enable the combination of different releases of on-board units (ATO, ETCS) or trackside protection systems on runtime.		6	7
Rail optimisation techniques	Depends on TMS (FA1) and progress related to activities.				

7.2.2.2. TEs: capabilities to achieve the desired operational outcomes

TEs are key for the successful implementation of the identified capabilities: improved operational performance, higher capacity and cost-effective deployment. Although these TEs are included as parts of the ultimate ATO GoA4 goal, their intermediate results and developments do not need to be used only in combination with DATO. The TEs for the capabilities are described below.

Capability for improving operational performance

Automating functions, such as the wake-up and train preparation capabilities, are needed to start operation, giving rise to the need for remote control, auto-diagnostics and operational tests. The automated self-repair/reset capability of DATO and next-generation ATC operated trains shall also be available.

Trains in automated operation must be continuously traceable for traffic control and train operators. For this purpose, safe absolute train positioning techniques and train control centre connectivity are crucial. This is also relevant for technical train status updates and control-centre-to-train dialogue communication, and includes the development of FRMCS, an on-board communication network, and 5G applications.

The EU-Rail System Pillar's *Report on FRMCS V2 and V3 Scope and Planning* lists the scope, content and planning of the FRMCS V2 and V3 specifications, with a first main objective being to define clear FRMCS V2 requirements for an industrial European trial, focusing on validating the FRMCS requirements relevant for interoperability in the EU, and validating an ecosystem of specifications for a safe migration of GSM-R (global system for mobile communications – railway) networks in Europe. This report defines the detailed content of V2 specifications, identifying priority items to be completed for the European trial, and proposing other items to be tested later.

EU-Rail will first support the development of FRMCS by testing and validating the FRMCS V2 specifications delivered in a technical opinion (and an addendum) by the ERA, based on input from UIC and an upcoming ETSI standard. It should include field tests for railway telecommunication services relying on a third-party service provider (e.g. public MNO) to the extent that these were not yet provided elsewhere.

As a subsequent activity supporting the development of FRMCS, EU-Rail should consider items mentioned to be tested later in the SP report, focusing on new applications (e.g. ATO GoA3/4, critical video, TCMS). It should also consider synergies for testing satellite communication supporting FRMCS, such as the IRIS[2] project. These can help to reduce investment and maintenance costs for railway lines in rural areas or stay resilient during disturbances and reduce terrestrial redundancy.

EU-Rail should consider the adaptation of FRMCS principles for smart wayside object controllers (with FA6) and for monitoring systems (for real time analysis and for predictive maintenance support – with FA3).

Another aspect could also be considered for FRMCS testing related to ETCS baseline 3 vehicles. Some railway stakeholders raised concerns on the challenging migration scenario that could be imposed on those vehicles when the migration to FRMCS leads to the trackside decommissioning of GSM-R. Alternative proposals to upgrade those vehicles to baseline 4, to be able to communicate over FRMCS, are proposed, and the ERA is tasked with studying them. In the event that those alternatives could be an interesting solution for preserving the already installed equipment, their testing would ensure that interoperability is maintained.

A safe unattended operation must be ensured by comprehensive, modular and scalable perception systems (on board and trackside) for both outdoor and indoor environments. These systems will provide relevant information to the decision-making processes about obstacles, lateral signalling, other vehicles, workers and passengers. Additionally, such systems will support asset monitoring and diagnosis, extending beyond their incident prevention capabilities. Aspects related to communication between on-board and autonomous wayside assets will also be handled, along with aspects related to georedundancy for securing overall operations.

In transition (either technical or operational) or shunting mode, automated train operation requires a remote operating functionality, going beyond driving and achieving full remote assistance and control, while supporting cross-border operations. Remote operation is also an important migration step in the development from ATO GoA2 to GoA4 for fully automatic vehicles and powerful environment perception. Suitable interfaces for the remote operating person must also be developed (e.g. remote driving desk), taking human factors and the required training into consideration.

To increase automation, AI-based solutions that enhance the performance of classical systems must be developed, incorporating human feedback and in the first stage developing recommendations to the driver.

The TCMS plays an important role in the implementation of DATO because it acts as the interface between the train and the ATO and in the interoperability and the ability to couple. The next-generation TCMS must support automation up to GoA4 and new communication solutions, such as FRMCS or 5G for the on-board wireless buses.

To maximise next-generation ATC performance, a new generation of braking systems is needed to bring adjustable/configurable emergency brake control, the holding brake function and integrated adhesion management, among other enhanced functionalities like new brake sensor systems to detect and evaluate collisions with objects on the track. New methods for the qualification of brake performance under degraded adhesion, using adhesion management systems, are needed so that performances can be assessed against a common framework. Besides braking systems, this is also important for acceleration, as slip and slide protection also needs to be optimised to ensure maximised capacity and safety. Automated shunting may be an important first application of GoA4 technology, which could lead to a specific migration strategy.

Capability for offering more capacity to customers

The combination of all and mixed forms of radio-based ETCS and ATO is key to increase the capacity of railway lines. It is important that, in this FA, innovation on DATO itself is accompanied by trackside and on-board ATP innovation, such as novel CCS architectures enabling a moving block with minimum infrastructure elements and based on a digital topology, as next-generation ATC can ultimately only jointly and in tight interplay achieve the envisioned increased system capacity, punctuality, resilience and flexibility. GoA4 operation will, for example, support dynamic timetabling, as there is no restriction on crew availability.

The extended virtual coupling, enabling significantly shorter headway and greater flexibility, supported by enhanced connectivity and localisation, will be based on SP outputs.

Capability for supporting cost-effective deployment

Technology and the operational procedures need to be validated and tested. Hence, uniform validation procedures, tools, certification methodologies and suitable testing facilities need to be developed to ensure fast and safe deployment.

From a procedural perspective, the aspects of operational harmonisation, coherent and safe procedures for fall-back, disturbance and emergency situations, virtual certification and homologation, migration and deployment, and testing and validation need to be addressed. For virtual and lab certification and validation, and automated planning and engineering, a neutral and sufficiently formal reference model is required as an enabler, along with the digital twin. A specific aspect which must be considered is the development of advanced HMI which can enable the operators to interact safely and reliably with fully automatic systems.

Using formal methods can help to ensure the safety, quality and applicability of specifications based on harmonised and unequivocal European rules. Therefore, formal methods will be used for specification and demonstration. Using appropriate system definitions and specifications as a basis for safety and quality assurance while mitigating investment risks, formal methods will be applied to address later RAMS life cycle phases, demonstrating the realised safety levels and building the necessary confidence in the systems.

Reducing side effects of change and controlling the independent evolution of subsystems and modules of the next-generation ATC systems are key enablers for cost-effective – avoiding big-bang testing – and large-scale deployment. Decoupling software from hardware and parts inside the software domain, and defining the steps needed to increase flexibility and reduce the amount of effort required for integration, needs to be targeted. Specifically adapted processes for specification, development, certification and safety cases need to be implemented in order to reduce the amount of effort required for integration. This will pave the way for modular computing platforms, which give rise to the possibility of consolidating applications. For the software part, adequate railway architectural software design patterns and methods enabling evolution need to be addressed, including the interaction between middleware and application parts. Conceptually separating functional views from the deployment and investigating service-oriented design need to be applied. As the management of interfaces' specifications and their underlying functionality are crucial factors enabling evolution while controlling interoperability, the use of formal modelling techniques to ensure quality, applicability and completeness needs to be further elaborated here. To make those improvements effective, an adapted development cycle, including an adapted safety cases procedure and modularised certification, is needed to reduce the amount of effort required for integration.

Table 7 presents an overview of the capabilities that enable the operational objectives. It also includes the TRLs for demonstrators in 2026, 2028 and 2030. For services in the third block, TRL are not applicable (n/a).

TABLE 7. **Overview of capabilities enabling operational objectives**

Capabilities enabling operational objectives	TRL in 2026	TRL in 2028	TRL in 2030
Capability for improving operational performance			
Functions/services/TEs for automated operation			
Connectivity: FRMCS.	6	7	7/8
Connectivity: satellite communication.	3	4	5
Connectivity: multiconnectivity platform (formerly ACS) and vehicle-to-everything (V2X).	5	6	7
ACS/FRMCS adaptation for wireless object controller (with FA6) and for monitoring systems (with FA3).		6	7
New **ATO technology solutions** for automated driving and decision-making, interoperable, and for all applications and segments, including freight-specific issues in commercial operations. Includes the already available integration of C-DAS and will include appropriate TMS interfaces for energy network management.	5	6/7	7/8
Absolute STP, highly accurate and safe, incorporating new sensors.	5	6	7
TIMS (train integrity and train length determination).	5/6	6/7	7/8
Digital register acting as a central data source for STP, ATP, TMS and DATO, for example.	6	6	7
Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.	5	6	7
Safe environment perception, including signal reading and OD, supporting cooperative awareness, supported by virtual certification.	5	6	7

Capabilities enabling operational objectives	TRL in 2026	TRL in 2028	TRL in 2030
Remote driving and command for depots, lines with low-density traffic, fall-back operations and shunting.	5	6	7
Autonomous route setting on networks with low-density traffic or in regional networks, terminals, depots and urban environments.	4	5	6
Capability for offering more capacity to customers			
Functions/services/TEs for reduced headway			
ETCS hybrid train detection, moving block and relative braking distance.	5	6	7
Virtual coupling, including self-driving freight wagons, supporting cooperative awareness.	4	5	6
Next generation of braking subsystems, to safely detect and manage low adhesion and reduce braking distances.	5	6	7
Capability for supporting cost-effective deployment			
Functions/services/TEs for cost-effective deployment			
Testing, validation and (virtual) certification platforms and facilities.	5	6	7
Modelling techniques to support development, engineering and planning, and V & V solutions.	n/a	n/a	n/a
Modular platform based on next-generation ATC architectures, for agreed on-board and trackside modular architecture.	5	6	7
Evolved **on-board communication networks**.	6	7	7
Deployment and migration strategic plans, including training and human factors.	n/a	n/a	n/a
Stable ETCS on board.	n/a	3	4-7

7.2.2.3. Demonstration implementations

Demonstration under real operational conditions (i.e. at high TRL) is crucial for checking the feasibility and impact of the (cluster of) technological components in the process chain, operated by railway undertakings and infrastructure managers. FA2 is proposing the following scenarios (eventually combined in shared set-ups).

- ETCS game changers, including moving block, hybrid train detection and FRMCS, showing increased system capacity.
- Next-generation ATC, both trackside and on board, allowing fast and simplified deployment and upgradeability.
- ATO GoA3/4 over ETCS, including operational scenarios such as shunting, management of degraded modes, remote control and cross-border operation, to assess the benefits of automation, namely the increased capacity, punctuality, flexibility and resilience and the reduced operating costs and energy consumption in at least four use cases:
  a. high-density main lines,
  b. regional low-traffic services closely tied to FA6,
  c. freight services, also considering self-driving freight wagons,
  d. Inspection vehicles.

- Automation applied to light-rail urban transport (i.e. tramways) in operation and in depots, and connected to other road users, to show the increased safety and punctuality and the reduced operational costs in urban environments.
- Test validation platform, to enable the implementation of next-generation ATC technologies in an efficient, cost-effective way.

Demonstrations will include interoperability aspects, challenging topology and climate situations across Europe, to show and assess the full impact of next-generation ATC. They will be divided into three clusters (2026, 2028 and 2030), with increasing complexity and maturity levels for the aforementioned scenarios.

- Demonstration cluster 1 (2026) consists of bringing S2R results and further rail sector innovations to a higher TRL, such as GoA3/4 over mixed radio-based ETCS levels (TRL 7), and remote driving and command in depots and yards (TRL 6), including perception systems, and demonstrators on next-generation ATC, and modular on-board and trackside ATC architectures. The first steps in the development of the new functions and TEs will also be completed, leading to PoCs and/or validation in a laboratory and in the field (i.e. up to TRL 5 in a lab and TRL 6 on-site). The modularisation of the ATC system is developed stepwise in close collaboration with the SP in the first cluster PoCs review.
- Demonstration cluster 2 (2028) integrates TEs and functions to enhance the performance and capabilities of next-generation ATC, supporting migration and enlarging the deployment scope of automation. This will enable the demonstration of ATO GoA3/4 in depots, yards and specific lines without train protection, shunting and stabling operations, and under ETCS and non-supervised modes (TRL 7). This cluster includes the validation of next-generation ATC tailored to regional low-density traffic lines and the first steps in highly automated urban light-rail operations (TRL 6). Modularisation is developed in close collaboration with the SP in order to create functional demonstrations.
- Demonstration cluster 3 (2030) goal is twofold. First, it will focus on mature solutions (TRL7/8) for the automation of the complete operational chain: from starting up and composing train consists, to running a train from start to finish in mixed operations of ATO and non-ATO trains and light-rail urban lines, with virtual coupling and other line capacity improvement concepts. And, second, demonstration will include interfaces, inputs and results from other FAs (such as FA1, FA3, FA5 and the TT). Modularisation is developed in close collaboration with the SP in order to develop prototypes.

It is expected that all three demonstration clusters take maximum orientation in the system architecture, including modular trackside and on-board architecture concepts, as defined in the SP. However, it is understood that, especially in demonstration cluster 1, a trade-off between the pace of demonstrator development and full architectural compliance may be necessary in order to not hamper development.

7.2.3. Impacts

7.2.3.1. Description of the impacts on existing rail services

From an operational standpoint, the impact of the next-generation ATC innovation consists, in reference to the master plan, of an increased punctuality, an increased railway capacity, a reduction in energy consumption, an increased flexibility in (re)planning and an increased cost-efficiency.

TABLE 8. **Descriptions of FA2 impacts in relation to the intended impacts laid out in the master plan**

Meeting evolving customer requirements

Because next-generation ATC allows for more accurate driving and stopping, which in turn induces better schedule adherence, increased punctuality can be achieved. There will also be an increase in flexibility in (re)planning because, when last-minute changes or disruptions occur, ATO trains can be rerouted in a shorter time based on the precision, performance, flexibility and the permanent availability of 'automated staff'. In addition, planning will be more flexible, as automated coupling and de-coupling will shorten shunting times. Also, shuttle trains that no longer need to change train drivers, will experience increased flexibility in relation to more demand-oriented services.

Improved performance and capacity

As a result of increased operational precision, the buffer time between trains can be reduced. This enables more trains to run on the network, leading to greater railway capacity. This is also the case due to the improved reaction time brought about by the optimal complementary working of man and machine, and shortened process times for starting up and turning trains, maintenance and cleaning activities. Finally, incorporating timing points on critical infrastructure can optimise the usage of the network even more.

Reduced costs

Another important aspect of next-generation ATC innovation is the increased cost-efficiency. By shortening circulation times for train staff and rolling stock, fewer staff and fewer trains are needed to provide the same services to the customer. This way, the same number of trains can be used to serve more passengers (durable expansion). Also, in conformity with the technical specifications, the train and infrastructure will suffer less wear with DATO which means a reduction in costs associated with maintenance and failure. The modular and, when possible, reduced number of ATC system components needed and the support of higher train densities reduces the infrastructure cost per train run and allows the offer of cheaper capacity.

A reduction in energy consumption and emissions is also achieved, as next-generation ATC incorporate rail operation optimisation techniques, with demand-oriented network improvement technologies and route-setting methodologies, leading to an optimal speed profile, which will be more precisely followed thanks to the more accurate driving and stopping.

Reinforced role for rail in European transport and mobility

Regarding societal impact, next-generation ATC will lead to a higher railway safety level (e.g. by fully supervising shunting processes), a decrease in travelling times for passengers and freight, greater customer satisfaction, a more modern and future-oriented job profile for both train drivers and planners, a modal shift to the railway sector from air/car transport, greater sustainability, and solutions for social/cultural developments. Simpler demonstrations and better supervision of safety levels are expected using supportive technology and by achieving a better collaboration between man and machine, reducing accidents and personal injuries. Improved capacity and punctuality will lead to a decrease in travelling times for both passengers and freight. This, along with improved riding comfort through better adherence to the optimal speed profile, will lead to greater customer satisfaction. Employees of the RUs and IMs may experience changes in their job roles. Train drivers will need to do less driving, possibly from a remote operation centre, and may have more of a monitoring role. Planners will get more support from the system itself, and managing disruptions would become more flexible. For society as a whole, a modal shift towards trains from air/car transport is envisaged as the railway sector gets more competitive with these modes in terms of travelling times and flexibility. This modal shift, together with better adherence to the optimal speed profile, will also lead to greater sustainability. All these operational and especially societal benefits of next-generation ATC will provide solutions for future social/cultural developments: urbanisation, population growth and climate change (increasing accessibility, flexibility and travelling times, which will also lead to less new infrastructure needed (lower (nitrogen) emissions), and higher sustainability of transport itself), as well as the future shortage of railway staff within the EU.

Improved EU rail supply industry competitiveness

Digital and autonomous train operation will modernise the rail system by increasing capacity and optimising rail operations. The development of a modular architecture based on new innovative solutions can provide a better-performing system.

7.2.3.2. Quantitative KPIs demonstrated in this FA

The KPIs described in detail in Table 7 can be used to identify the contribution of FA2 to the impacts mentioned above and defined in the master plan.

TABLE 9. **FA2 quantified KPIs**

Type of impact	KPI	Expected improvements
A first technical KPI which can show the improved flexibility of responsiveness is the system response time, which could be given based on the reaction requested from FA1.	Responsiveness is understood as being able to react to a request from FA1 in a shorter time than currently. Responsiveness provided by FA2 is the enabler for improved flexibility and can be measured as time.	Reduction from two hours to two minutes.
The accidentology indicator will show the improvement of operational safety for mixed traffic in urban environments with trams while reducing the human factor in the normal operation.	Number of collisions with third parties per 10 000 km travelled.	Decrease by 50 % (from approximately 0.2 to 0.1)
The improvement of the capacity can be used as an operational KPI, as the increase also indirectly improves travelling times, punctuality, quality of operation and reliability.	Number of trains online per hour and direction.	Increase of 10 %
The cost-related operational KPI is the reduction of LCC where especially the cost of operation includes energy consumption and productivity. Capital expenditure (CAPEX) is assumed to be kept at today's level but with additional functionality. Operational expenditure (OPEX)-relevant factors are reduced by various factors, such as staff productivity, and increased by greater automation in train driving and shunting, energy consumption reduction and improved punctuality through automation.	Energy consumption reduction in kWh measured as energy per passenger-km.	Reduction of 10 % compared to driver's average
	Increased staff productivity is understood as an increase in the productive hours, which are understood as the staff's worked hours minus waiting times, commuting/shuttling times, etc.	Increase of 30 %
	Punctuality is understood here as a reduction in cumulated delay time and is measured as delay/service in time.	Reduction of 20 %

7.2.3.3. Exploitation, deployment and migration considerations

A key aspect of this FA will be how to migrate from the current railway system to the future, more automated and digitalised railway system and how to deploy this new system. To make an efficient switch to this future reality, the FA2 results must support a step-by-step seamless migration with benefits for all involved partners. As governments benefit from investing less in new infrastructure or reducing the cost of current infrastructures, this leads to less traditional maintenance costs for the infrastructure managers. For operators, the exploitation costs must decrease in each step of that migration. For industry partners, the development costs are first time right and they can focus on deploying ETCS infrastructure on the one hand and next-generation ATC solutions on the other, leading to a better spread of their activities. Research centres will develop and deploy innovative technologies. This migration strategy will speed up the roll-out of next-generation ATC within the EU.

The challenge is to come up with a generic migration path that can be applied by all operators, infrastructure managers and rolling stock manufacturers (or their partners), while assuring proper decision-making based on the right business case inputs, so that a generic next-generation ATC migration path can be provided. This migration path will likely need to be coordinated with some other programmes (e.g. FRMCS, ETCS, ERTMS) and with the SP. In doing so, the roll-out of the technologies will be propelled by market forces. Overall, the business case at the system level is already quite clear, but it must be noted that, within the migration and transition, the gains and investment for each involved party are different, and therefore additional measures and research may be needed. Insight into these aspects is crucial for a smooth transition and must be considered throughout the innovation and specification phase as well. The migration path towards full deployment of next-generation ATC will be aligned with and complementary to the migration path of the broader CCS+ architecture proposed by the SP, including innovations for other trackside and on-board innovations (such as next-generation TCMS), in an adaptable stepwise approach. For example, TEs developed and demonstrated here should be used in and benefit from GoA1/2 and C-DAS implementations.

7.3. Flagship area 3 – Intelligent and integrated asset management

7.3.1. Objective and level of ambition

7.3.1.1. Targeted objective, new opportunities and associated risks

Designing, building, constructing, operating, maintaining and decommissioning rail transport systems are both financially and environmentally costly. Therefore, rail asset management is a key area to enhance via R & I, especially as more rail services will be needed to solve existing challenges and meet societal demands, following EU guidelines such as the European Green Deal.

In the future vision of rail asset management, assets status evolution information will be integrated into the TMS to improve services, reducing unavailability by limiting the impact of in-service failures and increasing safety. Moreover, the available information combined with AI and digital twins will introduce intelligence to the management and optimise the overall life cycle and operation of the rail system.

This FA has the goal of providing new innovative technical requirements, methods, solutions and services – including technical requirements and standards for future developments – based on the latest leading-edge technologies to minimise asset LCC or extend life cycles while meeting the safety requirements and improving the reliability, availability and capacity of the railway system, addressing both infrastructure and rolling stock.

The net result will be a common European asset management framework composed of a green, digital and safe set of solutions for the rail sector, focusing on the following three interrelated areas of application enhancing European rail industry competitiveness.

- Cost-effective asset management addresses short-, medium- and long-term interventions widely supported by digital (diagnosis) technologies and data analytics, thereby creating the basis for balancing operating costs, efficiency and reliability, while maximising the value of the rail system.
- Advanced and high-tech automated execution of construction and interventions supported by robotics and wearables, changing the way of working, improving the health conditions for workers ([20]) involved and increasing the quality and consistency of the results.
- Environmentally friendly production of resilient assets, supported by new design principles, innovative solutions and improved fabrication techniques, along with climate adaptation measures, including those addressing extreme events.

Addressing this broad scope as one FA, with the idea of tackling the issues jointly within a relevant group of stakeholders, will enable a faster route to market for the newly developed technologies, enhancing European rail services and safety, while decreasing costs and the environmental footprint. A joint effort increases the impact and creates the momentum to make a change. At the same time, it supports EU policies: for example, sharing asset management information. The activities considered in FA3 have a unique EU added value since the technological development and large-scale demonstrators can be scaled up and deployed at the EU level. Moreover, the solutions will support EU-wide standardisation processes and TSI drafting, which will benefit the overall railway sector.

This strategic agenda for new asset management technologies with an integrated approach also contains risks and problems that must be overcome, including but not limited to the following.

- No appropriate business cases for the technical evolution of various activities, leading to excessive costs for end solutions and hindering real market uptake.
- Insufficient consideration of human factors and of appropriate HMIs during the design and use phases of innovation, resulting in reluctance among users (e.g. maintenance staff) to adopt technologies such as augmented reality (AR) or localisation systems, further exacerbated by poor explanation and dissemination of their benefits.
- Reference system architecture frameworks and CDMs that are either inadequate or insufficiently developed to effectively integrate innovations and support changes within a holistic, system-wide perspective.
- Lack of information exchange or unavailability of data due to proprietary and/or heterogeneous systems and/or the lack of willingness and/or a legal framework for data exchange, impacting development and interfaces.
- Siloed proposals for technologies which do not consider overall value chain demonstration cases and/or that lack an integrated approach may lack real impact as they progress.
- A lack of accuracy in predictions damages the quality of the recommendations provided by applications in decision-making processes, resulting in requirements for the railway sector not being met.
- Unaccustomed certification processes for new assets, systems or processes, especially when not considering common safety methods and strong technical background since its inception.

([20]) Work in the rail industry is physically demanding and requires a lot of stooping and standing. Both fleet and infrastructure maintenance face similar problems: rising demand due to growing fleets and increased infrastructure usage, and an aging workforce. As the sector struggles to attract new talent due to the work being unattractive, improving productivity becomes essential. Robotics is the solution to these issues, bringing automation to the most repetitive, difficult, dirty and hazardous tasks. This is also in line with the EU's Occupational Safety and Health Framework Directive.

7.3.1.2. Innovation beyond the state of the art, including the integration of S2R results

Within the Shift2Rail JU, important research related and relevant to the scope of EU-Rail's FA3 has been carried out. It includes the following research areas of the Shift2Rail JU and their corresponding technology developments:

- **cost-efficient and reliable trains** with health monitoring systems and condition-based maintenance possibilities;
- **advanced traffic management and control systems** defining communication protocols;
- **cost-efficient and reliable high-capacity infrastructure** benefiting from innovative and optimised frameworks, processes and strategies;
- **technologies for sustainable and attractive European rail freight** (addressing both rolling stock and infrastructure), focusing on asset management from a maintenance perspective;
- **cross-cutting activities** with a common smart maintenance concept;
- **rail functional system architecture and CDM**, developing a CDM to facilitate data exchange.

In the current context, FA3 will introduce innovative and state-of-the-art technologies in the following fields (see Table 10).

TABLE 10. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail**

State of the art, including Shift2Rail results	Progress, innovation and new products
Cost-effective design, commissioning, construction, maintenance and decommissioning	
Progressive implementation of the building information modelling (BIM) methodology, addressing static railway information across Europe.	Integration of BIM tools to combine and standardise the configuration of static railway systems with digital twins in order to enable a dynamic view of the railway system, taking commonly agreed data structures into consideration to make sure data can be shared between various applications, stakeholders and disciplines, such as traffic management and ATO. Development of BIM technologies also potentially connected to digital twins for the predictive management of railway infrastructure vulnerable to the effects of climate change.
Area-specific asset perception systems that may not be connected to modelling and simulation workflows.	Digital capture of assets, modelling of physical phenomena (digital twins use cases) and simulation of complex interventions using AI, among others (Algorithms for detecting vulnerable areas).
Connection of RAMS information to LCC modelling, taking into account the whole life cycle of assets. Shift2Rail developments from previous projects such as In2Track2.	LCC automated models, based on digital twins and AI, assessing the effects of costs and the environmental footprint on different scenarios (e.g. new types of vehicles, climate change - with early warning solutions for incidents based on monitoring vulnerable areas new maintenance strategies, new materials).

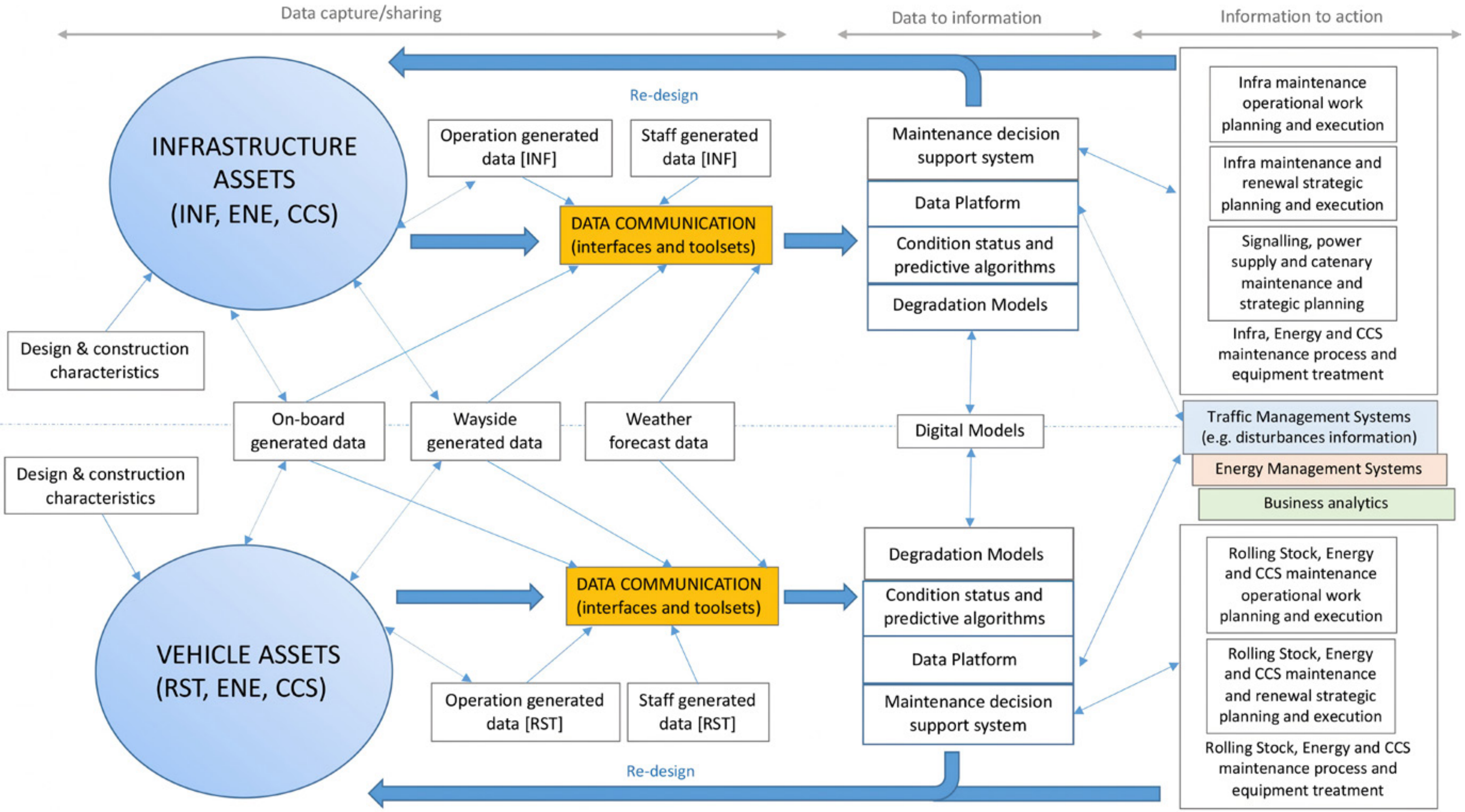
State of the art, including Shift2Rail results	Progress, innovation and new products
Vehicle–track interaction studies with low TRL development.	Implementation of innovative vehicle–track interaction solutions to optimise the design and behaviour of infrastructure and rolling stock and integrate with current in-service monitoring systems.
Preliminary study of new production processes and technologies addressing design and maintenance tasks, such as additive manufacturing (e.g. S-CODE).	Introduction and on-site testing of new production processes and innovative technologies in maintenance impacting operations.
Parallel approaches to reduce material use and waste, and to extend service lifetime.	New design techniques for infrastructure components to reduce the use of materials while maintaining and prolonging the time in service, effectively also contributing to rail resilience and environmental friendliness.
Atomised design solutions to improve future maintenance including, for example, new slab track designs within In2Track.	Improved design methodologies following the modular design-to-maintain for better operational performance paradigm. Action protocols and strategies for the management of the exploitation, redesign and execution of corrective actions (related to climate change and the development of associated resilience).
Maintenance procedures and methods	
Isolated but promising developments in asset monitoring and inspection which may not be connected to post-analytics workflows.	Use of diagnostic vehicles, in-service trains, checkpoints, wayside systems, on-board sensing and other methods feeding smart identification and definition of root failure causes, degradation models and maintenance thresholds for subsystems applying, among other things, AI techniques.
Breakthrough technology developments for non-invasive inspection within Shift2Rail.	Enhancements of non-invasive solutions to increase automated inspection, like exoskeletons, robots, biomimicry and drones, for construction and/or maintenance interventions, using internet of things (IoT), sensors, satellites, service trains or wayside systems to capture data.
Atomised use of data in area-specific applications such as infrastructure maintenance decision-making.	End-to-end integration of generated and operational asset data into automated operational and maintenance dispatch workflows.
Heavy dependency of decision-making on human experts. Growing problem of aging railway personnel.	Transfer of maintenance human expert knowledge into AI systems by codifying expertise, thereby providing AI-based assistance to human decision-makers. The objective is to improve efficiency, effectiveness and working conditions.
Preventive procedures dominate railway maintenance. Area-specific developments have arisen from projects such as In2Smart, In2Smart2 and related open calls.	Development, verification and high-TRL demonstration of algorithms for the prescriptive maintenance of subsystems.

State of the art, including Shift2Rail results	Progress, innovation and new products
Supporting technologies and innovative materials	
Low-TRL developments on the coordination between train operation and maintenance.	Cooperative planning tools to balance the impact on train service and assets management (connection to TMS and FA1), including possession planning and possession management tools. Integration of the predictive maintenance impact on the maintenance schedule.
Area-specific perception developments within Shift2Rail initiatives such as the technologies for autonomous rail operation project.	Sensor technologies for passenger and freight vehicles enabling automated detection, analysis, visualisation and geo-localisation of asset anomalies and external conditions.
TRL 3/4 developments for asset inspection in various areas such as UAVs or perception with some high-TRL demonstrations.	Automation of asset inspections via high-TRL applications of enabling technologies, such as UAVs. Increase in asset digitalisation, enhancing the data provided to prognosis and health assessment models.
Tailor-made pipelines for specific asset monitoring, analysis and prediction, including examples within In2Track2 and In2Track3, In2Smart2, PIVOT and PIVOT2.	The further developments on perception, data analytics and prescriptive maintenance will enable the creation of smart infrastructures and structures, providing an integrated framework for data monitoring, analysis and prediction.
Preliminary definition of data models, architecture and concept of digital twin within projects such as In2Smart.	Digital twin technologies addressing visualisation, prediction and simulation, thereby enhancing decision-making. Demonstration of the application of a use case for digital twins to railway asset management, in coordination with other FAs for potential integrated functionalities, where applicable.
Individual approaches for defects and health monitoring, addressing railways and rolling stock separately.	EU cooperative detection of defects and health monitoring to further progress on performance-based maintenance. Integration of sensor data from fixed and mobile operational assets, addressing both on-board and wayside systems, and developing a modular homogeneous system for railway checkpoints and route inspection reports
Application-specific interfaces to enable the use of predictive maintenance developments in projects such as In2Track (1, 2 and 3).	Development of HMIs, integrating AR and natural language processing technologies.
Preliminary study of the application of additive manufacturing and new materials in the railway sector (NextGear).	New materials and additive manufacturing processes extending the useful life of assets from a construction and maintenance point of view and contributing to rail resilience and environmental friendliness.

7.3.1.3. System integration, interactions with the SP and with other FAs

In this context, FA3 will leverage the integrated R & I programme of the partnership, contributing to a high level of integration and cooperation between the different actors, both within and outside the rail ecosystem. FA3 will take into account that bigger developments/demonstrators will allow for a better overview of the whole railway system from a maintenance point of view.

FIGURE 12. **Flagship Area 3 approach**



In general terms, asset management is the systematic process of developing, operating, maintaining, upgrading and disposing of assets in the most cost-effective way, therefore, using new technology such as mobile solutions, big-data applications or IoT, together with this systematic approach to the governance of maintenance over the whole life cycle of assets, will be a part of the development of smart maintenance.

The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initially identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

Following the framework defined by the SP, FA3 will push the boundaries of smart and prescriptive asset management, addressing, among other things, the following topics:

- the link to the TTs, using existing tools (e.g. BIM) and developing data models (e.g. CDM) and digital twins as a basis for advanced visualisation, prediction and simulation processes;
- a new tailored design and management paradigm for assets which will enable remote monitoring and autonomous interventions, when applicable, with low impact on system operation;
- enhanced decision criteria and migration strategies for the incremental adoption of the new asset management paradigm and transformation requirements;
- a tight coupling with TMSs fostering the exchange of information.

Details of the exchange between the FAs can be found in Annex B.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the CDM,
- the reuse of common foundation libraries of digital models,

- cybersecurity provisions.

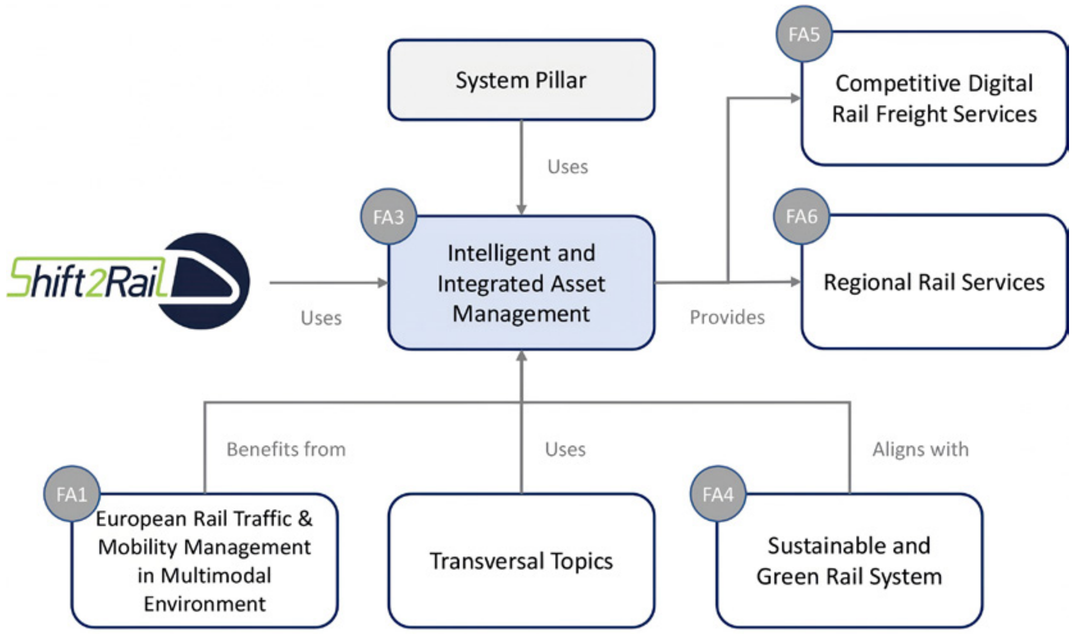
The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

In this context, FA3 will make use of the schemes, tools and digital enablers created in the TTs, while benefiting from an enhanced TMS within FA1. Within FA3, the development of digital twins is envisaged which, for example, will specifically tackle the vehicle-to-infrastructure interaction to aid the prediction of the degradation of components. These digital twins, specific to FA3, will be connected to and fed by others specific to other FAs. For example, to predict the degradation of the rails there could be an FA3-specific digital twin which uses information about the number of vehicles, their type, their speed and their wheel torque, which could be provided by a digital twin from FA1 and FA2.

Furthermore, there will be an alignment with the green solutions developed in FA4 with the aim of creating a sustainable and green rail system, meaning that FA3 solutions, including the design of resilient earthworks that take extreme climate events into account, will also help reduce the environmental footprint of the railway system. In this respect, FA3 will focus especially on reducing the environmental footprint of rail infrastructure (except stations), while FA4 will focus on rolling stock and stations.

Finally, FA3 will provide innovative technologies for maintenance automation to the freight services in FA5 and the regional rail services in low-density areas in FA6, to enable a sustainable and competitive digital freight system and to trigger the revitalisation of capillary lines. In this regard, solutions for monitoring and asset management from FA3 will be applicable on regional lines. The specific cost and performance requirements for additional elements and monitoring equipment for these types of lines are that they should be easy to install without many adjustments (self-supporting), and include a power supply (energy harvesting) and wireless communication protocols.

FIGURE 13. **Overview of the relationships within the EU-Rail JU**



The activities that will be developed within the FA3 will be tightly coordinated with the SP and a very important degree of collaboration is envisaged, for example, on the definition and standardisation of information exchange between on-board or wayside measurement systems and software platforms to display information, and on the standardisation of the validation procedures of additive-manufacturing-based repaired components.

7.3.1.4. Who does what by stakeholder group

FA3 will align stakeholders across the railway supply chain to trigger the market uptake of technology developments to assist asset management.

The vast group of **IMs and RUs** represent the core of Europe's operative rail network. IMs and RUs will provide a precise understanding of the rail system and the relationship between solutions and their impact on asset behaviour. As a group, they will ensure that the right priorities are set. Furthermore, they will support the testing of developments and host the required demonstrators.

Suppliers (including manufacturers, integrators, and service and technology providers) will develop solutions to be integrated in the existing assets and develop a new generation of assets to assist both rolling stock and infrastructure. The group of suppliers represents the core of the supply industry. They enable the shortening of development phases, the smooth adoption of new technologies, and integrate and migrate these technologies into mainstream products.

Research institutions and universities will support the generation of new technologies which will be matured into market-ready solutions in collaboration with the supply industry. More specifically, research centres can more easily bring in technologies from other sectors and support the research needed to make these technologies applicable to the railway system.

The three stakeholder groups above, representing the whole railway sector, will coordinate to provide the relevant **communication, dissemination and exploitation** channels to make an impact with the technologies developed within FA3, following Horizon Europe directives.

7.3.1.5. Interaction with other programmes, European and/or national

The R & I activities considered within FA3 are expected to interact with other programmes and initiatives at the European and national levels. It is worth mentioning the following European programmes:

- the European Partnership on AI, Data and Robotics, for data analysis and work automation, within Cluster 4 (digital, industry and space) of Pillar II of Horizon Europe;
- the European Institute of Innovation and Technology (EIT) within Pillar III of Horizon Europe, which has two specific knowledge and innovation communities – EIT Manufacturing, for new fabrication techniques, and EIT Digital, for the digitalisation of asset information and processes;
- the CEF, the LIFE programme and the digital Europe programme, for the funding of large-scale demonstrations;
- the EU recovery plan and European structural and investment funds.

Finally, interaction is also envisaged with other EU national programmes, and with programmes led by non-EU countries, particularly those that also prioritise smart and integrated asset management, such as the United Kingdom or Switzerland, where relevant and value-adding.

7.3.2. Results/outcomes

FA3's final operational solutions and outcomes have been categorised into five high-level capabilities that constitute the core of the innovative work envisaged over the coming years.

7.3.2.1. Operational solutions outcome

To achieve the overall goal of this FA, five high-level capabilities have been identified, addressing:

- data and information sharing,
- monitoring and inspections,
- decision-making,
- design,
- interventions.

While these capabilities are outlined individually, it's evident that desired outcomes often require a combination of these capabilities. This is especially clear in scenarios like robots intended for interventions, where the essential capabilities encompass inspection and/or monitoring, and decision-making.

The FA3 capabilities are presented as follows.

1. Information sharing across the supply chain and TMS

The focus here is on the ability to capture and share information securely across the entire rail system life cycle of rail assets, including operation. Furthermore, this area of action includes the secure exchange of information between the existing TMS and the IAM system. This requires the ability to tailor solutions to the needs of migration, evolution and competition throughout the life cycle of the subsystem, enhancing the modularity of the system. Developing technical solutions jointly, with all stakeholders, also creates the opportunity to challenge the legal constraints leading towards an appropriate legal framework.

2. Unmanned and non-invasive monitoring and inspections

The objective here is to enhance the capability for automated and unmanned inspection and monitoring, evolving towards non-invasive and self-diagnostic systems with no or minimal service disruptions. This encompasses various techniques, such as unmanned vehicles, IoT, robotics, railway checkpoints, drones and monitoring by satellite, and their connection to decision-making tools using advanced analytics, such as AI algorithms.

3. Advanced and holistic asset decisions

The focus here is on the capability of making decisions in an advanced, automated, centralised and holistic manner, considering the different assets, actors, standards and regulations, and in particular combining track and rolling stock data. This enabler will make use of big-data information coming from several sources, including TMS and maintenance control centres (capability 1) and IoT devices along the railway (capability 2), to provide predictive and prescriptive workflows for maintenance actions. Furthermore, digital twins and enhanced visualisation techniques (e.g. using AR technologies) will be exploited to support decision-making.

4. Advanced and holistic design and certification of assets

This outcome has a clear focus on the development of newly deployed components for the rail system. The new components will be developed based on the idea of improving the future life cycle and maintenance, following the design-to-maintain for better operational performance paradigm. This area of action will benefit from the use of modular design methodologies to reach its goal. Furthermore, in conjunction with the following capability, the use of additive manufacturing techniques will be addressed, along with the use of self-healing techniques and materials. On top of this, the new components will provide self-diagnosis and monitoring data (as per capability 2). Using mobile mapping techniques to capture massive amounts of geometric data of the infrastructure that has been built can support the design of railway infrastructure assets that are less vulnerable to the effects of climate change. This capability will particularly contribute to the reduction of the environmental footprint of railway assets and increase their resilience.

5. Remotely controlled and unmanned interventions

The objective here is the development of capabilities for remote, automated and unmanned intervention actions in rail systems. This will make use of various technologies, such as robotic systems and wearable devices benefiting from state-of-the-art AI algorithms, to support rail personnel, improve safety and increase the efficiency of intervention tasks. This area of action will also include the use of additive manufacturing technologies, in connection with capability 4.

7.3.2.2. TEs: capabilities to achieve the desired operational outcomes

The achievement of the objectives of FA3 will be demonstrated by complete and qualified solutions utilising the stakeholder experience in operational environments in the following three work streams, applicable to both rolling stock and infrastructure:

- **cost-effective asset management**, applying remote (e.g. satellite or drone), wayside and on-board monitoring technologies or data analytics;
- **advanced and high-tech automated execution of construction and interventions**, such as robotics, exoskeletons or other technologies supporting the execution of work;
- **environmentally friendly production of resilient assets**, including additive manufacturing or the application of the design-to-maintain paradigm.
  The implementation of each capability will be based on technical building blocks, TEs, classified in the table below with their associated envisaged maturity levels (up to – depending on the use cases).

TABLE 11. **Overview of capabilities enabling operational objectives**

	TRL in 2026	TRL in 2028	TRL in 2030
Information sharing across the supply chain and TMS			

	TRL in 2026	TRL in 2028	TRL in 2030
Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation) and to enable high-performance computing with the data.	6	7	8
Secure standardised interfaces, methods and processes for various data exchanges (e.g. between inspection devices and the asset management platform)	6	7	8
Unmanned and non-invasive monitoring and inspections			
Improvement in terms of cost reduction and/or in the accuracy and implementation of inspection systems (e.g. microwaves, microwires, magnetic fields, georadars, lidar, accelerometers, optical fibres) enabling asset diagnostics.	6	7	8
Advanced unmanned automated solutions (e.g. robotic vehicles) with AI and machine learning (ML) algorithms for automated (robotic) monitoring and inspections, including proof of safety for AI-based solutions (trustworthiness, robustness, interpretability).	6	7	8
Data fusion algorithms combining information provided by different inspection techniques to more accurately determine the health status of assets.	6	7	8
Development of context awareness techniques for unmanned interventions (e.g. accurate positioning, computer-based vision, laser scanning, georadar).	6	7	8
Development of synchronisation algorithms for accurate position and time stamping of inspection data.	6	7	8
Advanced and holistic asset decisions			
Harmonisation of railway asset LCC determination, using probabilistic models to take the cost of potential hazards and cost of potential unavailability into account.	6	7	8
Component failure probabilistic models to integrate the cost of potential hazards and cost of potential unavailability into the asset maintenance decision strategy.	6	7	8
Operational and IoT data with additional rail system information and knowledge.	8	8/9	–
Technologies to enable cooperative diagnostics between assets.	8/9	–	–
Predictive and prescriptive data analytics and ML algorithms for detecting anomalies and predicting failures.	6	7	8
Digital twins integrated with BIM, GIS tools, virtual reality and AR to enable agile visualisation of asset health status (historical, current and forecasted) for various stakeholders.	6	7	8
Trustworthiness, robustness, fairness, acceptability and interpretability of AI-based hybrid decision support.	6	7	8
Optimisation of human–AI interactions in hybrid decision support.	6	7	8
Advanced and holistic design and certification of assets			
New ethical-by-design materials and/or innovative materials and processes for additive manufacturing, with advanced LCC characteristics.	6	6	7
Advanced automated certification techniques.	6	7	8

	TRL in 2026	TRL in 2028	TRL in 2030
Energy scavenging approaches for self-supporting monitoring solutions.	5	6	7
Remotely controlled, unmanned and metadata-assisted interventions			
Development of non-invasive or collaborative unmanned robotic actuators (e.g. exoskeletons and collaborative robots).	6	7	8
Development of additive manufacturing techniques and validation standards for manufacturing and repairing assets.	6	6/7	7
Development of wearables to support interventions (e.g. AR, staff accurate positions for context awareness).	6	6	7
Advanced unmanned robotic vehicles with AI and ML algorithms for automated robotic interventions, which may include construction-related aspects, for new lines and renewals.	6	7	8

7.3.2.3. Demonstration implementations

The demonstration of the solutions in FA3 will encompass the outcomes of the five operational solutions, addressing data capture, data sharing and analysis, decision-making, innovative design, and intervention technologies. The **high-level principles** of the demonstrators in FA3 will be:

- the integration of the complete value chain;
- the exploitation of synergies between stakeholders at different levels, for instance, with respect to crossed monitoring;
- the prioritisation of activities to achieve the 2030 European objectives in rail mobility, exploiting Shift2Rail results.

The demonstrators will have to cover several **operational differences**, including the following.

- **Climate.** The proposed solutions will have to be able to take into account the wide variety of European climate types (some cases can address extreme climate events).
- **Line type.** Demonstrators will address high speed, conventional, regional, suburban and freight lines.
- **Traffic type.** FA3 demonstrators will cover passenger, freight and mixed lines.
- **Asset type.** Infrastructure and rolling stock will be addressed jointly, whenever possible, taking all assets into account, including track, civil structures, earthworks, signalling, vehicles, trackside, stations or power infrastructures.
- **Planning level.** Following the ISO 55000 standard, demonstrators will cover the strategic asset management plan (SAMP) level, the asset management plan (AMP) level and the implementation of the asset management plan (IAMP) level.

In the context presented in this section, FA3 will have seven **overarching demonstrators** with specific objectives, as presented below. Those demonstrators will have system demonstrations of the various developments and outcomes of the projects, including technologies and solutions targeting TRL 8 and European common integrated solutions. Due consideration will be given to the certification and validation of the new technologies and processes as part of those demonstrators. They will be implemented in an agile manner, without repeating three identical demonstrators seven times, implementing new capabilities at high TRL for each demonstrator, and taking stock of the development previously demonstrated within FA3 or done in S2R.

- **Asset management and TMS.** The main aim of the demonstrator will be to show the integration between the IAM system and the TMS, enabling the sharing of data and optimisation of decisions using common metrics.
- **Asset management and rolling stock.** The main objective of this demonstrator will be to present the monitoring of rolling stock (including on-board and wayside technologies), leading to decisions on and the planning of interventions, and redirecting rolling stock to workshops to execute the (re)scheduled work both manually and by using new technologies and solutions to conduct inspection tasks automatically.
- **Long-term asset management.** Development of LCC models for infrastructure. This demonstrator will include an analysis of the remaining useful life of cross-border infrastructure, and space-time cross-analysis and visualisation.
- **Asset management and infrastructure.** The objective will be to integrate field and on-board systems with central platforms capable of managing big data, enabling prescriptive interventions and minimising dangerous situations (such as extreme climate events) and operational service disruptions.
- **Asset management and digital twins.** The focus will be on design, maintenance, upgrade and renewal interventions driven by digital twins for the optimisation of processes, maintenance planning and the associated logistics. This will enforce the use of BIM to standardise system configurations and AI tools to execute simulations and predictions. The digital twin demonstrator will include visualisation, prediction and simulation.
- **Design and manufacturing.** This demonstrator will showcase the eco-friendly production of resilient assets supported by new fabrication techniques, such as additive manufacturing (focused on infrastructure assets).
- **Robotics and interventions.** This demonstrator will focus on showcasing high-tech automated execution solutions for construction and interventions supported by robotics and wearables, among other devices, building a safer and more automated railway environment.

At the project level, these high-level demonstrators need to be further elaborated and populated with specific, tangible and suitable use cases illustrating the impact of FA3 technologies in concrete solutions. The choice of these use cases will be based on sound business cases and supported by a wide range of stakeholders, possibly covering a variety of assets to demonstrate the versatility of the technologies, such as the following.

- Physical infrastructure: track, civil structures, earthworks, signalling, trackside, stations or power infrastructures.
- Rolling stock: passenger service, freight and light/urban vehicles.

The business cases will illustrate that major and widely recognised pain points are addressed, ensuring that the wide deployment of the outcomes will contribute to a significant improvement in cost reduction, direct cost or LCC, and/or the reliability of the system or work conditions.

Opportunities to create more aggregated demonstrators –particularly by linking demonstrators in the area of asset management through business cases that will link digital twins, TMS and asset management for rolling stock and/or infrastructure – will be pursued.

TABLE 12

#	Demonstrator name	High-level theme and result	Main capabilities involved	Link to other FAs	Railway line type					Traffic type			Asset type(s)							ISO 55000		
					Very-high-speed	High-speed and interurban	Suburban	Regional and community	Freight	Passengers	Freight	Mixed	Tracks and Switches and Crossings (S&C)	Civil structures and Civil Structures and Earthworks (EWs)	Signalling	Vehicles	Trackside monitoring	Stations	Power/energy	SAMP	AMP	IAMP
1	Asset management and TMS	Integration of IAM system and TMS	1 and 3	FA1	x	X	x	x	x	x	X	x			x	x		x			x	x
2	Asset management and rolling stock	Asset management of rolling stock operation, including specific solutions for freight	1, 2 and 3	FA5 TT	x	X	x	x	x	x	X	x				x						x
3	Long-term asset management	Infrastructure long-term asset management	2 and 3	TT	x	X	x	x	x	x	X	x	x	x	x	x	x	x	x	x		
4	Asset management and infrastructure	Asset management of infrastructure operation	2 and 3	FA1 TT	x	X	x	x	x	x	X	x	x	x		x	x					x
5	Asset management and digital twins	Digital twin asset management, addressing both rolling stock and infrastructure	3 and 4	TT	x	X	x	x	x	x	X	x	x	x		x		x	x	x	x	
6	Design and manufacturing	Advanced and holistic design	4	FA4			x				X		x			x			x	x		
7	Robotics and interventions	Remotely controlled and unmanned interventions	5	FA5 TT	x	X	x	x	x	x	X	x	x	x	x				x			x

7.3.3. Impact

7.3.3.1. Description of the impacts on existing rail services

This FA will provide prescriptive capabilities for an integrated asset management framework covering all the technological and physical elements of the European rail system of systems. It will also provide justified and transparent requirements for construction and maintenance. The objective is to produce significant value to the wider economy and the environment through a variety of innovative technical and operational solutions that will be delivered by joint R & I activities.

The expected outcomes of FA3 as a whole are:

- a strengthened European rail industry with greater competitiveness and more qualified products;
- higher volumes of traffic and more cost-effective rail transportation on existing lines;
- a reduction in CO_2 emissions through the maintenance of existing lines and the construction of new assets;
- an increase in the durability and reliability of assets, while optimising LCC, along with other positive direct effects resulting from synergies with other FAs.

In this context, following the master plan, FA3 will address the impacts presented in Table 13.

TABLE 13. **Descriptions of FA3 impacts in relation to the intended impacts laid out in the Master Plan**

Meeting evolving customer requirements Future rail asset management will improve the overall performance of the railway system and reduce unavailability. It will increase operational reliability by reducing the frequency of service disruptions and incidents through continuous and precise monitoring of the condition of key components, predicting failures in advance and scheduling preventive maintenance actions.
Improved performance and capacity Enhancing maintenance practices relies on accurate prediction capabilities to optimise maintenance procedures and reduce the downtime required for assets during maintenance activities.
Reduced costs The deployment of efficient work methods, development of guidelines for the design of low-maintenance and maintenance-free systems, and efficient and effective maintenance will reduce costs. With the technologies developed in this FA, the time required for and frequency of maintenance will be reduced thanks to the introduction of digital and AI solutions, reducing the need for human intervention.
More sustainable and resilient transport FA3 solutions will increase availability in the rail network and provide a more robust railway system based on fewer physical components, along with smart and more accurate monitoring and asset management. From a human factor's perspective, benefits will be realised by providing better working conditions and reducing on-site work for railway staff.

Europe's Rail

Improved EU rail supply industry competitiveness
Global technological leadership supported by a combination of innovation and technical standards will define innovative maintenance decision-making concepts. This FA will enhance industry competitiveness related to the design and maintenance optimisation of rail systems, taking current trends into account. The harmonisation and simplification of maintenance is achieved by applying and integrating advanced monitoring approaches, data analytics methodologies and decision support solutions.

The enhancements of the European rail asset management capabilities triggered by FA3 will finally be closely aligned with the overall strategic objectives set out in the SBA, as presented in the following table.

7.3.3.2. Quantitative KPIs demonstrated in this FA

To ensure the delivery of the aforementioned impact points, a close monitoring scheme using KPIs will be implemented. Considering the KPIs implemented within Shift2Rail, a new set of indicators will be defined for the specific solutions implemented throughout the programme.

A set of high-level KPIs has been identified for FA3, targeting the main impacts envisaged by the programme, as shown in Table 14.

TABLE 14. **FA3 quantified KPIs**

#	Demonstrator name	High-level theme and result	KPIs
1	Asset management and TMS	Integration of IAM system and TMS	• Qualitative and prompt integration of information, including reducing the time to transfer the asset condition status to the TMS by 50 %, in specific use cases.
2	Asset management and rolling stock	Asset management of rolling stock operation, including specific solutions for freight	• Up to 10 % reduction in maintenance costs in specific use cases. • 25 % reduction in in-service failures. • Increasing rolling stock availability respective reducing workshop downtime targeting 10 % in specific use cases
3	Long-term asset management	Infrastructure long-term asset management	• Tools that provide at least three possible long-term management strategies with an accuracy (as defined by ISO) improvement of 10 %.
4	Asset management and infrastructure	Asset management of infrastructure operation	• Reduction in maintenance costs, targeting 10 % in specific use cases. • 25 % reduction in in-service failures
5	Asset management and digital twins	Digital twin asset management, addressing both rolling stock and infrastructure	• 25 % increase in the number of assets managed and monitored by digital twins.
6	Design and manufacturing	Advanced and holistic design	• For repair: 25 % extension of remaining life. • 20 % time reduction (from design to manufacturing). • 20 % cost reduction.

#	Demonstrator name	High-level theme and result	KPIs
7	Robotics and interventions	Remotely controlled and unmanned interventions	• 25 % increase in inspection accuracy with respect to conventional actions. • 25 % reproducibility of inspections with respect to conventional actions. • At least 10 % reduction in the cost of interventions.

7.3.3.3. Exploitation, deployment and migration considerations

The developments in this FA, as outlined in the previous paragraphs, imply significant investments from the organisations involved in the EU-Rail JU and from the EU. The participation and commitment of a large community from both the user side and the supplier side is a good starting point for a guaranteed exploitation and wide deployment of the results.

To ensure and maximise future exploitation and deployment, the following set of additional measures has been established.

- An **integrated approach** in the demonstration scenarios so the new products and services are not presented in a siloed approach, but are integrated with others, further supporting a broader impact (e.g. autonomous inspection vehicle with a holistic approach of integrated asset management).
- The **involvement of final users** across the EU, including IMs and RUs, the rail supply industry and leading research centres, during the development and demonstration phases. The stakeholders included can be considered as references for commercial exploitation.
- The development of technologies aiming at TRL 8, bringing solutions closer to commercial exploitation, making them more attractive to suppliers and supporting the final-stage investments. This is driven by the success of the demonstrator and the visible market demand, and will require certification and validation processes to be taken into consideration, with the involvement of relevant authorities as soon as reasonably possible.

In addition, the deployment of new and advanced technologies requires a migration from the current state to the future one. As a baseline for the necessary migration paths, the following aspects will be taken into account:

- **coordination with the SP** to define a set of standards for information exchange at different levels, for instance, data from inspection results to holistic approach to strategic decisions;
- **the identification of potential adjustments of specific European regulations** to be adopted by Member States in order to enforce or enable the adoption of new technologies, for instance, referring to data interfaces.

7.4. Flagship area 4 – A sustainable and green rail system

7.4.1. Objective and level of ambition

7.4.1.1. Targeted objective, new opportunities and associated risks

This FA aims to provide new innovative products and services based on leading edge technologies to minimise the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier and more attractive, and to provide resiliency against climate change at a reduced total cost of ownership.

In order to achieve these general objectives, some high-level TEs have been identified:

- innovative solutions to minimise energy consumption and the associated environmental footprint of the overall rail system, considering assets, i.e. rolling stock, linear infrastructure and railway real estate (including stations, hubs and other railway buildings), and operating materials (fuel, coolants, oils, etc.);
- a holistic approach to the generation, storage and optimal use of energy in the infrastructure and, more broadly, the railway system connected to the European energy network;
- new tools and new designs of different subsystems and associated manufacturing processes based on a circular economy (6R model – reinvent, reduce, reuse, recycle, repurpose and realise) for a more efficient use of resources throughout their life cycle and a reduction of their environmental footprint;
- innovative approaches to design and use (processes and standards) focused on an increased capacity and modularity of solutions;
- improvement of systems, including electro-mechanical components supporting low consumption, emissions, noise and vibration levels;
- healthier and safer subsystems, such as air-filtration and disinfection systems and eco-friendly heating, ventilation and air conditioning (HVAC) with natural, halogen-free and low or even zero Global Warming Potential (GWP) refrigerants and technologies;
- new designs of rolling stock, in particular modular interiors for a more adaptive, attractive and economically sustainable railway for passengers, supported by industrial standards.

The work within this FA will enable a faster way to commercialise the newly developed solutions, making the European rail service more attractive, healthier and reducing its environmental footprint.

Given the level of investment needed for the decarbonisation of the overall rail system, for the assets and the associated operations, these R & I activities will accelerate the provision of decarbonised products to the market, supporting the objective of achieving a climate-neutral Europe by 2050.

To make this transportation mode healthier and more attractive and to provide resiliency against climate change (including extreme climate events), the following gaps and corresponding risks in minimising the overall energy consumption and environmental impact of the railway system will be taken into account.

- The development of technologies relevant to some of the FA4 activities is led mainly by other industries (e.g. hydrogen solutions within the Clean Hydrogen JU, batteries within the BATT4EU partnership, sustainable construction within the Build4People partnership), and might be difficult to be directly transferred to railways for various reasons, including the cost of technologies, standards incompatibilities and technical constraints.

- Siloed proposals for technologies not considering the entire value chain, missing some use cases and/or without an integrated approach may lack real impact as they progress.
- Insufficient technological performance or development in one entity's actions can dramatically affect the progress of a demonstration.
- The lack of appropriate business cases for the technical evolution of some activities, leading to the cost of a final product or service being too high for real market uptake (e.g. hydrogen production and storage).
- Longer and more costly than expected certification processes for new assets, systems or processes.

7.4.1.2. Innovation beyond the state of the art, including the integration of S2R results

The projects of our predecessor, Shift2Rail, achieved several goals in their specific innovation programmes. Building on those results and proposing a new field of activities, this FA 4 will further increase the TRLs of the relevant solutions, leading to new solutions in the following areas

TABLE 15. **Alternative energy solutions for rolling stock**

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
S2R IP1 'Traction' has undertaken the development of a new generation of traction drives using silicon carbide technology which will achieve TRL 7 in 2022. A carbon-free mobility roadmap for 2022 to 2030 details the work required to develop a credible alternative for diesel traction which meets technical performance requirements at acceptable costs. Basic research on battery- and hydrogen-powered rolling stock, including infrastructure and operational aspects for retrofitting existing regional trains, were undertaken before EU-Rail JU. IP5 studied last-mile propulsion and next-generation energy-efficient propulsion systems for freight vehicles. Work Area (WA) 5.1 'Energy' studied standardised methodology for the estimation of energy consumption through simulation and measurement, enabling the standardised specification of energy-efficient railway systems and generic energy labelling for rolling stock. In 2021, various low-carbon train experiments were carried out all over Europe. However, the technical performance was lower than required and/or the LCC was higher than expected, so there was a relatively low deployment of these new traction solutions that aim to replace the 9 000 regional diesel trains in Europe.	• To completely eliminate the use of diesel in Europe (and support exports), additional zero-local-CO2e trains and fuelling/charging infrastructures must be developed with the suitable technical, environmental and economic performance, aiming at multimodal H2 Hydrogen Refuelling Station (HRS) wherever applicable, for example. Moreover, additional harmonisation and standardisation efforts, including simplifying certification, are necessary to streamline European solutions, enable train interoperability, reduce costs and accelerate the deployment of solutions. Batteries (batteries electric multi-unit (BEMU) long range autonomy) and H2 hybrid trains with low LCC are needed, along with new remunerative energy services (peak power shaving, load shedding). Alternative fuelling solutions for regional railways, such as hydrogen, e-fuels and battery fuelling, are included in the broader scope of investigation. • New environmental aspects, the circular economy and recyclability must be taken into account in these new solutions, from the design stage to final demonstrations.

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Regarding hydrogen, a study on the use of fuel cells and hydrogen in the railway environment (21), commissioned by the Shift2Rail JU and the Fuel Cells and Hydrogen 2 JU, was produced in 2019, delivering a roadmap for R & I activities.	• Suburban catenary trains that have an on-board energy storage system (ESS) are also needed to increase the robustness of transport services in large urban areas, specifically the mass transit system, where a single power-supply weakness or failure can have an unacceptable impact on train punctuality: energy autonomy is needed for the comfort and safety of passengers or for traction to a nearby station. A powerful on-board ESS is also likely to eliminate the need for mechanical braking, thereby reducing energy losses, particulate matter emissions and maintenance costs. It is also a cost-efficient solution for when cities lack the capacity to strengthen substations and feed more trains. Moreover, it enables infrastructure peak power shaving, reducing energy costs.

TABLE 16. **A holistic approach to energy in rail infrastructure (design, production, use and intelligent management)**

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
S2R TD3.9 'Smart power supply' and TD3.10 'Smart metering energy' studied efficient energy management through the catenary for alternating current (AC) power supply, and energy management on the catenary for direct current (DC) traction. These studies, as the first steps, are limited to the proof and demonstration of the feasibility of the concepts. It includes modelling and simulation based on the theoretical and ideal operation of the system and its components. The legal aspect of the AC parallel operation of the substation, and the impact, performance and theoretical added value of the solutions have been considered. A first set of specifications of the components needed, the feasibility for industrial development have been carried out. Concerning energy storage, the state of the art is limited to the development of the storage technologies and their integration into the railway system for the specific applications of energy recovering (for on-track storage) and traction power (for on-board systems).	Further development of a solution for AC substation operation in parallel is needed to reach industrial maturity and prepare an on-site demonstration. It is also necessary to improve the specifications of the equipment to reach a maturity level enabling a manufacturer to develop/produce them. Solutions to manage the charging (including fast charging) and peak energy consumption on the railway electric grid, i.e. the local energy balance/management, must also be investigated. Solutions regarding the management of the ESS (on the track or on board) are also needed. Investigating those solutions will enable the management of storage systems for multiple services through a comprehensive railway system approach.

(21) https://rail-research.europa.eu/publications/study-on-the-use-of-fuel-cells-and-hydrogen-in-the-railway-environment/.

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Stations as relevant energy hubs Railways stations in modern cities, similar to harbours or airports, have complex energy systems (a variety of energy loads, sources and storages) and, as such, are relevant energy hubs integrated into the smart grid (as well as relevant nodes in the multimodal transport networks). In addition to this, railway stations are unique since the catenary and the train itself enable a link between the smart (city) grid and the smart rail grid. Extensive research regarding energy management for smart grids and under electricity market rules are mentioned in the H2020 bridge initiative (https://www.h2020-bridge.eu/), which compiles most of the H2020 projects related to this topic. S2R TD3.9 and TD3.10 cover the railway power system.	Models and AI solutions for optimal energy management, taking the interaction between the infrastructure and the train, the station as a building and the surrounding area into account, will integrate the **stations**, **energy hubs** into a broader **smart grid** aligned with the electricity market (virtual power plant for balancing markets, local flexibility markets, ancillary services, etc.) and energy communities' trends. This encompasses the forecasting of energy needs and the optimisation of energy costs and CO_2 emissions.
Hydrogen train use Using hydrogen as a fuel in the rail sector is supported by growing hydrogen developments in the transport domain. The technologies for hydrogen-powered engines are known, even though their maturity needs to be increased, with many implementation projects and niche vehicle fleet purchases being developed all over Europe Hydrogen can be implemented in retrofitting cases and in new builds. Growing hydrogen use calls for a storing and refuelling system adapted to the railway's needs, while at the same time being integrated into the local hydrogen system, easing scale effect integration, especially with the other transport modes. Storage solutions for railways are currently not standardised.	• Development of a standard interface between a hydrogen refuelling station and hydrogen vehicles, regardless of the producer of the rolling stock. The interface should ensure an appropriate refuelling time with the appropriate level of safety. It may be necessary to create algorithms to support the refuelling process and maintain optimal conditions. • Preparing and testing a model of a scalable hydrogen refuelling station that will enable the use of renewable energy sources (RES) and guarantee flexible expansion through modular additions. Because of the possible large increase in demand for hydrogen fuel in the future, it will be necessary to estimate the maximum efficiency of electrolysers for producing hydrogen from RES and develop plans to use external sources to supply the refuelling station. • Preparation of safety standards related to the storage and transport of hydrogen by rail, and appropriate safety standards for the refuelling station environment. • Inclusion of rail applications within a wider ecosystem approach, namely H_2 valleys, in collaboration with the Clean Hydrogen JU.

TABLE 17. **Sustainability and resilience of the rail system in a holistic approach to asset management, delivering more value**

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Adaptation to climate change No work has been achieved on adaptation to climate change in Shift2Rail. The life duration of railway assets (from 40 years for rolling stock to 100 years for a railway track) shows that long-term effects must be taken into account in their conception and maintenance. A working group was launched in July 2020 to consider climate change in the European standard EN 50125-1:2014 'Railway applications – Environmental conditions for equipment', without any help from climate experts or climate data provided. This work is limited to technical aspects, as the impact on organisations falls outside of its scope. Though the Copernicus Climate Change Service (https://climate.copernicus.eu/) supports society by providing information about the past, present and future climate in Europe, in the railway sector, climate experts with specific software are not available to analyse the available data. The Commission adopted its new EU strategy on adaptation to climate change on 24 February 2021. The strategy contains 4 objectives: to make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change.	The aim is to implement the EU adaptation strategy in the railway sector to make it resilient to climate change. • Smarter adaptation: develop robust data (analyses of past, present and future climate parameters applicable to the European railway activities) and provide risk assessments (common safety methods and LCC) regarding rolling stock, stations, workshops, infrastructures, operations and staff organisation. • Faster adaptation: identify existing solutions and develop new ones for existing and future railway assets to reduce climate-related risks, including SSBD. • Systemic adaptation: develop and implement adaptation strategies, including preventive and corrective actions (technical or organisational), and constraints applied on conception, or during maintenance or operations. • Harmonisation and standardisation: develop and implement standards for eco-friendly materials.
Smart and sustainable stations The Shift2Rail TD3.11 'Future Stations' has researched and identified innovation drivers to improve the design and maintenance of stations and their surroundings. The demonstrators have been prepared mainly with a focus on optimising station management in terms of cost and efficiency, with solutions being oriented towards improving the design of selected station modules/components, and improving attractiveness (accessibility, customer experience, usability) and safety, including crowd management. The achieved preliminary research within S2R provides the basis for the development of innovative solutions and their dissemination, forming the foundation of the railway sector's transition of stations to a circular economy model covering a significant extent of their full life cycle by 2030. The TER4RAIL (TER4R) project partly addresses the question of how rail can play a role in reducing global warming, limit rising global temperatures and ensure a liveable environment for the next generations.	• New layout concepts for the design of stations favouring modular and nature-based solutions, supported by BIM methodologies. • Designs for more resilient infrastructure that is better able to withstand extreme hazards, including extreme climate events. • Multimodality aspects for H_2, where applicable. • Design of the energy systems of the station, supported by BIM-based building energy management systems. • Use of the digital twin (DT) of the station for the operation and maintenance of the energy systems. Use of the DT of the station for circularity analysis. Use of the DT to simulate hazard scenarios, to design more resilient infrastructures and to prepare better contingency plans.

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
A sustainable rail system / circular economy Creation of a working group inside the Comité Européen de Normalisation [European Committee for Standardisation] (CEN) (CEN/TC 256/SC 2/WG 54) concerning the acceptance of new materials.	Development of environmentally friendly materials (recyclable, reusable, repairable, etc.) that are mainly composite-based. These materials should be adapted for a manufacturing process valid for market railway solutions and should also help to increase the resilience of railway assets. Applicability on running gear and interiors of C4. The adoption of new materials and processes is enabled by the upcoming standard in which stakeholders from the whole railway industry are participating.
Noise and vibrations Before **S2R**, rail noise and vibrations were the focus of several FP7 projects, Acoutrain (noise) and RIVAS (vibration), and Roll2rail in H2020. **S2R** developed many activities in various projects – FINE1 (noise) and FINE-2 (noise and vibration), Destinate (noise), Transit (noise) and Silvarstar (noise and vibration) – providing methodologies and tools for the development of methods for predicting noise and vibration performance at the system level, including rolling stock infrastructure and its environment, ranking and characterising each contributing source to optimise cost–benefit scenarios and comfort. Several IP3 and IP5 projects produced noise mitigation measures.	Further simulation methods and tools for train, infrastructure noise and vibration and traction noise are needed to better predict, design and develop the required technical solutions. Furthermore, the reduction of noise compared to state-of-the-art technologies must be considered and proven as a significant parameter of sustainability in the relevant EU-Rail JU activities.

TABLE 18. **Systems improvement, including electro-mechanical components supporting low consumption, emissions, noise and vibration levels**

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Trains currently base the implementation of key functions on **compressed air** (brake, suspension, pantograph, MTB – magnetic track brake, sanding). The air generation treatment unit systems used to provide compressed air have **poor energy efficiency** (approximately 20 %), a consistent **weight** (800–900 kg per train), generate **high levels of noise and vibration**, require significant **maintenance activities** and have high **costs**. The major trend in other transport modes (road, aviation) has been to remove actuators powered by fluids and replace them with electric actuators. The same major trend appears in railways and the ultimate step will be to completely remove air compressors and related pipes, creating ‘airless’ trains.	The first major step is to create an airless bogie, completed by an airless pantograph. This will reduce energy consumption, maintenance requirements and noise, and improve reliability; the weight saved can then be used to improve the performance of other train systems (BEMU autonomy, for example, if compressor and piping weight is replaced by batteries). This will also simplify the architecture of the train and its manufacturing, while requiring increased resilience to climate change and natural and human-made hazards, without increasing noise emissions. The required new components are: • an EMB system, for which development started under S2R but the final demonstration is still forthcoming; • an electro-mechanical pantograph (not available on the market yet), which has to be developed and demonstrated; • airless suspensions, which also need to be developed.

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
	Industrial standards, traditionally conceived for pneumatic systems, must be revisited from an electro-mechanical perspective, ensuring functional interoperability with the existing systems by complying with the applicable TSIs and European standards and ensuring equal or better safety and availability.
EMB system requirements, prototyping and testing in S2R up to TRL 6 Work on the EMB system has been done within IP1. By the end of 2020, functional and performance requirements were collected, evaluated and agreed. The main standards for the transitions to the new technologies were considered and concept developed. Brake calculation confirmed the feasibility of the new approach. By the end of Shift2Rail in 2023, a description of the functionality at the braking system level, including vehicle interface, signalling and wiring on a functional level, was delivered and the technology was tested for feasibility.	Regarding the EMB system, the next step to reach TRL 8 is the integration of this novel braking system into trains originally designed to have pneumatic/hydraulic braking systems. This comprises interfaces for command and diagnostics, energy storage and power supply concepts, RAMS considerations and vehicle authorisation. The most crucial task is the field test to solve all questions for vehicle integration and bring operational experience and market acceptance to maturity. This braking system will also need to improve resilience to various unexpected natural or human-made hazards while mitigating noise emissions from parked trains.
Eco-friendly HVAC units with CO_2 as a natural refrigerant have been simulated, developed and tested in real operation within S2R projects. Outside of S2R, the application of the natural refrigerant R290 (propane) for rail HVAC units has been investigated in early prototypes. However, these solutions are less energy-efficient, less resilient and less performant with regard to the expected higher ambient operation temperature than those proposed in new R & D done by the EU-Rail JU.	These initiatives will lead to a further reduction in HVAC energy consumption (30 % less than the existing system and 24 % less than CO_2 technology) by minimising the environmental impact of the materials/refrigerants used. The reduction in energy consumption is particularly important for battery trains, since HVAC consumes up to 30 % of the total energy used by the train. HVAC improvements will need to ensure: • improved resilience to climate change and various unexpected natural or human-made hazards; • enhanced efficiency in terms of both weight and energy consumption. The improvements will mainly be achieved by implementing technologies with a higher coefficient of performance (COP) in cooling and heating modes. A technology with a usable COP > 4 in cooling mode will be considered. Examples include: • application of the magnetocaloric effect for cooling/heating; • natural refrigerants (e.g. water) for a COP up to five; • optimisation of the design of concepts, units and components; • implementing the work at the European level is improving the operators and train manufacturers needs to be taken into account by HVAC manufacturers. And reversely, HVAC manufacturers will test along their developments of innovations, the acceptance by operators and train manufacturers. Moreover, all needed European debate (standardisation, validation process, etc.) needs to implement the work EU-Rail JU level.

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Train weight reduction Using a composite car body to reduce weight up to TRL 6/7 has been done in S2R IP1. Running gear steering systems (especially in bogies), active suspension, new materials and new strategies have been developed to reduce **weight**, **noise** and **vibration**. No relevant research activities beyond TRL 4 have been carried out at the European level to introduce permanent magnet surface mounted (PMSM) configurations in traction vehicles with **recycled magnets** to improve sustainability and the valorisation of waste and reduce the number of parts.	Train weight reduction still needs to be improved as any component or subsystem have been optimised in the S2R projects. This will boost energy efficiency, support increased passenger capacity, allow more batteries to be installed on the BEMU, resulting in longer autonomy, and reduce noise, train costs and maintenance costs. To simplify the train architecture and save weight, innovations at integrated component and subsystem levels are proposed. Three main axes will be used to achieve weight savings in bogies, drives and gearboxes: • using **new materials in structural and non-structural parts** (**composite**, etc.); has been partially done in S2R; • using totally new **3D printing** (and associated powders) for bogie parts; • **changing bogie architecture** to a frameless architecture. These new ways of designing/manufacturing bogies will require the development of **new standards**, particularly concerning validation/certification and **TSIs** for new concepts, materials and processes. The new bogie should bring weight savings of up to 25 % (up to 12 tons on a regional train with four cars). This and new running motors and running gear will improve technical and environmental performance, and support enhanced resilience, capacity, accessibility and waste valorisation, while reducing track damage.
Aerodynamic improvement This field has reached a certain level of maturity in VHSDT but still need a lot of improvement in regional and intercity trains. The roof of the train usually hosts the traction and HVAC equipment but, due to cultural habit, the aerodynamic aspect (air drag) is not optimised because maintenance teams want direct access to roof components.	With energy efficiency and cutting CO_2 emissions becoming increasingly important, new aerodynamic parts (hoods) must be installed on the roofs of trains. This issue encompasses not only technical challenges but also cultural and normative debates. Indeed, installing these hoods on trains requires the approval of the operator / maintenance team, and the safety aspects (elimination of the risk of a hood flying off while driving) must be agreed at the European level and in line with international standards.

TABLE 18. **A healthier and safer rail system**

State of the art, particularly based on the results from Shift2Rail results	Further innovation needed and covered by thisFA
Air quality on board trains Since the beginning of the COVID-19 pandemic, many suppliers have proposed materials offering new functionalities, claiming to be bactericidal, germicidal, fungicidal or even viricidal. However, the efficiencies claimed by these materials are not comparable or verifiable directly on rolling stock because the standards and testing protocols used are not adapted to rolling stock applications or operating constraints. Measurements of air quality on trains, in tunnels and in underground or covered stations have been developed all over the world in recent years in answer to people's growing concern with living in a healthy environment. They show that technically and economically efficient solutions have to be found to improve the air quality. This was not addressed in Shift2Rail.	• Technologies and methodologies to reduce health risks for rail passengers and staff. • Air-distribution and airflow management concepts aimed at more effectively removing contaminants from the passenger compartment while maintaining a comfortable temperature. • Air-filtration and disinfection systems for enhanced air cleaning in the HVAC system. • Enhanced surface materials to reduce the survival time of viruses and bacteria. • Passenger flow management to reduce contamination risks. • A standardised measurement protocol to assess the efficiency of technologies that aim to improve air quality on board trains, in underground stations and in tunnels. • Measurement and live visualisation of air-quality parameters to enhance passenger trust. • Technologies for both new train generations and the improvement of existing rolling stock. • All aspects to be considered with respect to rail-specific requirements: LCC, safety, reliability, endurance, etc. • Development of a standard to demonstrate effectiveness under train operating conditions.
Non-exhaust emissions No work has been achieved in S2R on the topic of non-exhaust emissions, such as particulate matter emitted from the wear of mechanical braking systems, wheel-rail contact and pantograph-catenary line contact. The EU's clean air policy aims to reduce air pollution as close as possible to the levels recommended by the World Health Organization, thereby minimising the harmful effects on human health and on the environment. The railway sector needs to reassure all customers and inhabitants that public transportation is harmless and the best way to reduce air pollution. Underground stations are a point of attention, because in addition to pollution from outside air, specific activities such as train braking or maintenance work can emit fine particles that can accumulate in these enclosures. Without waiting for the establishment of a dedicated regulation, some actors (railway operators, universities, etc.) carried out campaigns of measurements and analysis, and tested various solutions to improve air quality. However, few works have been published and there is still no solution available on the market for railways and subways.	The aims are to build a better understanding of the issue of non-exhaust emissions, such as particulate matter emitted from the wear of mechanical braking systems, wheel-rail contact and pantograph-catenary line contact, then assess the risks and elaborate a sound action plan to deal with the issue. Efforts will anticipate future regulations on air quality and ensure that rail travel is the best answer. The scope of these efforts is ambient air, with a focus on underground railway rights-of-way. The following actions are needed. • **Analysis of air quality** on board trains, in underground stations and in tunnels. • Assessment of **rail emissions factors**: characterise the non-exhaust emissions emitted by rolling stock, railway stations and railway infrastructures (ballast abrasion, pollution during work, aging of the underground infrastructures) and determine the influencing factors (link between air quality, emissions and asset characteristics). Assessment of polluting factors: characterise emissions caused by the use of operating materials, for example, on-board and wayside lubricants, and determine the influencing factors (improvements of eco-friendly solutions over conventional products regarding emissions to air, ground and water).

State of the art, particularly based on the results from Shift2Rail results	Further innovation needed and covered by thisFA
Developing electrical braking may be a solution but the potential effects are still unknown. Vacuum cleaning trains exist, but their operational speed of 5 km/h doesn't comply with infrastructure maintenance constraints and their effectiveness in improving air quality has never been measured. The UIC air quality sector was launched at the end of 2020 to share knowledge, select and share actions, share collaborative expertise and perform cross-analyses on results. The working group ISO / TC 269 / SC 2 / AHG 4 was launched in 2021 to standardise the methods for characterising and measuring particulate emissions from friction materials. The next Euro 7 standard for the road sector aims to tackle emissions from tyres and brakes to ensure that particle pollution from all sources is reduced to the lowest levels possible.	• Understand the **effect on health** of air quality, specifically in underground stations and tunnels, to help select efficient solutions. • **Air quality mapping**: define a method to evaluate and report the non-exhaust emissions emitted by railway activity (European Pollutant Release and Transfer Register (E-PRTR) – UIC reporting on Sustainable Mobility and Transport). • Develop and assess **solutions to reduce** non-exhaust emissions at the source, such as low-emission brake pads, operating fluids and materials. • Assess **solutions to collect** historic non-exhaust emissions, such as emission collection/filtering/treatment on board trains and in underground railway stations. • Define a **method to evaluate and report the efficiency** of air pollutant reduction solutions in operational conditions.

TABLE 19. **Attractiveness**

State of the art, particularly based on the results from Shift2Rail	Further innovation needed and covered by this FA
Current trains, including the new generation, are not designed for modernisation, nor for second life. The interiors are based on a tailor-made design specific to each series, and quick-fit fasteners are almost non-existent, especially for specific hard points. This limits the range of solutions for reuse and increases purchase and replacement costs, despite the requirements of operators over the last 10 years. The driver's cabin is a bulky, expensive and not a very scalable space. Only one of two is active during operations. **Shift2Rail TD1.7** '**Modularity in use'** looked into reducing the global cost of refurbishing interiors, but the budget and scope were limited to the 'technical tube': face and roof. Impacts for car body shell, floor, plug-and-play fixation systems were not considered. A final demonstrator is planned for 2022 (TRL 5). The emerging concept of having only one driver's cabin would reduce CAPEX and OPEX costs. Two forward-looking concepts will be proposed in 2022 (TRL 4-5). Due to budget constraints, the scope is focused on use cases without any hard technical considerations. **S2R projects** showed that the European marketing services of operators and manufacturers generally look no further than five years ahead when addressing passengers' needs. The capacity to refurbish quickly is therefore crucial, especially for meeting the mid-life maintenance milestone.	Further collaboration with operators, car-manufacturers and suppliers is of utmost importance to define new industrial standards and/or European standards, taking into account accessibility, modularity and circular design, easing the specific services, the increase in passenger capacity, the capacity for micro-freight, the transformation of day trains into night trains at sustainable cost and the daily turnaround of night trains into day trains to increase their economic viability. The following activities aim to reach TRL 8: • To develop and test common plug-and-play fixation systems for hard fixation points, both for new train generations and for the improvement of existing ones. • To find a better compromise between standards and the best customisation. • To integrate new sustainable materials. • To integrate circular design into standards. • Specific activities could be, for instance, quick mechanical and electric fixation systems, or a new driver's desk (design, integration of new technologies and HMIs).

7.4.1.3. System integration, interactions with the SP and with other FAs

Regarding the existing development of the functional system architecture (SP), it is important that the energy management should be considered from a systemic perspective, moreover in the electrified network.

The details on the interaction between the SP and the IP are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initial identified needs.

By the ramp-up phase of the relevant projects of the SP and the IP the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

The following links with the other FAs of EU-Rail must be taken in consideration.

- DAS/C-DAS and energy management linked with FA1 (in terms of TMSs), FA2 (in terms of ATO) and FA5 for specific freight purposes.
- There will be an alignment with the green solutions developed in FA3 to create a sustainable and green rail system. FA3 will focus in particular on reducing the environmental footprint of rail infrastructure (except stations), while FA4 will focus on rolling stock and stations.
- FA4 will share relevant technologies that can support the development of light vehicles for regional lines, such as reduced-weight vehicle components (bogies, HVAC, etc.) and alternatives to diesel, especially if such technologies may have low-cost variants (potentially relevant for export markets). Technologies of modular stations with multimodal links and refuelling technologies will also be relevant for regional lines. It should be noted that impact will probably be limited since FA6 only concerns the revitalising of capillary lines and will develop specific low-cost and agile vehicles having few synergies with the classic regional trains with four to six cars studied in FA4.
- Digital twin TT, link on FA4 virtual validation and certification as digital models of on-board subsystems are needed on both FA4 and digital twin sides.
- Digital twin TT, link on FA4 regarding the design, construction, operation and management of railway infrastructure, including energy management (shared also with the SP) within the energy hubs integrated into the smart grid.
- Digital Twin TT link on FA4 concerning aerodynamic performance, which is crucial for the energy efficiency of the vehicles.
- Digital twin TT for stations applications, supported by BIM.

Details of the exchange between the FAs can be found in Annex B.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the CDM,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

7.4.1.4. Who does what by stakeholder group

FA4 will align stakeholders across the railway supply chain in order to increase the sustainability of the European railway system, their assets and their operations.

IMs and RUs manage rail operations on the European network. They will ensure that the technologies proposed are relevant to the system as a whole, including assets and operations, ensuring the right priorities are considered. They will support the development of the technologies through their engineering capacities, applying their knowledge of asset behaviour throughout the whole life cycle. Furthermore, they will support the testing of developments and host primarily the required demonstrators.

Manufacturers, integrators and service and technology providers will develop solutions to be integrated in the existing assets, along with a new generation of assets to assist both rolling stock and infrastructure. The suppliers group represents the core of the supply industry, enabling the shortening of the development phase, the easy adoption of new technologies and integrating and migrating these into mainstream products.

Research institutions and universities will apply their scientific knowledge to support the creation of new technologies which will be matured into market-ready solutions. More specifically, research centres can more easily bring in technologies from other sectors and support the research needed to make these technologies implementable in the railway system.

The three stakeholder groups above, representing the entire railway sector, will coordinate with each other to provide the relevant communication, dissemination and exploitation channels to make an impact with the technologies and specifications/standards developed within FA4.

7.4.1.5. Interaction with other programmes, European and/or national

Regarding energy storage systems and H_2 fuel cells (FCs), FA4 activities will have to be coordinated with the European partnerships, BATT4EU and the Clean Hydrogen JU.

Regarding potential H_2 activities, synergies with national and regional (especially European structural funds) investments for R & I will be considered, given the various prototypes, and even small fleets of vehicles being financed across Europe.

Regarding alternative traction systems, the railway sector is experiencing a noticeable difficulty in investing in new freight solutions. In particular, the need to replace diesel freight locomotives underlines the following challenges in finding viable alternative (H_2) solutions.

- Lack of compact (weight and volume compatible with locomotives limitations) high-power FC systems (around 4 to 6 MW per locomotive).
- Lack of compact hydrogen storage. Currently, United States diesel freight locos can carry around 18 000 litres of diesel. This equates to about 70 tons of H_2 and H_2 tanks in current 350 bars compressed H_2 technologies. This is not very convenient for freight locos and better solutions are needed (like fuels that are liquid at normal conditions). New concepts for on-board hydrogen storage (liquid organic hydrogen carriers, cryo-compressed H_2, etc.) are still being developed, and the impacts of refuelling more frequently could also be explored/assessed.

The Clean Hydrogen JU will work on similar needs for maritime and road applications and FA4 will want to follow up the progress done by Clean Hydrogen JU, in particular on the following.

- FC systems and fuel storage solutions in heavy-duty vehicles (HDVs) and trucks: the power range is about the same as in regional train power packs (237 kW for HDVs; 300 kW for regional trains). HDV ramp-up is expected in 2026.
- Maritime developments: even if the driving profiles are not the same, it may be interesting to follow up the new 3 to 10 MW FC systems.
- Any other developments for compact, high-power systems.

The progress of existing (2021) projects will also be taken into account. This will include following up on the ShipFC project (2 MW and NH_3) and another project on 3 MW polymer electrolyte membrane FCs and liquid H_2.

Some projects in the aeronautic domain are also of interest. The Clean Sky JU will work on FC systems (250 kW FC in 2025), high-power (1 MW+) FCs and liquid H_2.

If marine or aviation developments are successful, they could potentially be applied in the railway sector, if feasible (both technical and normative aspects will have to be evaluated).

The stations' topics should reflect connections to the EU partnerships, Built4People and New European Bauhaus.

The interactions of stations as energy hubs with the activities proposed and granted by Cluster 5 of Horizon Europe should be considered; interactions with other EU national programmes are also envisaged.

7.4.2. Results/outcomes

7.4.2.1. Operational solutions outcome

For the holistic approach to energy management in the railway infrastructure, the following solutions will be provided:

- developments aimed at establishing a more integrated and standardised rail power smart grid, integrating greener energy sources, cutting energy consumption peaks and enabling better control and management;
- developing better energy management at the station level (stations as energy hubs), providing more intelligent and integrated control systems and enhancing energy flexibility and resilience on the electrical smart grid.

For the holistic approach to circularity and resilience, the following solutions will be provided:

- technologies for a more sustainable and hazard-resilient design of railway infrastructures and rolling stock, taking into account the whole life cycle of the assets and supported by digital twin developments;
- sector tools or a platform for the efficient implementation of circular economy solutions in the railway sector (infrastructure, rolling stock and buildings), and for communicating accurate environmental data to stakeholders;
- guidelines for the design of modular stations tailored to various sizes and intended uses.

Airless trains are supported by advanced electro-mechanical components that eliminate the need for air management and the associated compressors on board trains, increasing energy efficiency and aerodynamic performance and reducing the weight of the train. This revolutionary technical advancement will lead to many positive changes and simplifications in rail operations.

Regarding the development of a healthier, safer and more attractive railway system, the following solutions will be provided:

- vehicle-level HVAC optimised for airflow management to support the control of epidemics (e.g. COVID-19) (TRL 8/9);
- passenger flow management integrating various health and safety measures (TRL 8/9);
- COVID-19-proof and non-toxic materials, among other solutions, to combat the dissemination of pathogens, along with a performance test protocol of their biocidal effectiveness via laboratory tests and comparison to real conditions on Rolling Stocks (TRL 7);
- industrial standards (design, analyses, methods, etc.) making it easier to quickly modify interiors (TRL 8), supporting a big increase in the integration of secondary raw materials and bio-sourced materials (TRL 6/7).

7.4.2.2. TEs: capabilities to achieve the targeted operational outcomes

To achieve the operational outcomes targeted in this FA, several technical capabilities were identified. To develop flagship demonstrations, the TEs must deliver functions with enough maturity, indicatively above TRL 7. An estimation of the technical readiness in 2026, 2028 and 2030 is proposed.

1. Alternative energy solutions for rolling stock

As a basis, the following enablers will consider the development and validation of traction system components to improve technical, environmental, circular economy and LCC KPIs.

They will provide:

- innovative energy management models and systems that can be integrated into energy optimisation models and systems considered by FA1 (e.g. connected DAS) and FA2 (ATO driving curve);
- public and industrial standards.

Complementary to new on-board hardware and software solutions, methods and tools will be developed, particularly for multi-physics modelling and virtual simulation creating digital twins of on-board subsystems and components, leading to virtual certification.

TABLE 20. **Overview of capabilities enabling operational objectives 1**

	TRL in 2026	TRL in 2028	TRL in 2030
High-performance **BEMU train**, with long-distance autonomy (target of 200 km), optimised aerodynamic with mobile fairings adapted to maintenance constraints with high safety locking devices, weight savings, standardised and interoperable batteries charging interfaces and data protocol with infrastructure, smart eco-mode functions to minimise energy consumption on-board, Traction Battery second life (after end of life in Traction duties). Adapted operation rules will be implemented to ensure full acceptability by operators and train drivers. Standardised interfaces will be developed for those in charge of maintenance to ensure cost-efficient changes of the battery racks during the train's life.	6/7	7/8	8
H_2 hybrid trains: • design of HDV (with gas H_2, liquid H_2); • assessment and safety analysis of new technologies for on-board hydrogen storage (H_2 storage vehicle for traction unit or tank wagon); • demonstration on an infrastructure inspection/maintenance vehicle and/or hybrid H_2-powered loco for freight/passenger use, mainly focused on the management and reuse of wasted energy.	6	7	8
Suburban catenary trains with an on-board ESS having a high level of braking energy recovery and energy autonomy for passengers' comfort and safety, and traction to a nearby station. A direct connection between the ESS and the electrical engines has to be established to ensure high efficiency with a combination of supercapacitor batteries (power) and Li-ion batteries (energy).	4		

2. A holistic approach to energy in rail infrastructure (design, production, use and intelligent management)

A holistic approach to energy management in the railway system, incorporating increased use of RES, energy storage devices and smart local energy management, will support global mobility decarbonisation efforts and improve the energy efficiency of the railway system, alongside the definition of relevant standards.

TABLE 21. **Overview of the operational outcomes 2**

	TRL in 2026	TRL in 2028	TRL in 2030
Railway strategic hydrogen demonstrator Development of a universal hydrogen refuelling interface and digital algorithms to improve refuelling efficiency.	6	6/7 ([22])	7/8
Rail power smart grid in different systems (e.g. 25 kV AC, 1.5 and 3 kV DC), incorporating various sources of renewable energy, energy-harvesting technologies, breaking energy recovery and the parallelisation of AC substations, along with the integration of energy storage. All these are supported by the latest power electronics technologies (e.g. silicon carbide). Appropriate planning of the location and connection of RES and energy storage systems, along with energy flow management, metering and the cooperation of sources with traction loads, supported by AI. Innovative energy management models and systems that take into account vehicles operating in the infrastructure, from a systemic perspective, and can be integrated into energy optimisation models and systems considered by FA1 (e.g. connected DAS) and FA2 (ATO driving curve) will be provided. Typical use cases are mass transit systems or lines with low-density traffic where the integration of local RES and new technologies, such as power electronics enabling parallel substation operation, are key enablers to increase the reliability and efficiency of the power supply capacity at a sustainable cost. In DC electrified networks, in which energy cannot be normally injected to the public grid, these developments will avoid the need to invest in new substations. In AC electrified networks, significant improvements will be made, such as decreasing LCC, controlling imbalances in the external network (by using single-phase current), enabling the parallelisation of substations, eliminating neutral zones and incorporating RES.	5/7	6/8	7/8
Stations as energy hubs Railway stations are important energy nodes in the modern city's smart grids. A variety of energy loads (HVAC, public address system, lighting, offices, leisure/shopping spaces, etc.), sources (e.g. RES, such as wind or solar energy) and storage options (e.g. reversible charging of electric vehicles in parking lots) converge at railway stations. This may be also be the case for some airport terminals. In addition to this, two other relevant energy items come into play at stations: the catenary, interacting directly with the station's energy hub, and the train itself, with its ability to transfer braking energy to the station's energy hub. Technological challenges include the **energy management of hubs integrated into smart grids** under market rules, the recovery of braking energy, the prioritisation of RES and local consumption (aligned with energy communities' trends), and development of market mechanisms to exchange energy under these conditions.	6	7/8	8

([22]) Not all items will progress further in wave 2/3.

3. Sustainability and resilience of the rail system in a holistic approach to asset management, delivering more value

TABLE 22. **Overview of the operational outcomes 3**

	TRL in 2026	TRL in 2028	TRL in 2030
Adaptation to climate change • Climate database tool of past, present and future climate parameters (temperature, rain, wind, etc., with statistics such as extreme values and standard deviations), applicable to the specificities of European railway activities (in categorised zones), taking into account Intergovernmental Panel on Climate Change scenarios. • Risk assessment report (reliability, costs, etc.) on railway assets: rolling stock, stations, workshops, infrastructures, operations and work organisation. • Report to implement adaptation strategies with time planning: preventive and corrective actions (technical or organisational), constraints to be applied on conception, maintenance or operations. Evaluate the performances of existing solutions (in the world) and identify the need for new solutions for existing railway assets (retrofit) and future ones (new conception) to reduce climate-related risks, as needed.	5	6	7
Smart green railway stations (including other railway buildings) Methodologies and guidelines for optimising station layout design, favouring modular and nature-based solutions and aimed at reducing the carbon footprint. Design of more robust and resilient infrastructures that are able to withstand extreme climate change and other hazards. Development of a BIM-based (openBIM standards) DT of the station (including energy systems). Use of the DT for life cycle and circularity analyses of the station assets and materials. Use of the DT for the simulation of extreme hazard scenarios in order to achieve a more resilient performance. The development, testing and implementation of modular, replicable, functional utility solutions, taking into account the specifics of the working environment in the railway area, is the basis for the future ecological railway station, which will be attractive and useful in three dimensions: functional (design-optimised), rational (efficiently supplied (water, energy, air) and managed) and perceptible (attractiveness, accessibility, safety).	5/6	7/8	8
Eco-design holistic methodology and tools system New design solutions harmonised with regulations and the standardisation of railway systems from an environmental point of view (infrastructure, stations, rolling stock).	5/6	6/7	7/8

	TRL in 2026	TRL in 2028	TRL in 2030
Reduction of noise and vibrations from railway infrastructure and rolling stock • Further improvement of noise source characterisation (e.g. aerodynamic noise sources) to improve procedures and methodologies for virtual certifications. • Development of a noise perception indicator for rolling stock (including High-Speed Line) and simulation tools for noise emissions and propagation, and for evaluating the impact of noise exposure and the acceptance of rail services (potentially in combination with other pollutant emissions, e.g. vibration and non-acoustic factors). • Investigations about noise and vibration emissions over lifespan and their degradation, including improvement of maintenance rules to keep tracks and rolling stock (e.g. wheel roughness and flat wheels) constantly under TSI noise limits • Use of fibre-optic sensing along the track to measure, monitor and assess the vibration generated by the trains, and a model to predict degradation and the effect of maintenance. • Development of effective mitigation measures for ground-borne vibrations originating from tracks or on the transmission path from the tracks to the receivers (i.e. buildings), including their prediction (insertion loss) across different environments or soil types, to be integrated into the ground-vibration prediction tool. • Reduction of curve squeal: development of infrastructure-based solutions beyond current friction modifiers, along with design guidelines and specifications for rolling stock (focus on city lines), aimed at reducing squeal noise through a system-level approach. Research will also address test procedures for acceptance inspections of low-squeal-noise rolling stock, and how these can be integrated into noise prediction and impact assessment studies.	5/6	6/7 ([23])	7/8

4. Improvement of electro-mechanical components and subsystems for rolling stock

TABLE 23. **Overview of the operational outcomes 4**

	TRL in 2026	TRL in 2028	TRL in 2030
Airless bogies, brakes, pantographs and suspensions Develop and introduce to the market an EMB system, electro-mechanical pantographs and a novel concept of suspensions control, shrinking or even eliminating air compressors and the associated maintenance costs. Advantages of the new system include: lower energy consumption, a more effective transfer of braking signal, improved braking accuracy through the elimination of pipe leakage issues, reduced overall system weight and layout complexity (associated with compressors and pneumatic piping) and better diagnostics. These brakes will also need to be more resilient to natural and human-made hazards than current brakes.	6/8	7/9 ([24])	8/9

([23]) Not all items will progress further in wave 2/3.
([24]) Not all items with progress further in wave 2/3.

	TRL in 2026	TRL in 2028	TRL in 2030
Vehicle weight reduction Lightweight, eco-friendly **high-speed train bogie** frame (conventional and based on independent rotating wheel), etc., to improve consumption/emissions ratios per passenger/km, and to increase climate resilience.	6	7	8
Eco-friendly HVAC system / HVAC system with green refrigerants or new cooling technologies with low GHG emissions Deliver alternative technologies to replace hydrofluorocarbon refrigerants. • New technologies will reduce the energy consumption of HVAC systems (30 % less than current HFC technology) due to the better COP in cooling and heating pump modes. • Tools and methodology to measure and optimise the energy consumption of HVAC units under real operating conditions. • The new HVAC technology will need to weigh less and be more resilient to climate change and natural and human-made hazards.	6	7	8/9
Optimised motors and gearboxes to improve energy efficiency, weight and noise reduction, following circular economy principles and using recycled materials.	6	7	n/a
High-performance bogies, gearboxes and suspensions: high-capacity independent wheel **regional intercity bogie**.	6	7	8
Virtual aerodynamic certification to reduce the number of full-scale tests and therefore costs by introducing enhanced experimental and numerical methods.	6	6/7	7/8

5. A healthier and safer rail system

TABLE 24. **Overview of the operational outcomes 5**

	TRL in 2025	TRL in 2028	TRL in 2030
Air-distribution and airflow management concepts aimed at more effectively removing contaminants from the passenger compartment while maintaining a comfortable temperature.	6	7	
• Air-filtration and disinfection systems for enhanced air cleaning in the HVAC system. • Enhanced surface materials to reduce the survival time of viruses and bacteria. • Low-emission components and materials.	7/8	8/9	
• A standardised measurement protocol to assess the efficiency of technologies that aim to improve air quality on board trains, in underground stations and in tunnels, reducing the health risk for rail passengers and workers. • Measurement and live visualisation of air-quality parameters. • Evaluation of low-cost sensors and AI for spread out measurements and analyses of air quality on board trains, in underground stations and in tunnels	6/7	8/9	

	TRL in 2025	TRL in 2028	TRL in 2030
• Tool simulating air quality in railway stations. • A standardised method to report the non-exhaust emissions emitted by railway activities. • A measurement method to evaluate and report the efficiency of solutions for reducing air pollutants in underground railway rights-of-way. • Solutions to reduce non-exhaust emissions at the source, such as low-emission brake pads. • Analysis of existing solutions to collect historic non-exhaust emissions, such as emission collection/filtering/treatment in underground railway stations.	7	8/9 ([25])	

6. Attractiveness

TABLE 25. **Overview of the operational outcomes 6**

	TRL in 2025	TRL in 2028	TRL in 2030
Interiors designed with modularity principles and plug-and-play systems in mind, using materials that have a low environmental impact. • Facilitation of refurbishment, particularly at mid-life, based on circular economy principles. • Innovative concept to re-use sleeper trains as day trains, increasing the economic viability of night trains (technical modularity). • Interior's adaptations: plug-and-play electrical and mechanical systems. • Easy adaptation of rolling stock to meet capacity demands, including the integration of relevant information devices.	6	7/8 ([26])	8/9
Interiors designed using innovative low-tech and circular design principles. • Design and materials that prevent obsolescence through an innovative low-tech approach. • Interior's atmosphere provided by new materials that have a low environmental impact. • Facilitation of refurbishment, especially at mid-life.	4	7/8	8/9
Interiors designed for on-demand/modular comfort. • Privacy, anti-theft protection. • Relative adaptability of the lighting and acoustics for each passenger or zoning of passenger's room. • New holistic approach regarding the accessible, odourless, touchless, hygienic design of interiors, especially spaces with a substantial flow of passengers (e.g. toilets).	6	8	8/9
Accessibility for PRM. • Full autonomous access to vehicles for PRM throughout the entire lifecycle of rolling stock.	6	7/8	n/a
New architecture • One driver's cabin per train, with a new driving HMI.	6	7	8

([25]) Not all items will progress further in wave 2.
([26]) Not all items will progress further in wave 2.

7.4.2.3. Demonstration implementations

Demonstration 1: Alternative energy solutions for rolling stock

- High-performance BEMU (long-range autonomy, optimised aerodynamic performance, higher environmental performance, lower LCC, circular economy, interoperable, standardised charging interfaces and data protocol with infrastructure, standardised interfaces of battery racks).
- Suburban catenary trains with on-board ESS, providing:
  a. high energy efficiency (50 % less consumption),
  b. a high level of braking energy recovery (-90 % particulate matter emissions due to mechanical braking),
  c. energy autonomy for passengers' comfort and safety, and traction to a nearby station,
  d. energy services such as peak power shaving or load shedding,
  e. a lower LCC (traction chain, mechanical braking, reduced investment in substation reinforcement).

- Hybrid catenary train with batteries to reinforce service robustness.
  a. H_2 hybrid battery vehicles with FCs, such as autonomous vehicles for infrastructure inspection (focused on the management of wasted energy).

- Smart eco-mode train which can automatically adapt its energy consumption to suit various service situations/ Renewable energy sources produced on board to meet permanent energy supply needs / Smart Energy Mode for hybrid trains.

Demonstration 2: A holistic approach to energy in rail infrastructure (design, production, use and intelligent management)

Railway smart grid system

The development and operational on-site integration of several solutions enabling smart energy management and improving energy efficiency are the focus here. The demonstrators, being applicable to DC or AC electric networks, will include:

- the integration of RES with various types of energy storage systems for production, management and consumption within a local balancing area, and the development of tools for selecting energy source types and locations;
- energy metering, measurement, data management and decision tools;
- the deployment of high-power and high-energy storage systems along the track for grid and substation support;
- the development and implementation of a system for the parallel operation of 25 kV substations;
- the specification, development and integration of superconducting cable in the operational network.

Station energy hub integrated in the smart (city) grid

Here the focus is on finding smart grid solutions for developing and operating train stations as energy hubs. This includes energy harvesting around the stations, local energy storage, local energy production (including renewable energy), the deployment of monitoring and IoT systems (including energy metering), and the development of models and AI tools to optimise energy management for the station, including those linked to the other urban electric mobility systems.

New refuelling station system

- Demonstration and development of standardised and interoperable hydrogen refuelling stations (using a local RES for production *in situ*). Various interfaces will be considered for different types of hydrogen (liquid for combustion engines and/or gas). For batteries train standard of current collector for different type of current.
- Demonstration and development of standardised and interoperable charging installations for fully battery-operated trains.

Demonstration 3: Sustainability and resilience of the rail system in a holistic approach to asset management, delivering more value

Net-zero-emission rail

The primary aim is to develop solutions to foster the environmental advantages of rail and enable its transition (infrastructure, rolling stock and buildings) from a linear to a circular economy, reducing all types of pollutants (noise, vibration, air pollution, light, etc.) throughout the whole life cycle and taking into account the whole logistics chain (methods, methodologies, tools, intelligent solutions, materials, ecolabel, eco-certification). Other aims include extending the life cycle of resources in the railway sector by employing a circular economy (6R model), and developing knowledge bases and collaborative tools for effectively forecasting and assessing life cycles, incorporating factors such as the environmental, social and economic costs and impacts.

- AI for natural risk assessments on the railway.
- Train demonstrator with eco-friendly material interiors and external claddings.
- Low-carbon sleeper demonstrator.
- Transparent sustainability labelling calculation method (energy, materials, noise, reparability).
- Industrialisation, recommendations, rules to increase the local, circular and re-use economies.

Removal of non-exhaust emissions

The goal is to characterise and remove the non-exhaust emissions emitted as particulate matter from the wear of mechanical braking systems, wheel-rail contact and pantograph-catenary line contact, emissions from railway stations and railway infrastructures (ballast abrasion, pollution during work, ageing of the underground infrastructures), and historic pollution.

- Solutions to remove the particulate pollutants (on-board RS collector, on-board RS filtering/treatment solutions and underground railway station filtering/treatment solutions) and measure the efficiency of the reduction of pollutants.
- Train demonstrator with low water, oil and grease consumption: reduce water, oil and grease consumption during operation and maintenance processes.
- Study and development of a low environmental impact substation taking noise, vibration, electromagnetic compatibility, materials, landscape integration and energy consumption into account.

Reduction of noise and vibration in railway infrastructure

- Demonstrating a low-noise and low-vibration track incorporating certain track components (e.g. optimised rail pads and rail fastening systems), leading to a definition of models supporting predictive maintenance recommendations.
- Addressing the effects of noise and vibration on physical surroundings using optical fibres alone or in combination with assisting technologies, leading to simulation studies and models for protection and the reduction of impacts on the physical surroundings (any buildings of concern, including stations). As a result, models and physical demonstrators are developed, leading to predictive maintenance recommendations for the infrastructure and the proposal of physical concepts for the surroundings.
- Addressing the squealing noise emitted by wheel dampers, through modifications of the rail geometry or the lubrication of rail heads, while developing the associated models.

Smart green station

- Optimisation of the layout of the station, favouring modular and nature-based solutions. BIM-based design.
- Design of the station's energy systems and building energy management systems. BIM-based design.
- BIM-based DT of the station.
- Use of the DT of the station for the operation and maintenance of the energy systems.
- Use of the DT of the station for a circularity analysis. Use of the DT to simulate hazard scenarios, build more resilient infrastructure and prepare better contingency plans (including extreme climate events)

Demonstration 4: Improvement of electro-mechanical components and subsystems for rolling stock

- Eco-friendly HVAC system (linked to capabilities 3 and 5):
  a. implementing energy-efficient, more resilient and lighter HVAC based on novel technologies and/or materials,
  b. supporting temperature management of other subsystems, such as a battery chiller/charger or a FC system (linked to demonstrations 1, 3, 4 and 6).

- Technological solutions for the migration to airless trains (linked to demonstrations 1, 3 and 6):
  a. EMB systems,
  b. novel electro-mechanical pantographs.

- High-performance bogies, gearboxes, suspensions and materials (linked to capability 3) make the running gear cost-efficient and eco-friendly, especially through the use of new technologies, such as 3D printing, which can yield totally new designs and topologies.
- Demonstration of drag-reduced equipment aerodynamics involving the study of various spoiler and pantograph configurations using Computational Fluid Dynamics (CFD) and an experimental demonstrator.

Demonstration 5: A healthier and safer rail system

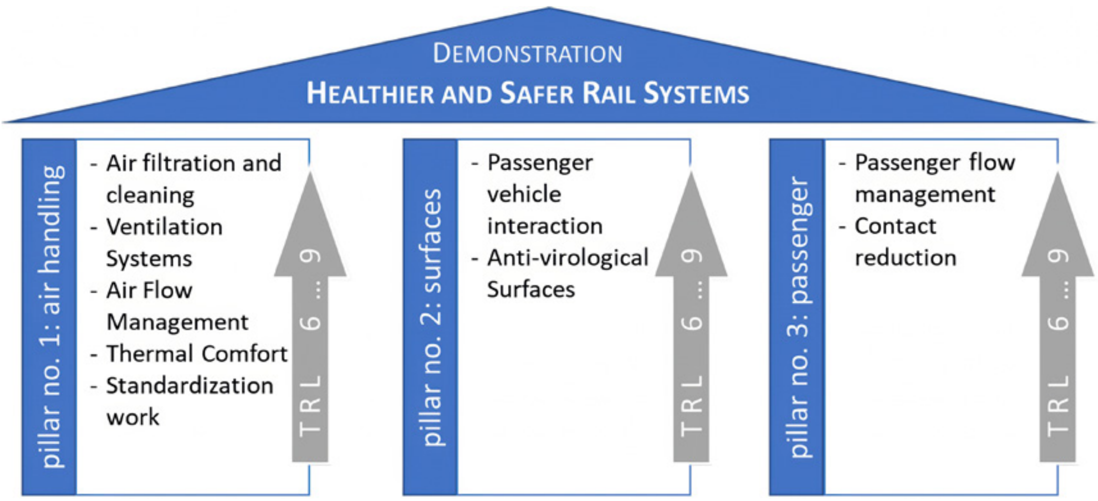
The demonstration of novel systems and technologies that enhance air quality through air purification and air distribution while maintaining a comfortable temperature is proposed. It should address the topics of air quality, in term of pandemics (exceptional), the spread of viruses and bacteria (seasonal) and fine particles (always), and thermal comfort. To guarantee a platform-independent approach, multiple specific sub-demonstrators will be set up, each of them contributing to the overall goal of demonstrating a healthier environment in the rail vehicle, for both new designs of future trains and the refurbishment of existing trains.

The demonstrator aims to tackle the following specific aspects:

- reducing the airborne spread of contaminants;
- air-filtering devices and air-distribution systems;
- the installation of disinfection systems;
- the use of surface materials that reduce the survival time of viruses and bacteria;
- thermal comfort in modular interiors;
- the assessment of available technologies and their adaptability to existing HVAC designs;
- passenger flow management, incorporating various health and safety measures;
- the development of simulation tools to increase knowledge and optimise solutions;
- creating a test protocol to evaluate the efficiency of the solutions;
- reducing maintenance costs (e.g. with heat exchangers) and negative effects on train reliability (e.g. HVAC in heatwave conditions);
- the deployment of predictive health monitoring and live visualisations of air quality and other HVAC-related parameters;
- providing a database for standardisation work regarding air quality.

These can be organised into three main demonstrator pillars: air handling (air purification and distribution), treatment of surfaces and passenger flow management.

FIGURE 14. **Main demonstrator pillars**



Multiple enablers will pick up these issues and present solutions from technology demonstration (TRL 6) to implementation on in-service passenger trains (TRL 8/9) for different train platforms and HVAC configurations. Consequently, especially regarding the first pillar, the collaboration partners should work in parallel. This will contribute to a healthier and safer passenger rail-system in terms of air quality in the vehicle and pandemic-resilient passenger transport. For the specific demonstrators to reach their full potential, joint contributions from the relevant stakeholders, i.e. train operators, (train) manufacturers, (HVAC) suppliers and scientific institutions, are envisaged.

Demonstration 6: Attractiveness

- Using preferably virtual reality or AR, 3D modelling, numerical simulations or technical mock-ups, the following independent intermediate activities are proposed for 2025:
  a. interiors demonstrator with attractive low-cost and low-tech design,
  b. interiors demonstrator with modular interiors providing on-demand comfort,
  c. attractive, safe and performant dwell-time mass-transit interiors demonstrator,
  d. interiors demonstrator designed by the user's perception,
  e. interiors demonstrator with attractive circular design.

- Integrated demonstration is planned for 2027, combined where feasible with the following train demonstrators from FA4 or other FAs:
  a. real-scale fix mock-up to offer maximum freedom for new design (not real environment),
  b. a real environment demo of a high-speed vehicle demonstrator,
  c. an operational demonstrator in an existing train to test parts of innovations.

7.4.3. Impacts

7.4.3.1. Description of the impacts on existing rail services

TABLE 26. **Descriptions of FA4 impacts in relation to the intended impacts laid out in the master plan**

	Meeting evolving customer requirements FA4 will aim to further decrease the environmental footprint of the whole railway system. It will provide green solutions by developing a pollutant-free, low-noise system while delivering enhanced services and comfort for the customers. Solutions to meet high-level sanitary requirements, guaranteeing customers a safe and healthy journey, are also covered in FA4.
	Reduced costs In addition to the sustainability benefits gained from the solutions, cost efficiency also needs to be carefully assessed. Energy storage systems (batteries, etc.) and H2 have to be considered. These can come from other modes of transport and be adapted to the rail environment in order to optimise investment costs. This is also applicable for the charging infrastructures for refuelling solutions.
	More sustainable and resilient transport In this FA, sustainability plays a central role. Some selected areas of innovation contribute significantly to improving the environmental performance of the railway system. For HVAC, regulations enforce the use of sustainable gas. Activities will develop new technologies, allowing the rail system to more easily provide the necessary service adaptations to the customers. This is particularly relevant given the longer periods of hotter temperatures expected throughout Europe. If rail energy consumption is at a low level concerning the competing mode of transport, the continuous technologies evolution (power electronics, storing energy system) leads to significant decrease of energy consumption. These efforts to create a zero-CO2e-emission rail system must be accelerated. This FA will also accommodate innovative solutions that mitigate the levels of noise and vibration and other emissions.

Improved EU rail supply industry competitiveness
Rail is considered one of the most environmentally friendly modes of transport. However, to maintain its environmental performance in line with current political and societal expectations. the rail sector should continuously improve its environmental footprint to keep its competitive advantages over other modes of transport. This objective will be fully supported by the technologies developed within this FA, such as the new proportion system.
Industrial standards will facilitate the quicker and greener transformation of European rail vehicles and support the transformation of the rail system into a circular economy.
Health and safety requirements are also relevant, especially in situations like the recent COVID-19 pandemic. They ensure that customers are provided with the best possible sanitary conditions.

7.4.3.2. Quantitative KPIs demonstrated in this FA

To ensure delivery of the aforementioned impacts, close monitoring will be implemented using KPIs. Starting from the KPIs implemented within S2R, a new set of indicators is proposed for the specific activities/solutions implemented by the (flagship) projects.

Within each of the aforementioned dimensions, there are several KPI categories that break these dimensions further down into elements for which specific KPIs can be defined.

TABLE 27. **FA4 quantified KPIs**

KPI title / type of impact	Dimension/KPI	Baseline / expected improvement
Autonomy. Linked to sustainability via CO_2 reduction on regional diesel trains.	Extended reach (km)	Baseline 80 km and target 200 km for regional trains.
Physical energy consumption (train, infrastructure, station).	kWh/passenger-km $kgCO_2/m^2$ per year kgH_2/tonne-km per vehicle	Existing electric railways and up to 30 % in specific use cases (linked also to ATO – DAS, HVAC, airless train for energy consumption reduction and innovative traction systems).
Physical CO_2e emissions Life Cycle Assessment (LCA) linked to new propulsion systems, stations and infrastructure.	$kgCO_2$/passenger-km $kgCO_2/m^2$ per year	Up to 30 % in specific use cases (e.g. various fleets on specific railway lines, reduction to 0 % for regional trains on non-electrified lines, by substituting diesel with batteries/H_2, and inspection vehicles)
Noise emitted by train, infrastructure at component level.	dB(A)	Between 3 and 8 dB(A) for specific use cases on existing electric railways and in diesel trains, hydrogen trains, infrastructure and stations (e.g. brakes (compressor), HVAC subsystems, pre-heating operations, depot facilities).
LCC reduction.	%	Between 5 and 10 % for specific use cases, including externalities costs.

7.4.3.3. Exploitation, deployment and migration considerations

FA4 envisages the development of a set of technologies whose overall goal is to minimise the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier and more attractive and to provide climate-resiliency.

These technological developments come with a need for significant investment from the organisations involved in the EU-Rail JU and from the European Commission. Although the involvement of a large community from both the user side and the supplier side is a good starting point for a wide deployment of these developments, a set of measures should be employed to ensure that stakeholders make good use of them in the future. These measures are:

- applying an integrated approach in the demonstration scenarios, so the new products and services are integrated with other ones rather than being insular, amplifying their impact;
- ensuring development up to TRL 7/8, to meet the requirements for commercial exploitation;
- involving end users that can be used as references for commercial exploitation.

In addition, the products and processes which are currently being used in the railway system to minimise overall energy consumption and environmental impact are not prepared for 'cooperation' with new technologies. Therefore, deployment and migration from the current situation to the future one must be taken into consideration. To address this, the following measures should be established.

- Coordination with the SP to define a set of data exchange formats / CDMs, especially for energy management at different levels, at the local level (e.g. interfaces in the rail system smart grid ensuring the integration of different suppliers) and at the system level via connections between subsystems (e.g. TMS with energy management).
- The definition of a specific European regulation, to be adopted by the Member States, enforcing or enabling the adoption of new technologies (e.g. eco-design, recycling).

7.5. Flagship area 5 – Sustainable competitive digital green rail freight services

7.5.1. Objective and level of ambition

7.5.1.1. Targeted objective, new opportunities and associated risks

The European Commission sets the objectives and opportunities for rail freight with the European Green Deal, Regulation (EU) No 913/2010 ([27]) and the sustainable and smart mobility strategy: 'In recent years, innovative companies have demonstrated that rail freight can operate reliably and be attractive to customers. However, many domestic rules and technical barriers, as well as other pain points stated in section 2, still hinder performance and impact the competitiveness. Rail freight needs serious boosting through increased capacity, strengthened cross-border coordination and cooperation between rail infrastructure managers, better overall

([27]) Regulation (EU) No 913/2010 of the European Parliament and of the Council of 22 September 2010 concerning a European rail network for competitive freight (OJ L 276, 20.10.2010, p. 22, ELI: http://data.europa.eu/eli/reg/2010/913/oj).

management of the rail network, and the deployment of new technologies such as digital coupling and automation.'

Hence, the objective of FA5 is to make rail freight more attractive through increased capacity, for example with **DAC**, which is one cornerstone and enables more functionalities in freight (a steady supply of power and data will enable more use cases, which will positively impact single wagonload traffic, block trains, combined transport, etc., increasing network capacity in a smart way for all types of rail freight transport), and **significantly improved cross-border operations** (as around half of all rail freight in Europe crosses borders) and multimodal **customer services**. Increased capacity is the key factor enabling a shift of transport volumes to rail, substantially reducing the related GHG emissions.

FA5 tackles these challenges by having **two clusters** which are interlinked but still distinct. The first cluster, '**full digital rail freight operations**', is focused on substantially increasing the productivity, quality and capacity of rail freight by fully digitalising and automating operational functions and processes, including innovative freight assets. The second cluster, '**seamless rail freight**', is focused on increasing the efficiency of the immaterial (information/data) layer of transport and on gaining time and reducing costs by ensuring a seamless environment (for planning/execution/management between different actors/countries/modes) for the long term, while also including short- and medium-term achievements and quick wins. Both clusters are fundamental to achieving the European Green Deal objectives and only together will they secure significant rail freight improvements. FA5 is crucial, as it will provide the required concepts, guidelines and technical solutions for pilots/demonstrators preparing suitable market-ready solutions.

- '**Full digital freight train operations**' aims to boost operational rail freight performance (transport time, quality, information and volumes) in order to meet customer requirements by fully digitalising and automating operational functions and processes (e.g. yard/depot/terminal automation and control) through the use of enabler technologies (DAC and related automation components) and additional subsystems and components (e. g. systems for the intelligent freight train), such as energy management distributed systems (harvester and storage), along with developing freight wagons and upgrading locomotives to accommodate the related DAC-functionalities, including ATO technology interfaces.
- '**Seamless rail freight**' aims to significantly increase productivity (including average transportation time and capacity utilisation), reliability and flexibility, by fully digitalising planning and management functions, streamlining cross-border processes and better connecting rail freight with other modes of transport (both physically and digitally, including yard, depot, terminal, transport-network and customer-related planning, and dispatch in connection with TMS). This includes providing easy access to the service offers, including multimodal journey planning, booking and transport companions. Additionally, this cluster is focused on ensuring a consistent data flow from the customer in order to optimise preparation at all handover points (yards/borders/recipients). The planning and management of fully automated shunting operations (ASO) enables fully automated marshalling yard operations and more efficient last-mile distribution and collection of wagons.

These freight-focused innovations, especially in combination with FA1, FA2 and FA3 developments and the respective investments in their implementation, will enable rail freight traffic – in particular along European RFCs – to increase by 50 % by 2030 and double by 2050, thereby supporting the ambitions of the Commission's sustainable and smart mobility strategy.

Building blocks need to be embedded into a set of new solutions resulting in the improvement of the entire railway system (e. g. DAC as an enabler for ETCS moving block) environment. By incorporating building blocks, large-scale demonstrators will integrate the components in an interoperable way. This will leverage results from past and ongoing initiatives, enabling the shift to FDFTO in daily operations in Europe, yielding a fully functional holistic system.

Thus, allowing, together with digital European cross-border path and train planning and management processes, digital customer interaction, booking and other services. as well as streamlined operations at, for example, borders to build up 'seamless freight operations'. This will also include a seamless data flow between different stakeholders, i.e. customer, suppliers, employees, IMs, RUs, etc., along the supply chain and particularly at handover points. Hence, there is a special focus on the elimination of manual processes and an exchange of resources driven by capacity. All technologies must contribute to the increase in productivity, efficiency and service quality ('use-case driven'), resulting in seamless freight planning and shipper-tailored intermodal transport services, including offering and booking, thereby increasing the competitiveness of rail freight. As seamless freight results in fewer stops at borders, it will also have a positive impact on energy consumption.

To enable suppliers to develop technologies at competitive costs and promote effective implementation and use by the operators, certain potential gaps and risks have to be taken into account and eliminated or minimised. Possible gaps and associated risks include the following.

- Unclear and changing business cases and varying use-cases could lead to unstable requirements and, consequently, re-iterations in the developments. Furthermore, developments can be hindered by the lack of operational and technical information, or data quality and availability issues from legacy systems, which serve as a starting point for European and interoperable solutions.
- Functional requirement specifications from an operational point of view will not all be ready and agreed (e.g. brake test target of operators, shunting) by mid 2022 (some will be completed later) in order to meet TRL targets regarding TEs.
- A delay of the ERA authorisation process or a lack of capacity from the ERA side for authorisation.
- The number of different systems to be connected and their complexity can be a risk in standardising and harmonising processes, technologies and cross-border systems and can delay achieving the objective of making European systems interoperable.
- The iteration process during development. Underestimating requirements and failing to achieve authorisation/certification could result in higher investment costs.
- In combination with authorisation processes and the national reluctance to replace/update legacy systems, an improperly designed, prepared and coordinated migration strategy can slow down the pace of innovation for cross-border solutions.
- The migration from a brownfield environment and the underestimation of the complexity of adaptation may be a risk especially in combination with a lack of clear and harmonised operational rules and technical regulations and standards.
- Aspects of the HMI have to be considered and carefully analysed, especially in highly automated customer-centred last-mile operations.
- To support system-level integration and eliminate fragmentation, this FA shall define digital freight operations (e.g. DAC, train composition changes, yard operations) in a way that supports future inclusion in the operational framework. Freight process innovations shall follow a modular, functional specification structure aligned with the proposed operational architecture, allowing flexibility in the risk-based approach at the SMS level, while ensuring a harmonised approach across Member States.

7.5.1.2. Innovation beyond the state of the art, including the integration of S2R results

New technologies are being developed to market maturity on the basis of initial results from past research projects such as Shift2Rail or the EDDP, and tested and demonstrated in the broader context.

In addition, the European system approach/perspective for all technologies and other innovations will be brought into focus in order to ensure that the European railway area can continue to grow together. The results from S2R innovation programmes and (national) research programmes will be used to exploit the results, improve the capabilities and interoperability of solutions and to test and validate them at a high TRL. Harmonisation and standardisation will help to overcome many clustered innovations, which so far are not designed or work together with proper interfaces in an EU-wide environment.

TABLE 28. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail**

	FDFTO
State of the art and S2R results	The relevant topics addressed in S2R IP5 are: 'Fleet digitalisation and automation' (TD5.1) through DAC that is now is on the verge of implementation, freight ATO and C-DAS; 'Smart freight wagon concepts' (TD5.3) through next generation intelligent freight wagons for core market and extended market sectors, including innovative freight bogies, better aerodynamics and telematics supporting CBM, for instance; 'New freight propulsion concepts' (TD5.4), focusing on operation on non-electrified and electrified lines, the control of distributed power locomotives for train lengths up to 1500 m, if allowed by the infrastructure, and fine-tuning the system with energy management and peak power shaving concepts. Special attention can be given to the EDDP enabled by S2R (TD5.1); outcomes are to be considered as S2R results. The EDDP provides preliminary specifications for DAC mechanical, pneumatical, data/energy and preparatory works on additional automation components (electro-pneumatic brake, technical wagon inspection, train, automatic brake testing, etc.), works on migration, cost benefit analyses, etc., serving as a basis for FA5. Since FDFTO also includes additional components for which DAC is the enabler, past or current works on those also have to be taken into account.
Further/new results	What still needs to be realised within the FPs is the PoC, further developments and practical testing as well as the further development of the missing parts of the TEs of the EDDP theoretical proposals, followed by the adaptation and the seamless functionality of those systems on the backbone including authorisation. With the goal of reaching the highest level of automation (DAC5 automated decoupling for freight cars and locos), DAC might serve as a stepping stone to enable early migration. The implementation of DAC and interlinked additional components will affect the day-to-day operations of RUs, IMs and customers along the logistics chain, for example. The required changes will enable a transition to intelligent FDFTO, affecting the operations and processes at yards (also demonstrating full automation) or border stations.

TABLE 29. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 2**

	Seamless freight
State of the art and S2R results	Currently the key elements for seamless freight operation (elimination of manual processes, exchange of resources driven by productivity and not by borders, continuous cross-border path planning and management, digital resources planning and data exchange) are focused on national specifications rather than on the SERA, leading to inefficient, complex and expensive operations at border crossings, for example. There are early concepts for internationalisation, but these are not yet prepared for market-ready innovations and products. Management and production systems are partially complete, but legacy systems are neither interoperable and nor prepared to act as part of a dynamic seamless system, due to missing interfaces and real-time optimisation components. The main results from S2R IP5 which can be used as input for seamless freight come from TD5.2 'Digital transport management', in which dedicated components for a network management approach have been developed. These include initial concepts and solutions for automatic real-time decision support in yards and terminals and for yard management, and the intelligent video gate concept, which uses AI to recognise codes and signs on wagons, such as intermodal loading unit numbers. Innovations for seamless freight operation will also use results from RFC studies and projects, such as European capacity and timetable management and rail collaborative decision management, along with results from T4R or other projects. Substantial results achieved in the TMS and ATO in S2R IP2, and in IPx (Linx4Rail) for architecture and CDM, shall be also considered as a basis to be applied in coordination with FA2. The conceptual work done in relation to digital capacity management and TTR, and on the exchange of commercial documents in the Digital Transport and Logistics Forum, shall also be considered. Data exchange shall rely on already defined standards such as TAF TSI and if needed contribute to their revisions.
Further/new results	To achieve the goals, innovations for European cross-border solutions – and in some cases the innovative adaptation of national components – will be required to ensure compatibility with EU systems. Besides internationalisation with a focus on a real, integrated SERA, new capabilities like technologies for digitalising current manual tasks and automatic cross-border slot finding will also be developed and demonstrated. The same applies to the various specific stand-alone systems of the different participants that must be effectively enabled and linked with each other, including various optimisation functions that address the newly available comprehensive data/information. The aim is to extend the optimisation from planning to real-time operations, applying a system-wide perspective with agreed rules and roles, to enable optimised and improved planning and operations. Identifying suitable (multimodal) transport options, booking and monitoring them will be facilitated by modern tools for transport planning, with innovative routing engines. Information will be shared using continuously updated data from the involved stakeholders about resource/slot availability for short-term requests or adaptations. A user-friendly European digital platform will connect the customer with the rail transport providers and streamline access to rail freight services, including intermodal transport services.

7.5.1.3. System integration, interactions with the SP and with other FAs

All **FA5** activities will contribute to the **SP** and benefit from its input for interface and system integration management related to FDFTO and seamless freight.

The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initial identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

Several activities within FA5 require transversal cooperation with other EU-Rail JU FAs.

Seamless freight is closely linked to **FA1** 'TMS+' when it comes to providing a European solution for network management planning and control, and mobility management in a multimodal environment. FA5 will provide all the necessary requirements to FA1, where the TMS technology will be developed for freight-specific needs. FA5 will therefore not develop any main-line TMS technology but integrate it in the RS/infra and use the technology developed in FA1 in its demonstrations.

To ensure that the developed solutions are technologically consistent, coordination and potential collaborations will also be set up with **FA2** 'ATO+' on digital and automated train operations of both passenger and freight rail transportation. In general, the relevant TEs, such as new ATO technology solutions, and automating functions, such as train preparation and remote driving and command, will be developed in FA2. FA5 will provide all the necessary requirements to FA2 and will also work on special functions, for example, automatic and autonomous shunting operations / train protection systems for shunting and reaction systems (push/pull functions).

For the efficient driving and energy management of the freight trains, technologies developed in **FA1** regarding TMS for network management of energy**,** in coordination with FA2, FA4 and FA5 expertise/requirements, will be used by **FA5**.

By nature, the **FA TTs** will be linked to FA5 for potential coordination and collaboration on a DT and on data models, and any other kind of transversal enabler.

Details of the exchange between the FAs can be found in Annex B.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the CDM,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

7.5.1.4. Who does what by stakeholder group

The aim is to demonstrate all solutions under real operational conditions. Hence, a strong involvement of all relevant stakeholders (RUs, IMs, terminal and intermodal operators, suppliers and those involved in R & D) is crucial.

The operators will host and organise the framework for these demonstrators. For the demonstration and implementation of the aforementioned developments, operational solutions, TEs, guidelines and standard protocols potentially delivered by the SP shall serve as the framework to be followed. However, deployment within a short/medium time frame requires that the technical solutions be aligned with essential railway operational rules and standards which have not yet been harmonised at the national level. Consequently, the operators will play a key role in the development process, by specifying their output requests and V & V process, and by coordinating the demonstration in most cases, whereas the decisions regarding specific technical developments and implementation are in the hands of the technology suppliers.

RUs and IMs (and, in specific cases, terminal and intermodal operators and others, such as wagon owners), define use cases and play a strong role in demonstrators/pilots. They describe what is needed, carry out safety analysis preparations for and test the developed products. RUs eliminate inefficient processes, bringing automation to the next level, thereby increasing productivity, quality and capacity. This leads to greater competitiveness and new market opportunities and offers more flexible and innovative services to seamlessly integrate into the value chain of customers. IMs provide capacity in a smart way (ensuring data quality), increase occupational safety and offer services that make running trains 'as easy as running trucks'.

Suppliers and technology providers propose respective developments and solutions and provide innovations going beyond the state of the art, based on the needs of their customers. They develop and integrate new products and systems and contribute to standardisation on a normative level to ensure a sustainable exploitation of the developments supporting the growth of the European railway sector. Suppliers shall provide compatible and interoperable solutions and products based on open interface specifications in a technical ecosystem, to ensure interoperability of systems and seamless freight services.

Research institutions and academics study the economic impact of innovations with the help of quantitative transport models and simulation tools, identifying the optimal design of multimodal transport networks and optimal employment of resources. Additionally, research institutions will play an important role in basic research on new technologies, such as hybrid locomotives for freight applications and transport logistics services. They also assess the impact of innovations. Researchers provide the scientific input (including methods and R & D simulation tools to analyse and optimise the efficiency of freight transport) that is needed to develop scalable business-oriented solutions.

Authorities provide a level playing field for rail (e.g. through regulations and financing).

7.5.1.5. Interaction with other programmes, European and/or national

The R & I activities considered within FA5 are expected to interact with other programmes and initiatives at the European and national levels. It is worth mentioning the following European programmes:

- in Horizon Europe, Pillar II, Cluster 4 (digital, industry and space), the European Partnership on AI, Data and Robotics, for data analysis and work automation;
- in Horizon Europe, Pillars II and IV, Cluster 5 (climate, energy and mobility), the road transportation and waterborne transportation supporting multimodal transportation;
- in Horizon Europe, Pillar III (innovative Europe), the European Institute of Innovation and Technology, which has two specific knowledge and innovation communities – EIT Manufacturing, for new manufacturing techniques, and EIT Digital, for the digitalisation of freight transportation;
- the CEF, the Life programme and Digital Europe, for the funding of large-scale demonstrations;
- the Horizon Europe Clean Hydrogen Partnership.

Finally, interaction is also envisaged with other EU national programmes (e.g. German national program of the BMVI, Spanish CDTI Misiones, Austrian national R & D program of the BMK) and with programmes led by other, non-European countries also prioritising rail freight transportation, such as the United Kingdom or Switzerland.

Besides the coordination activities within the EU-Rail JU aimed at ensuring a system-wide approach and enhancing the competitiveness of rail freight, external initiatives, such as the work of the Alliance for Logistics Innovation through Collaboration in Europe on the physical internet logistics system, will be taken into account to ensure optimal integration of rail within multimodal transport chains.

7.5.2. Results/outcomes

7.5.2.1. Operational solutions outcome

Today's rail freight transport suffers from a lack of competitiveness, especially in relation to road transport. The organisation of transports is neither flexible nor quick enough to meet the requirements of a modern logistics chain that claims to be increasingly environmentally friendly, but still relies on means of transport that are reliable in terms of just-in-time and just-in-sequence and can react to transport volume fluctuations at short notice. A relatively low digitalisation level and limited cross-stakeholder/cross-border coordination prevents the optimisation of rail operations and often results in quality and reliability levels below the requirements of the logistics market. It also prevents the transparency of the logistical chain and its holistic integration. The operational deficiencies also lead to higher costs for the railway undertakings and intermodal operators, consequently putting an additional burden on the competitiveness of rail freight. Therefore, operational solutions developed within the FA cover the entire rail freight logistics chain, increasing its sustainability and safety, aiming at a significant modal shift to rail. Functional process descriptions and standardised interface specifications for digital freight services (e.g. DAC operation, digital coupling, automatic integrity checks), developed to be compatible with the evolving operational framework, will be structured to support SMS risk analysis and regulatory evolution. The aim is to enable better planning and operation of trains themselves and better integration within multimodal transport chains. The identification of suitable transport options and their booking and monitoring will also be key for attracting more customers to rail-based services. The operational solution outcomes shown in the table below will be covered. Nevertheless, even though high TRLs are targeted for 2026 and 2028, further technical development will be needed to extend the scope of the solutions.

The rail freight sector currently faces the following pain points and bottlenecks:

- a high number of manual interventions in operations;
- limited infrastructure capacity utilisation (main line / terminal / marshalling yards / handover stations / others);
- limited rolling stock capacity utilisation (locomotives / freight wagons / drivers / others);
- inefficient cross-border planning and subsequent inefficient operations;
- limited cross-stakeholder planning, coordination and (traffic) management;
- non-integrated train path and service planning (unattractive international train paths);
- integration challenges in just-in-time supply chains;
- demographical changes, including the declining attractiveness of jobs in the rail sector;
- a limited overview of available multimodal transport services, and non-user-friendly booking systems for the customer;
- limited transparency for customers on punctuality and other quality issues, including for the last mile, terminal operations, and other modes involved in intermodal transport;
- limited ability to handle short-term demand changes.

It is clear which functionalities/enablers will enhance daily operations and overcome challenges in the rail freight sector; these functionalities are outlined in chapter 7.5.2.2. By fully digitalising and automating operational functions, in combination with applying a holistic approach to seamless rail freight, there will be a substantial increase in productivity, quality and capacity utilisation within the rail freight system, in line with European Green Deal objectives. This use-case driven approach will be maintained, whereby technology development is guided by the functionalities requiring improvement, ensuring Europe-wide interoperability and adherence to rail industry standards.

The table below presents the ways in which the application of the output from FA5 will impact operations.

TABLE 30. **Impact of the application of the output from FA5 work in operations**

	Operational solutions outcome
FDFTO	To achieve efficient and productive operations enabled by the full automation and digitalisation of operational functions and processes through technology development aimed at reducing manual work, respective automation components need to be elevated to high TRLs and embedded into a fully integrated system, thereby ensuring improved service quality for customers, for example. This includes: • Operations: automated coupling/uncoupling of locos and freight wagons with data and energy for wagons/interoperable train communication, data/energy system (back bone), recording of train composition and abandon of rear signal for e.g. yard automation, as further extension distributed power for heavier-/ longer trains, electronically controlled brake system, automatic brake test and calculation of braking capacity, automated parking brake, train integrity, increased speed via braking performance, automated technical wagon inspection • freight wagons / loading units for multimodal transport applications (based on customer needs analyses); • yard automation and digitalisation.

Operational solutions outcome	
Seamless rail freight	To ensure seamless and efficient transport services and cargo flows, the transport and operations management along with the routing and booking options will be transformed from a fragmented and national or stakeholder-specific approach to an international/European comprehensive systemic approach, meeting the shippers' requirement of a flexible, dynamic and reliable transport offer, which can be easily accessed and booked. This encompasses the entire freight chain, with a focus on the following areas. **Planning** • Seamless, harmonised and streamlined planning of rail freight services via integrated cross-border timetable planning, management and path-ordering systems covering all planning horizons, especially the specific needs of ad hoc services. • Integrated/connected slot planning and booking functionalities for last-mile services. **Operation** • Dynamic dispatching tools used in cross-border and last-mile operations. Innovative, smart and harmonised concepts for (cross-border) operations and concepts for the efficient and effective management of resources in the event of deviations, and reduced response time for ad hoc European path requests/ re-planning. • Intermodal monitoring and prediction systems. • Improvement of operation across borders and areas/stakeholders (main line, connection line, yards/terminals) by increasing the accuracy of predictions (e.g. estimated time of arrival) and target times, leading to a significant decrease in average transportation time. • Standardised European railway checkpoints at border crossings or other operational stopover points. Digitalisation of manual processes. • Innovative, smart and harmonised process for technical wagon inspections (e.g. additional inspections at borders for non-Authorised Train-Traffic Inspector trains). • Multi-country licensed loco drivers. • Cross-border management reducing time for train preparation, in particular at border crossings (non-Authorised Train-Traffic Inspector trains, inspections, multi-license loco drivers). **Management/selling/booking** • Seamless multimodal integration with easy access to (intermodal) rail services. • Fully digital European customer-oriented solutions (services, interfaces), and solutions for multimodal transport planning and booking platforms to integrate rail freight into modern supply chains, as easy as it is to offer and order a multimodal passenger journey. • Seamless and harmonised data exchange at railway checkpoints for smooth European rail freight operation.

7.5.2.2. TEs: capabilities to achieve the targeted operational outcomes

To realise the operational solutions, it must be assured that TEs are developed and that the respective innovations can be implemented and fully used to adjust regulation or standards. The following table gives an overview of TEs, which often depend on the successful realisation of R & I undertaken in other FAs, FA5 being more oriented towards the demonstration part

TABLE 31. **Overview of capabilities enabling operational objectives**

Cluster		TE		2026	2028	2030
FDFTO	DAC backbone	DAC Link with other FAs: TT. (*) The use-case-driven DAC energy supply and data/communication solution, being the backbone, will enable expansion to further functionalities in the future.				
			DAC type 4 (including type 5 upgradability)	TRL 7	TRL 8	
			DAC (hybrid) couplers for loco	TRL 7	TRL 8	
			DAC energy supply and data/ communication solution/backbone (*)	TRL 7	TRL 8	
	DAC-based/ DAC-enabled applications	Digital automatic uncoupling				
			DAC type 5	TRL 7	TRL 8	
			Automated parking brake system		TRL 6/7	
		DAC based digital train preparation				
			Train composition detection/ management system	TRL 7	TRL 8	
			Automated/automatic brake test system	TRL 7	TRL 8	
			Digital wagon inspection (including rolling stock and infrastructure assets) Link with other FAs: data transmission to FA3.		TRL 5/6	TRL 6/7
		DAC-based train operations Link with other FAs: • all developments on TIMS are conducted in FA2 to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art); • safety data is transmitted to FA1; • FA5 requirements, feedback and adjustments that may become necessary for the use of DAC.				
			DAC-based train integrity and train length determination	TRL 7	TRL 8	
			Distributed power concepts and solutions	TRL 5/6	TRL 6/7	
			Electro-pneumatic brake		TRL 6/7	TRL 7/8

Cluster		TE	2026	2028	2030
FDFTO	DAC-based/ DAC-enabled applications	DAC-based yard operation (specificities, but on the basis of FA2 outputs) Scope of the FA5 work: mainly limited to demonstrations, but also some freight-specific shunting/yard technologies + special functions for the automatic and autonomous shunting operation / train protection system ATP for shunting as well as reaction system (push/pull functions), positioning, object detection), requirements/feedback to FA2 for automation. Link with other FAs: • All development on movement automation technologies (e.g. GoA2 and GoA4).			
		Fully automated shunting loco movements (GoA4)	TRL 5/6	TRL 7	TRL 7/8
		Yard digitalisation for fully automated train composition and dispatching (ASO)	TRL 5/6	TRL 7	TRL 7/8
		Yard automation equipment	TRL 5/6	TRL 7	TRL 7/8
		Data exchange on wagon condition (visual recognition methodologies and AI-tools for yard automation)	TRL 5/6	TRL 7	TRL 7/8
		DAC-based wagon concepts, including multimodal transport applications Link with other FAs: FA3 and FA4.			
		DAC wagon retrofitting (in particular special wagons, e.g. T3000)	TRL 7	TRL 8	
		Low-weight, low-energy, low-noise, high-performing wagon concepts and self-propelled wagons	TRL 5	TRL 6	TRL 7
		Automated/autonomous loading/ unloading technologies for last-mile distribution, and new market needs (e.g. hydrogen storage/transport)	TRL 5–7	TRL 7/8	TRL 8

TABLE 32. **Overview of capabilities enabling operational objectives 2**

Cluster	TE	2026	2028	2030
	Seamless planning of rail freight services • Integration of cross-border timetable planning functions, management and path-ordering systems covering digital capacity management planning horizons and, in particular, the specific needs of short-term path requests for (international) freight services. • Integrating and connecting last-mile (e.g. accession lines, shunting, yards and terminals) slot planning directly or via interfaces. Scope of the FA5 work: limited to demonstrations and some specific freight developments and FA1 requirements for TMS. Link with other FAs: all general development of planning systems within TMS is conducted in FA1.	TRL 6/7 TRL 6	TRL 8/8 TRL 88	TRL 8 TRL 8
	Dynamic dispatching tools used in last-mile operations • Harmonised real-time interfaces between TMS and, for example, yard/terminal management systems and agreed data structure/quality. Dynamic yard/terminal management systems upgrade with optimisation functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1). • Dynamic freight-specific real-time functions for interaction within TMS (FA1) and other management systems. Scope of the FA5 work: limited to demonstrations and some specific freight developments for terminals/ yards, including interfaces and FA1 requirements for TMS. Link with other FAs: all general development of TMS is conducted in FA1.	TRL 7/8 TRL 6 TRL 7 TRL 4/5 TRL 6/7	TRL 8/8 TRL 7/8 TRL 7/8	TRL 8 TRL 7/8 TRL 7/8
	Intermodal monitoring and prediction system • Gathering and processing of influencing data. • Connection with rail TMS systems and other resource management systems. • AI-based prediction models. • Accuracy and computational learning functions.	TRL 8 TRL 6–8 TRL 7 TRL 8TRL 7	TRL 8 TRL 6–8 TRL 8 TRL 8	TRL 8
	Standardised European railway checkpoints at borders and other operational stopover points • Digitalisation and partial automation of manual processes through innovative sensors, video gates and handheld (potentially other) devices, based on a process analysis. • Interoperable IT systems for data management and processing.	TRL 7 TRL 8 TRL 7 TRL 8	TRL 8 TRL 8	

TABLE 33. **Overview of capabilities enabling operational objectives 3**

Cluster	TE	2026	2028	2030
	Seamless multimodal integration • Integrated multimodal transport planning, management and operation systems including innovative routing engines. Combination of multimodal services (e.g. rail connected with short- and deep-sea shipping, barges and road transportation) in transport planners (including pricing information, if available) with booking functions. • Routing and capacity management algorithms to enable demand-responsive transport network planning. • Ad hoc dynamic capacity allocation depending on resource availability. Link with other FAs: • if applicable, relevant traffic influence data should be openly available to FA1 for TMS; • potential alignment of the technological framework with FA1 to be anticipated.	TRL 6/7 TRL 4–6 TRL 4/5	TRL 7/8 TRL 5–7 TRL 5/6	TRL 8 TRL 6–8 TRL 7
	Seamless data availability/exchange using the platform-of-platforms approach, where applicable • Application of common data model / conceptual data model. • Connected via the platform-of-platforms approach (including interfaces, converters, verification, management and security). Link with other FAs: • if applicable, relevant traffic influence data should be openly available to FA1 for TMS; • potential alignment of technological framework with FA1 to be anticipated.	TRL 6–8 TRL 7	TRL 7/8 TRL 8	TRL 8 TRL 8
	Technology upgrade of legacy/national systems to provide/consume/process harmonised data from international (European) applications/innovations • Converters into standard formats. • Dedicated interfaces for live data. Link with other FAs: • all relevant traffic influence data needed by FA1 that can be made available by FA5 should be openly shared to FA1 for TMS; • potential alignment of technological framework with FA1 to be anticipated.	TRL 7 TRL 6/7	TRL 7/8 TRL 7/8	TRL 8 TRL 8

7.5.2.3. Demonstration implementations

Within the field of FDFTO, on the basis of the developed, tested and specified technology (e.g. DAC and hybrid couplers for locos and other components), demonstrators and pilots in Europe (including Central and Eastern Europe/ South Eastern Europe) must be organised to validate, assess, evaluate and show the required functionality and added value of the new solutions and technologies and the numerous additional train functions that will be made possible through automation and digitalisation. Testing under daily operational conditions will prove functionality and demonstrate market readiness, promoting harmonised freight operations. If the vehicles fitted with DAC need to be authorised, the DAC specifications should be complete and there should ideally be no remaining risks and open points, such as specific requirements for ATEX (ATmospheres EXplosibles) environments, running dynamic behaviour in locomotives with hybrid coupling systems, longitudinal compressive forces in track gauges other than 1 435 mm, and reliability requirements.

This will provide valuable findings for various TSI revisions that will come up during the EU-Rail JU period, enable necessary safety analysis or safe system integration followed by authorisation prerequisite for deployment. Testing infrastructure, assets (locos, wagons) and operational staff/experts for the application of technology (operational real application) and maintenance are to be provided. For the most efficient and representative demonstration for Europe, a demonstration program (which will include accession and main lines, customer sidings, departure sidings, shunting yards and freight terminals). The demonstration programme will consist of two main focus areas, operations (associated with preparation and train run, for example) and shunting operations (border stations with major shunting operations and at least one national fully automated yard), also in respect to preparing the migration phase (including all respective topics concerning the management of damaged vehicles and operations within workshops).

Within the field of seamless freight, various demonstrators can be used as pilots in the area of cross-border planning and operations, and in common platform interfaces with customers. RFCs can potentially act as facilitators to ensure that the innovations are interoperable throughout Europe. All demonstrations should be transferable to other countries/regions, ensuring benefits for the European rail sector, the SERA and society in general.

The demonstration of harmonised processes using a systematic approach includes stakeholder interactions at handover points (e.g. at borders or any other operational milestone / stopover point) and interfaces for both stakeholders and customers.

Suitable locomotive prototypes with integrated DAC or hybrid couplers will be tested under various operational scenarios. By collecting as much return of experience as possible from all participating DAC manufacturers, a tried and tested product for DAC and hybrid couplers for locos will be delivered. The same is envisaged for fully digitalised freight wagons transporting dangerous goods (e.g. hydrogen).

The following table gives an overview of timeline for potential demonstration implementations. As a general approach, it is planned to set up demonstrators in the first phase that combine specific selected components/parts/modules of the TEs expected to reach a high TRL by 2025 for various reasons. This strategy aims to facilitate a smooth and early start to the migration phase, especially for DAC, while also enabling early benefits for IMs, RUs and freight customers. In the second and third phases, either additional functions and components will be added to the demonstrations or the TRL of the initial demonstrations will be increased.

Since several TEs depend on the output of other FAs, the demonstration plan is also linked with the other FAs, in particular at the TRL implementation level.

TABLE 34. **Link of the demonstration plan with the TRL implementation level**

	Demonstrator	2026	2028	2030
full digital freight train operations	**Demonstration of European FDFTO (1)** Large-scale demonstrator trains testing the TEs in various European regions under real operational conditions: • DAC type 4 (including type 5 upgradability), • DAC (hybrid) couplers for locos, • DAC energy supply and data/communication solution/backbone, • DAC type 5, • train composition detection/management system, • automated/automatic brake test system, • DAC wagon retrofitting (in particular special wagons, e.g. T3000). Tests specifically focus on proving: • full functionality (added value for the sector, respecting/meeting customer needs), • safe system integration, • interoperability, • harmonised (cross-border) operation. To prepare the Europe-wide roll-out and finalisation of standardisation, the following applies. • All TEs will be taken into account in defining the target architecture of the intelligent freight train to ensure a fully functional future system, thereby preventing the emergence of parallel or isolated solutions. This approach ensures that the development of the components – whether initiated at the outset or later – remains coherent and seamless, facilitating their integration into future FDFTO. • This will provide valuable findings for various TSI revisions that will come up during the EU-Rail JU period, enable necessary safety analysis or safe system integration followed by authorisation prerequisite for deployment. • The use-case-driven DAC energy supply and data/communication solution, being the backbone, will enable expansion to further functionalities in the future.	TRL 7	TRL 8	

Demonstrator	2026	2028	2030
Demonstration of European FDFTO testing further components (2) Upgrading large-scale demonstrator trains testing the TEs in various European regions under real operational conditions: • automated parking brake system, • digital wagon inspection (including rolling stock and infrastructure assets), • distributed power concepts and solutions, • electro-pneumatic brake, Tests specifically focus on proving: • full functionality (added value for the sector, respecting/meeting customer needs), • safe system integration, • interoperability, • harmonised (cross-border) operation. To prepare the Europe-wide roll-out and finalisation of standardisation, the following applies. • All TEs will be taken into account in defining the target architecture of the intelligent freight train to ensure a fully functional future system, thereby preventing the emergence of parallel or isolated solutions. This approach ensures that the development of the components – whether initiated at the outset or later – remains coherent and seamless, facilitating their integration into future FDFTO. • This will provide valuable findings for various TSI revisions that will come up during the EU-Rail JU period, enable necessary safety analysis or safe system integration followed by authorisation prerequisite for deployment. • The use-case-driven DAC energy supply and data/communication solution, being the backbone, will enable expansion to further functionalities in the future.		TRL5/7	TRL 7/8

Demonstrator	2026	2028	2030
Demonstration of European FDFTO testing further components (3) Large-scale demonstrator trains testing the TEs in various European regions under real operational conditions: • train integrity and train length determination, • automated/autonomous loading/unloading technologies for last-mile distribution, and new market needs (e.g. hydrogen storage/transport). Tests specifically focus on proving: • full functionality (added value for the sector, respecting/meeting customer needs), • safe system integration, • interoperability, • harmonised (cross-border) operation. To prepare Europe-wide roll-out and finalisation of standardisation, the following applies. • All TEs will be taken into account in defining the target architecture of the intelligent freight train to ensure a fully functional future system, thereby preventing the emergence of parallel or isolated solutions. This approach ensures that the development of the components – whether initiated at the outset or later – remains coherent and seamless, facilitating their integration into future FDFTO. • This will provide valuable findings for various TSI revisions that will come up during the EU-Rail JU period, enable necessary safety analysis or safe system integration followed by authorisation prerequisite for deployment. • The use-case-driven DAC energy supply and data/communication solution, being the backbone, will enable expansion to further functionalities in the future.		TRL 7	TRL 7–9
Demonstration of a fully digitalised and automated yard (4) • Fully automated shunting loco movements (GoA4). • Yard digitalisation for fully automated train composition and dispatching (ASO). • Yard automation equipment. • Data exchange on wagon condition.	TRL 5/6	TRL 7	TRL7/9

TABLE 35. **Link of the demonstration plan with the TRL implementation level 2**

Demonstrator	2026	2028	2030	Alignment with other FAs
Seamless freight corridor showcase The comprehensive innovations for the planning and operation of cross-border freight trains will be demonstrated on up to two European corridors. The seamless interaction across borders and among the stakeholders concerned will be demonstrated through pilot implementations of key enablers such as: • integrated cross-border timetable planning, management and path-ordering systems covering digital capacity management planning horizons and, in particular, the specific needs of short-term path requests for (international) freight services; • integrating and connecting last-mile (accession lines, shunting, yards and terminals) slot planning directly or via interfaces; • harmonised real-time interfaces between TMS and, for example, yard/terminal management systems and agreed data structure/quality; • dynamic yard/terminal management systems upgrade with optimisation functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1); • dynamic freight-specific real-time functions for interaction within TMS (FA1) and other management systems; • real-time gathering and processing of influencing data; • connection with rail TMS systems and other resource management systems; • AI-based prediction models; • accuracy and computational learning functions; • standardised European railway checkpoints at borders or other operational stopover points, and digital showcase of further manual processes at border crossings resulting in border crossings of less than five minutes; • digitalisation and partial automation of manual processes through innovative sensors, video gates and handheld devices, based on a process analysis; • interoperable IT systems for data management and processing; • harmonised procedures and regulation; • multi-country licensed loco drivers, enabled through certified secured translation tools and simulators for gaining local line knowledge; • harmonised cross-country operation and rostering concepts.	TRL 4–8	TRL 5–8	TRL 5–8	FA1, FA2

Demonstrator	2026	2028	2030	Alignment with other FAs
The demonstrations will be extended stepwise in scope and function, building on each other and on the initial results, increasing the TRL or adding additional enablers to be demonstrated. Therefore, the indicated TRL is not applicable for all enablers, but should be reached by some of the components.				
Seamless customer freight showcase The seamless planning management and booking of multimodal rail-based transport involving multiple stakeholders will be demonstrated by combining the key enablers in an innovative open system. The following enablers will be used for multimodal integration. • Integrated multimodal transport, planning, management and operations systems using innovative routing engines. A combination of multimodal services (e.g. rail connected with short- and deep-sea shipping, barges and road transportation) with tools for transport planning (including pricing information if possible) and user-friendly booking functions. • Demand responsive transport network planning, routing and capacity-management algorithms • Ad hoc dynamic capacity allocation depending on resource availability. The following enablers will be used to ensure seamless data availability and exchange: • increased availability and quality of data through the reduction of technical barriers to the generation and exchange of data; • the application of a common data model, where applicable, or appropriate interfaces, converters, verification, management and security, connected via the platform-of-platforms approach. The following enablers will also be partially used in this demonstrator: • intermodal monitoring and prediction system (real-time gathering and processing of influencing data; connection with rail TMS systems and other resource management systems; AI-based prediction models; accuracy and learning functions); • technology upgrade of legacy/national systems to provide/consume/process harmonised data from international (European) applications/innovations; • advanced converters into standard formats; • dedicated real-time interfaces.	TRL 4–8	TRL 6–8	TRL 6–8	

Demonstrator	2026	2028	2030	Alignment with other FAs
The demonstrations will be extended stepwise in scope and functions, building on each other and on the initial results, increasing the TRL or adding additional enablers to be demonstrated. Therefore the indicated TRL is not applicable for all enablers, but should be reached by some of the components.				

7.5.3. Impacts

7.5.3.1. Description of the impacts on existing rail services

FDFTO enabled by key technologies for transforming the European rail freight sector will increase productivity (time and cost reduction), efficiency (process automation yielding faster, simpler and more efficient processes) and service quality, resulting in enhanced competitiveness. Together with a 'smart' increase in capacity, more freight traffic can be shifted to the European rail system, making a significant contribution to the European Green Deal, while also enhancing worker safety and promoting value creation across Europe. The development of innovative freight assets (e.g. innovative freight wagons, last-mile solutions, terminals) would add to the competitiveness of rail freight by reducing LCC and operational costs while also increasing the level of automation of operations and, for example, supporting wagon loads, intermodal terminals, and low-volume solutions.

A **seamless rail freight** system would incorporate other businesses and significantly reduce average transportation times within integrated and harmonised European mobility networks thanks to its agile, interoperable and open environment, in which companies could optimise their operations. For RUs, this would enhance productivity, capacity utilisation and planning possibilities and, through the reduction of cross-border barriers and multimodality, provide faster transport handling, resulting in higher reliability. In addition, comprehensive multimodal and transparent customer information, in combination with user-friendly booking and managing functions, would lead to an increase in customer satisfaction and easier access to rail-based services, and the use of harmonised European data would improve predictability and planning possibilities for IMs. These improvements will enable RUs to develop new and better transport services for customers that will be more efficient, more flexible and capable of competing with road freight, making it much easier for customers to use rail and integrate its use into their supply chains.

TABLE 36. **Descriptions of FA5 impacts in relation to the intended impacts laid out in the master plan**

	Meeting evolving customer requirements The improved freight operations resulting from the programme will support more flexible and punctual freight services by reducing overall transportation time. It will increase customer satisfaction and ensure that customer needs, such as tractability of goods and more efficient cross-border services, are met.

Improved performance and capacity
FA5 will considerably increase productivity and capacity through the introduction of key features, like DAC, which will help improve reliability and flexibility by fully digitalising operations, planning, management and booking functions. It will deliver 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.

Reduced costs
FA5 solutions and improved freight operations will increase the profitability of freight services. A specific example is DAC, which, beyond the mechanical connection of wagons, serves as a platform for numerous applications on intelligent freight trains. It is fundamental to significantly increasing the overall attractiveness and cost-efficiency of rail freight.

More sustainable and resilient transport
FA5 will deliver innovative solutions which aim to optimise energy consumption and reduce the associated environmental footprint of rolling stock.

Reinforced role for rail in European transport and mobility
FA5 solutions will ensure that rail is easily integrated into the logistics value chain, if not its backbone for land transport. Improving the business case of rail freight by developing and integrating new technologies (such as DAC) to increase the use of existing rail infrastructure and improve operational functions and processes while enabling harmonisation in rail freight.

Improved EU rail supply industry competitiveness
Digital and automated solutions will modernise the rail freight market, reducing the cost of the freight vehicles and increasing the punctuality and availability of freight services.

7.5.3.2. Quantitative KPIs demonstrated in this FA

The fundamental aim of the research program is to enable rail freight to achieve a radical increase in the market share of rail freight. It should be noted that the KPIs will need to be estimated ahead of the implementation of the innovations produced by the research, so a forecast is needed. Effects will be quantified at regular intervals during demonstrator projects. The effects on a broader, European scale will be measurable before 2030, once technologies have been deployed. It is recommended to model KPIs by using current freight service data and projected improvements following technology implementation, so as to more accurately estimate impacts and adjust priorities accordingly. KPIs will reflect customer requirements and are to guide how rail freight services as a whole will be elevated to a higher level of performance. The following section provides an initial indication of potential KPIs that can be accurately measured.

Specific KPIs

More specifically, FA5 aims to achieve the following quantitative KPIs. It must also establish the conditions for measuring and quantifying KPIs, and develop a model for calculating and quantifying whether the KPI, based on the best-case scenario in Europe, has been met at the demonstrator level (not at the European level). The baseline for KPIs is 2018–2022, subject to availability and taking into account the need to offset the effects that COVID-19 on data.

Demonstrate European FDFTO

- 40–50 % reduction in train formation/decomposition (shunting/coupling/uncoupling) time.
- 40–70 % reduction in train preparation / departure process time.
- Demonstrate increased average train length (in metres) up to maximum length in existing infrastructure limitations or higher loads: train length increased to 1 500 m.

Develop seamless rail freight

- 10–20 % reduction in average transportation time on reference corridor.
- 50 % reduction in operational dwell time at borders and other handover points.
- 20 % reduction in the number of additional operational stops (and thereby reduce energy consumption).
- 70 % reduction in handling/response time for ad hoc cross-border path requests.
- At least 50 % reduction in handling/response time for connected comprehensive multimodal offers.
- At least 10 % reduction in energy consumption and the environmental footprint, by making fewer stops at borders and increasing the use of multimodal railway transport.

7.5.3.3. Exploitation, deployment and migration considerations

Exploitation, deployment and migration considerations in FDFTO

Rail freight has a low level of innovation implementation, mainly due to slim business margins and fragmented technical approaches – both of which need to be addressed to boost progress in an interoperable, connected rail system where systemic innovation can only be achieved through collaboration. There is a need for a systemic approach with regards to the digitalisation of, for example, customer support systems and network/yard optimisation tools. Furthermore, a systemic approach is also needed in the digitalisation and automation of the system (full digital operations). Rail freight is facing a multitude of challenges, such as capacity constraints, the prevalence of manual interventions, insufficient customer information and the fact that the automation of freight trains has hardly changed for decades. Inefficient, non-atomised and analogue processes clearly need to be changed. Based on what will be developed in strong cooperation with key stakeholders of FA5, FDFTO promises to deliver a significant increase in productivity, efficiency and service quality, enhancing the competitiveness of European rail freight. The exploitation, communication and dissemination of FA5 results are essential for successfully achieving the objectives and ensuring the overall acceptance and implementation of FDFTO results. It is essential to secure the European rail freight sector's acceptance of the project outcomes.

One special characteristic of rail freight in Europe is the exchange of wagons. A full digital freight train comprises wagons from different owners, especially in the context of single wagon load operations. Therefore, interoperability between the wagons from different operators and wagon owners has to be ensured. This requires concerted standardisation efforts, including the creation (or adaptation) of standards and modification of the relevant TSIs. The SP should handle these tasks.

With its automatic coupler and the digital applications on board, a full digital freight train is not compatible with the screw-coupled wagons presently in operation. This means that a migration within the existing wagon and locomotive fleet is necessary. During the migration period, the two kinds of trains – each with a different coupling system – must operate simultaneously, resulting in a higher number of trains and increased capacity requirements in yards. The SP should define a migration concept, balancing operational constraints with available production and workshop capacity, to install full digital freight train equipment on wagons and locomotives.

The SP acts as an important interface during this process, providing harmonised operational procedures and accurate Cost-Benefit Analysis (CBA) assessments. This will help make the target picture for the European railway sector more concrete, which is a prerequisite for identifying the value creation for Europe. This will require investments at the policy level to ensure successful deployment. A unified, European FDFTO framework is needed to address technical specifications for TEs, guidelines, system architecture, operational procedures and standardised training – all developed in coordination with the SP and aligned with other initiatives, including funding opportunities for paradigm shifts. With strategic planning, implementation and management aimed at achieving a coherent functioning/implementation of the intended operational solutions outcomes, incorporating the TEs for which the European demonstration (highest TRL including customers) acts as a steppingstone, a successful migration will enable the transition from the current situation towards FDFTO.

To attract the market and involve relevant stakeholders, the demonstrations in the programme should be close to operational readiness and have a European generic perspective.

The best migration paths for each individual element need to be mapped out in parallel with the development work, depending on which vehicle fleet and which transports are concerned by the outcomes and whether separated migration is feasible or a network-wide migration is required. The development cycle needs to incorporate relevant feedback to adapt the results as needed for migration.

Exploitation, deployment and migration considerations for seamless rail freight

Since traffic does not usually start or end exclusively at a border or along an RFC, efficient and harmonised interfaces with the existing processes and tools of individual IMs, RUs and other freight stakeholders (e.g. ports, yards, lorry operators) are needed. The solution, based on what will be developed in close cooperation with the supply industry and academia in FA5, will lead to a significantly more competitive rail freight sector – resulting in lower emissions and higher customer satisfaction.

Migrating the results from FA5 will be challenging in some cases, not only because RUs are competing but also due to the need for the harmonisation and standardisation of R & D results. For the latter, a strong interaction with the SP is required. To ensure a smooth migration and to reflect the European approach, demonstrators and pilots in FA5 should already have a clear Europe-wide focus – such as on the ScanMed, Baltic–Adriatic or North Sea–Mediterranean RFCs. FA5 results will also support any large-scale testing of DAC pre-deployment trains in Europe.

7.6. Flagship area 6 – Regional and innovative rail services aimed at revitalising capillary lines

7.6.1. Objective and level of ambition

7.6.1.1. Targeted objective, new opportunities and associated risks

Problem statement and objective

Regional railways (lower usage lines or secondary networks) play a crucial role not only in serving Europe's regions but also as feeder lines for passenger and freight traffic to the main/core network. They provide the essential function of green transport while also connecting to other public transport services (e.g. bus) and first- and last-mile solutions, such as cars, bike-sharing walking from railway stations to remote locations. However, these railway lines need to be revitalised or even regenerated to make them economically, socially and environmentally sustainable and meet current customer needs. The overall objective of this FA is to ensure the long-term viability of regional railways by decreasing the total cost of ownership (TCO), in other words, cost per kilometre, both in terms of OPEX and CAPEX, while ensuring high service quality and operational safety. In addition, the desired results aim to increase customer satisfaction and establish rail as an attractive and preferred transport mode.

These goals are expected to be achieved through a concept tailored to regional railways that includes digitalisation, automation and the utilisation of mainstream and emerging technologies for signalling and trackside components, rolling stock and customer information. Cost drivers, including infrastructure and energy components such as TTD (axle counters, etc.) and level-crossing control systems, should be replaced with more affordable wireless and energy self-sufficient components. Furthermore, a modular and standardised concept for vehicles that specifically addresses the requirements of regional lines is needed. Hence, the following key objectives will be pursued:

- lowering CAPEX system costs;
- increasing productivity by addressing OPEX (unit costs per train-kilometre);
- improving customer satisfaction.

While the initial investment costs may be substantial, the migration should involve a complete system overhaul rather than retaining existing technology with high OPEX.

Digitalisation provides opportunities to make regional railways more attractive for customers and add new revenue streams. The outcome and demonstrated solutions shall not only be applicable for specific lines or regions but be adequately scalable and interoperable to become a European solution. Furthermore, proposed solutions and technologies could be applied to provide a more cost-efficient infrastructure in other settings. In addition, standardised solutions might apply for specific regional railways that are not functionally/operationally connected with the main-line network or for the purpose of pilot applications aimed at further development for global application. Large numbers of legacy systems and technologies, along with the integration complexity of the proposed solutions, may complicate adaptation. The main clusters within FA6, described in detail in the following sections, are: regional system solutions, CCS and operations, regional railway assets, rolling stock and customer service.

Nevertheless, to enable suppliers to develop technologies at competitive costs and operators to implement and use them effectively, certain potential gaps and risks have to be taken into account and eliminated or minimised. Possible gaps and associated risks include:

- an insufficiently clear definition of a harmonised regional system solution may lead to a multitude of heterogeneous systems with a high level of complexity, hindering standardisation and harmonisation;
- the lack of technologies suitably adapted in time for regional lines may limit FA6's planned demonstrations and pilots;
- insufficient alignment with the EU-Rail JU SP and other FAs;
- insufficient alignment with TSI revision cycles;
- a lack of standardisation and harmonisation;
- the migration from a brownfield environment and underestimation of the complexity of adaptation, particularly when combined with a lack of harmonised and clearly defined operational rules.

7.6.1.2. Innovation beyond the state of the art, including the integration of S2R results

TABLE 37. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail**

	Regional system solutions
State of the art	CCS and TMS systems originally developed for light rail, which will also be used on low-density lines.
S2R results	• Developments on formal methods, GNSS positioning systems and similar technologies, among others. • Ontology/semantics-based interoperable network, already used by S2R IP4 to facilitate multimodal journey planning and work within S2R IP2 and I2M for real-time traffic management.
Further/new results	• In coordination with the system architecture under development within the EU-Rail JU SP, functional blocks and interfaces will be investigated in order to identify all the possible needs and solutions applicable to low-density lines. • The design and development of flexible forms of rail services and their intermodal (rail–road) integration are considered and supported by migration strategies and socioeconomic evaluations of innovation.

TABLE 38. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 2**

	CCS and operations
State of the art	• Centralised traffic management, which involves controlling all parts of the network. • Automated conflict resolution systems for train route setting, enabling measures to avoid or minimise delays.
S2R results	Moving blocks, ATO and systems for train integrity.

	CCS and operations
Further/new results	• TMS encompassing overall line control and supporting innovative technologies, including ATO and autonomous or remote controlled driving, adapted/simplified for the specific characteristics of low-frequency traffic. • Safety layer based on CCS / ERTMS level 2 aiming to reduce signalling assets (lateral signals, TTD systems, level-crossing treadles, etc.), integrating interlocking functionalities and TMS. • Cost-efficient on-board equipment matching the needs of the operational requirements while also guaranteeing a minimum necessary compatibility/ interoperability with main-line CCS (ERTMS). • Development of integrated automation solutions, including ATO up to GoA4, ASTP, remote operation and virtual coupling. • Development (in collaboration with the SP) of adapted operational rules and procedures for regional lines supported by advanced TMS features; possible update of the CCS and OPE TSIs.

TABLE 39. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 3**

	Regional railway assets
State of the art	Codes and regulations have been developed over the years to meet main-line requirements, while requirements for lines with low traffic volumes have been relatively neglected. Flexible interpretation of standards, improvisation and proven experience currently form the basis for addressing urgent maintenance needs on less intensively used lines. Regulatory improvements tend to focus on enhancing track quality to reduce total costs on lines with dense traffic, where track availability is costly because it is the most limited parameter. The management of lines with low traffic volumes has other limitations. Here, track availability for maintenance is higher, so optimal quality can be tailored to regional needs, though scientific support for such tailored management is currently missing or not practically implemented.
S2R results	• Relevant frameworks for analysis have, to some extent, been developed within S2R. Inputs for regional conditions and safety calibrated limitations are missing. • IP2 smart wayside object controllers (SWOC).
Further/new results	With the aim of developing cost-efficient solutions by lowering both OPEX and CAPEX, the goal is to use results from other FAs and adapt them for regional usage, targeting: • assets that will be (further) developed to reduce unit costs per train-kilometre and guarantee an appropriate level of operational safety on regional railways; • a particular focus on the interoperability of assets, making use of technologies developed in other FAs while also being simplified/adapted; • technologies with a high level of scalability (economies of scale) which will be harmonised for all operators and infrastructures across Europe.

TABLE 40. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 4**

	Rolling stock
State of the art	• There are currently no vehicles available that have been specifically developed for the requirements of regional railway systems. The vehicles used are either (adapted) main-line or tram-based vehicles. • Relevant bus and light ferries technologies.

Rolling stock	
S2R results	• Lightweight materials; active suspension; silicon carbide traction equipment; flexible and lightweight user-centred interiors; lightweight doors; airless brakes.
Further/new results	The goals are: • to develop a common vehicle architecture, which will be harmonised for all operators and infrastructures across Europe; • to develop modular vehicle interiors that can be easily adapted to the specific needs of each service, with flexible spaces allowing for several uses, including the transport of goods; • to identify the requirements for a low-cost vehicle design that reduces the vehicle acquisition cost (CAPEX), taking advantage of economies of scale while reducing the OPEX of the global system; • to define and develop the best balance between service, performance and vehicle costs, using a systemic approach; • to develop solutions for small-size vehicles (e.g. 100 passengers) with alternative propulsion systems and new energy management solutions, such as on-board energy recovery; • to harmonise the requirements for such vehicles for use across Europe, allowing faster type certification/authorisation; • to develop applications for innovative and/or sustainable materials for train car bodies and interiors; • to further develop the full digitalisation of on-board systems; • to analyse the requirements for safety and interoperability, with the aim of adapting them to the needs of low-density lines in order to reduce costs, most likely resulting in a set of proposals for standardisation and TSI updates (Rolling Stock — Locomotives and Passenger Rolling Stock , CCS and OPE) in the upcoming revision cycles.

TABLE 41. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 5**

Customer service	
State of the art	There are many digital journey assistants and ticketing and time tabling applications on the market with which one can plan, book, pay for and execute travels, share travel info with others, get information about connecting transports, etc.
S2R results	• S2R developed prototypes and demonstrations for sharing solutions, facilitated door-to-door travel and the use of AR to enhance the travelling experience.
Further/new results	The goal is to develop customer solutions for regional railways, such as: • the standardisation and creation of a modular, safe and secure railway station, connecting different transport modes and including PRM aspects, aiming to: a. reinforce interchanged services by improving the management of hubs for multimodal and autonomous mobility in order to guarantee fully sustainable value chain multimodal mobility flows, including the distribution of freight in sparsely populated areas, b. develop use cases for business continuity with emergency recovery and disaster preparedness initiatives, c. develop a common, tailored and sustainable new distribution chain for new energy (i.e. for electric or hydrogen vehicles) for road and rail systems in rural areas.

Customer service
• a passenger information system (PIS), which involves: a. the integration of information systems, infrastructure and services with other regional/municipal transport modes (bus, tram, metro, taxi, demand responsive transport /on-demand transport) and additional solutions, such as bicycle rental services and tourist information points, b. developing digital integration with a distributed computing model that connects the shared transport modes, implemented as a platform that monitors and provides a digital abstraction of all mobility resources and enables the development of new coordination capabilities that match mobility demand to available mobility supply in an efficient and flexible way.

7.6.1.3. System integration, interactions with the SP and with other FAs

Several objectives within FA6 require transversal cooperation with other EU-Rail JU FAs, as some of the enabling technologies, (including train integrity, moving block, advanced signalling and train protection, FRMCS, and intelligent and efficient maintenance) will be developed within those FAs.

However, it is important to note that regional railways have their own characteristics and requirements. Enabling technologies developed for regional railways must take such characteristics into account. Most importantly, regional railways operate under tight economic conditions. Hence, the applied technologies should be modular and limited to essential functionalities, while still respecting high safety requirements and not being driven primarily by cost considerations.

The relationship between FA6 and other FAs is summarised below.

SP

This FA provides input for the SP by defining a clear set of constraints and requirements and, in turn, operates within the proposed framework set by the SP. Hence, input received from the SP is fundamental for the development of technological enablers.

The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initial identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the SBA and the master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.

- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.
- **FA1**: FA6 specifies the requirements for regional railways and **uses the enablers developed in FA1** to develop a simplified TMS and on-demand passenger services requiring flexible timetabling.
- **FA2**: FA6 specifies the requirements for regional railways and **uses the enablers developed in FA2** to develop cost-effective CCS and ATO solutions for functions such as fail-safe train positioning, train integrity and train length detection, along with cost-effective communication. Both FA1 and FA2 provide the operational backbone for FA6.
- **FA3**: **FA6 uses the enablers developed in FA3** (e.g. infrastructure inspection systems to be installed in commercial vehicles, autonomous inspection vehicles, algorithms to predict asset degradation, robotic solutions to perform maintenance tasks, and new manufacturing and repairing techniques based on additive manufacturing), taking into account the scope and objectives of FA6 to minimise asset LCC and decrease OPEX.
- **FA4**: **FA6 uses the enablers developed in FA4 where relevant**, including alternative low carbon, and low-weight and energy-efficient systems to achieve cost-efficient decarbonisation and climate resilience.
- **FA5** and **FA7**: DAC is an essential prerequisite for single-staffed last-mile shunting operations and improved integration in multimodal transport chains. This multimodal shared-mobility solution developed in FA7 and FA5 can be used in FA6 to increase the attractiveness of regional railways for customers and generate additional revenue streams.
- FA TT 'Transversal Topics' will be linked to for potential coordination and collaboration on data models, serving as a kind of transversal enabler. Further development of the ontologies and specific regional line applications related to digital twins (DTs) and automation processes is also foreseen.

Details of the exchange between the FAs can be found in Annex B.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the CDM,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

In addition, FA6 will also seek input from outside the EU-Rail JU, such as from the Clean Hydrogen JU or European R & D programmes related to space. At the same time, it is important to avoid highly specific, isolated solutions for regional railways and instead find the right balance. Technologies should provide a seamless transition between main lines and regional lines. The overall system integration approach will be achieved through highly visible demonstrators.

7.6.1.4. Who does what by stakeholder group

IMs and RUs are primarily responsible for the collection of requirements. They also provide the required infrastructure for testing the feasibility of proposed solutions and demonstrating results.

Suppliers are mainly responsible for developing and providing regional system solutions and tools based on the operating community's requirements and specifications.

Research institutions are in charge of transferring results from basic research and other research fields to the necessary applications for regional railways, and providing methods to IMs, RUs and suppliers. They will support the development of technologies based on requirements from IMs, RUs and industry, and address any possible scientific or methodical issues that may arise during the execution of this FA. They will also participate in demonstrations, particularly in the evaluation of testing.

7.6.1.5. Interaction with other programmes, European and/or national

The R & I activities considered within FA6 are expected to interact with other programmes and initiatives at the European and national levels. This FA interacts with two major programmes. It is linked (input/output) to and interacts with the SP and also interacts with European projects like 5GRAIL (grant agreement (GA) ID: 951725), focusing on FRMCS. FRMCS will define the worldwide standard for railway operational communications, conforming to European regulations and responding to the needs and obligations of rail organisations outside Europe. The work on functional and technical requirements, specification and standardisation in 3rd Generation Partnership Project (3GPP) and on harmonised spectrum solutions is currently led by UIC, in cooperation with the whole railway sector. In addition, collaboration with EUSPA on using satellite services (satcom and GNSS) for rail application is envisaged.

In addition, there is a strong connection with the Clean Hydrogen JU for the prospective implementation of alternative fuels on regional lines, and with BATT4EU for the potential use of battery-powered light vehicles. Last but not least, FA6 takes into account national R & D programmes, from countries such as France and Austria (e.g. the Austrian Research Promotion Agency's 'Mobilität der Zukunft' [Mobility of the future]), which have been set up recently to launch R & D initiatives for regional railways or CCS deployment. These initiatives are aimed at enhancing safety on low-density lines, such as in Czechia.

7.6.2. Results/outcomes

7.6.2.1. Operational solutions outcome

The main outcome of this FA is a low-cost technical and operational framework for low-density lines, aimed at reducing the cost per kilometre in terms of both CAPEX and OPEX while also enhancing customer satisfaction. It should be applied as a Europe-wide solution. While the framework and provided solutions must be adapted to the specific requirements of regional railways, their interoperability must also be ensured to provide an added European value.

The framework includes architecture aligned with SP CCS reference architecture, cost-efficient infrastructure and energy components, a light, flexible and modular vehicle concept suitable for regional line characteristics, and safety and asset management. In addition, a PIS will benefit from the solutions available for main-line services while combining data from regional railways with data from other modes of transportation and local services. It also offers added value for customers. The purpose of a PIS is to offer value-added services through data integration. If the solutions that are currently available do not provide the required functionalities, a new PIS will be developed.

A regional system solution, aligned with the SP, will be proposed to integrate developments from other FAs on infrastructure, CCS, TMS and vehicles, along with a data sharing and analysis platform. Integrated automation solutions, including ATO up to GoA4, ASTP, remote operation and virtual coupling, enhance cost-efficiency and flexibility. Fully digitalised and connected rolling stock, such as completely FRMCS-compliant, integrated TCMS and using a train as a data hub for maintenance, for example, will enable the full potential of digitalisation.

This FA will also develop cost-efficient components, including wireless and energy self-sufficient infrastructure components, to decrease the operational and overhead cost, standardised, modular railway stations as well as energy supply. Due to the lower density and capacity needs of regional lines in comparison to main lines, a zero-emission vehicle concept for both passenger and freight, tailored to regional lines, will also be developed. This vehicle will be a modular, low-cost, light-rail train, with clearly defined modules and interfaces, ensuring interoperability. Innovative and more sustainable materials will enhance both the sustainability of the regional solutions and their deployment within the rail sector.

To further optimise operations and reduce operational costs, tools and methods in the areas of predictive maintenance and asset localisation will be put into regional operation based on FA3 findings. Cost drivers and the corresponding solution requirements will be validated by a requirement specification and analysis.

It is without question that all solutions will be delivered at the European level, securing the scalability of solutions along with added European value.

TABLE 42. **Overview of the operational outcomes**

	TRL in 2026	TRL in 2028	TRL in 2030
Low cost framework for regional/low-density lines			
Suitable regional system solution	4/5	6	7
Cost-efficient CCS system (ATO, ATP, comms, TMS, interlockings, positioning, train integrity)	4/5	5/7	6/7
Optimised railways assets (field elements, SWOC, fuelling)	4/5	5/6	6/7
Sustainable rolling stock (light, cost-efficient, modular, flexible and sustainable materials)	3	4	4/5
Suitable customer services (PIS, congestion management)	6/7	7	7

7.6.2.2. TEs: capabilities to achieve the desired operational outcomes

In order to achieve the envisaged goals, several TEs must be provided. These should include cost-effective, highly accurate/advanced train positioning and a train integrity system, with satellite- or fibre-optic-based localisation capabilities, for example. Communication systems should enable the transmission of CCS data to public operator services (such as MNOs) or via satcom, such as IRIS[2]. To remove the cost of cabling and installing wayside equipment, elements such as object controllers and field elements will be radio connected and locally powered. Hence, SWOC from the Shift2Rail program need to be further adopted/developed for regional railways. In addition, the overall architecture integrated within the overall regional or full network CCS will offer many possibilities, such as real-time, on-demand timetable management, integrated management of rail and road services, and autonomous or remotely controlled movements and virtual coupling. ATO should be able to detect obstacles on the track and remain operational in all weather conditions. Level crossings should ideally be energy self-sufficient and should provide their status data to other information systems, including road.

The overall architecture will capture technology innovation outputs from FA6 and assess their impact on current European TSIs (and, where applicable, National Notified Technical Rules regulations). The regulatory impact will be discussed together with the SP in order to make suggestions on what changes are needed to deploy the innovative technology.

While FA6 will have to create various tailored solutions, it remains closely connected with the design and development undertaken in other FAs.

For this reason, the TRL at various stages of the project is linked to the achievements in the other FAs. It is expected that the minimum TRL of the specified components will be roughly equal to the corresponding TRL in the original FA, also taking into account the effort required for possible adaptation in FA6.

It is crucial that FA6 provides input to the other FAs based on the specific needs of low-density lines. Similarly, FA6 will also use inputs, such as from FA TT, on conceptual data models and DTs, as a common approach on definitions and processes to be applied in its specific use cases. This approach will not only enable alignment in terms of TEs but will also benefit from the contributions of partners in other FAs. FA6 will provide the specifications for TEs required for regional railways to other FAs. If needed, the provided solutions will be further developed within FA6 to specifically address the requirements.

The following table gives an overview of TEs, including required capabilities, expected TRL at the time of need, and their connection with other FAs through TRL alignment. In the development of TEs, TSI revision plays a crucial role and needs to be taken into account.

TABLE 43. **Overview of technical enablers**

Cluster	TE	TRL		
		2026	2028	2030
Regional system solution	**System specification for regional lines** In the first step, overall system functional blocks and interfaces will be investigated in order to identify all the possible needs that apply for regional applications in cooperation and alignment with the SP and the other FAs. The work includes an analysis of the effective deployment of interoperable radio-based ATPs (e.g. ERTMS/ETCS up to level 2), following the most effective principles (e.g. centralised versus distributed architecture, train control principles) that will enable wayside assets to be powered and controlled, with the overall goal of creating a cost-effective solution (e.g. reducing cabling and wayside infrastructure). An effective balance between rule-based and technical safety will be considered. Moving block and virtual coupling should be investigated regarding their application (pros/cons/impacts) and customisation for typical regional lines. In the second step, following the consolidated requirements, the signalling functions, including interfaces with interlocking and TMS, will be integrated and implemented.	4/5	6	7
CCS and operations	**Interlocking/RBC for regional lines** Interlocking and radio-based solutions adapted to regional line railways. Alignment needed with the SP and with FA2 regarding autonomous route setting.	4/5	6	7
CCS and operations	**ATO over ETCS adapted to regional operations** Progressive evaluation and implementation of driver advisory systems and radio-based, all-weather ATO over ETCS up to GoA3/4 applicable and adapted to regional operations, including OD systems. Aspects to be considered include energy savings and the optimisation of driving schedules and remotely controlled trains, especially, though not only, in shunting areas or last-mile movements. Scope of FA6's work: limited to demonstrations and providing requirements to FA2 for regional specificities. Link with other FAs: all developments on ATO are conducted in FA2.	4/5	6	7
CCS and operations	**Hybrid train detection, moving block and relative braking distance** Scope of FA6's work: limited to demonstrations, providing requirements and the development of regional specificities, in coordination with FA2. Link with other FAs: all developments on MB and virtually coupled train sets are conducted in FA2.	4/5	6	7

Cluster	TE	TRL		
		2026	2028	2030
CCS and operations	**Cost-effective communications** Cost-effective use of dedicated railway mobile networks or third-party communication infrastructures (e.g. 4G, 5G, satcom via IRIS[2] and IoT communications) for innovative information exchange between regional railway subsystems (e.g. train to train, train-to-trackside/ wayside assetstrackside-to-trackside). Particular attention will be given to aspects of multi-bearer platforms and their use (building on Shift2Rail results on ACS and FRMCS), the transmission of vital CCS data over public networks, new communication service features and their application in regional railways, and cybersecurity aspects. The objective is to provide an effective communication tool for various potential applications, including ETCS, ATO (up to driverless operations), high-quality passenger services, smart maintenance, and support for innovative ways to connect rolling stock and wayside elements. **Cost-effective communication** requires synergies between FRMCS infrastructure for critical, performance-related and passenger services. • **Cost-effective communication** requires synergies between FRMCS infrastructure for critical, performance-related and passenger services. It should be underlined that aspects related with dedicated railway mobile networks will be in the remit of FA2, but the rest including investigation of public networks will be in the FA6 remit. Scope of FA6's work: limited to demonstrations, providing requirements and the development of regional specificities, such as satellite communication, in coordination with FA2.	4/5	6/7	8
CCS and operations	**TMSs for regional lines** TMSs for regional lines improving the resilience of a connected rail network, optimising train operations, including during disturbances. Regional lines are characterised by **managing traffic for different purposes**, such as transporting passengers and freight/ goods and carrying out social tasks (e.g. cutting trees or running special train services to meet increased demand due to local concerts, festivals, etc.). Moreover, regional lines usually have **big depots**, where various types of trains are parked and maintained (preventive maintenance, reactive maintenance, washing, etc.). This operational complexity means that regional lines could benefit from applying FA1 TMS algorithms that support the optimisation of tactical/planning, real-time and on-demand timetables. Scope of FA6's work: limited to demonstrations, providing requirements and the development of regional specificities, in coordination with FA2 and FA1. Link with other FAs: • all general development of planning systems within TMSs is conducted in FA1.	4/5	6	7

Cluster	TE	TRL		
		2026	2028	2030
CCS and operations	**Cost-effective fail-safe train positioning** Cost-effective interoperable fail-safe train positioning comprising, among others, hybrid multi-sensor (including GNSS) technologies and on-board databases of digital maps, as a means to reduce the number of balise installations, increase operational efficiency and decrease the TCO in the context of regional lines. • FA6 requirements will be submitted to FA2. • FA2 will develop the solution. • FA6 validates and applies the solution for the demonstrator.	4/5	6	7
CCS and operations	**Cost-effective, fail safe, on-board train integrity** Cost-effective fail-safe on-board train integrity to verify the completeness of the train while it is in operation. • FA6 requirements will be submitted to FA2. • FA2 will develop the solution. • FA6 validates and applies the solution for the demonstrator.	5/6	6/7	7/8
CCS and operations	**Cost-effective fail-safe train length detection** Cost-effective fail-safe train length detection to determine the beginning and end of the train and detect its length. • FA6 requirements will be submitted to FA2. • FA2 will develop the solution. • FA6 validates and applies the solution for the demonstrator.	4/5	5/6	6/7
CCS and operations	**Wayside elements** Infrastructure components and wayside elements for regional railways, including signalling, level crossings, switches and track vacancy detection, that are energy self-sufficient and/or wireless-enabled to reduce costs, cable and power supply and enable remote control or full or partial automation and/or autonomous operation.	4/5	6	7
CCS and operations	**SWOC** Further develop (if needed) the concept of SWOC from the Shift2Rail programme and apply it.	4/5	5/6	6

Cluster	TE	TRL		
		2026	2028	2030
CCS and operations	**Digital platforms for CCS validation and TSI certification in the regional line domain** Technology infrastructures available to the stakeholders involved in regional line APIS (authorisation for placing into service) processes will provide integral solutions to speed up related activities and reduce associated costs, focusing in particular on the application of digital certification in this line typology. Inspired by the Commission's zero on-site testing initiative, these platforms aim to bring a range of CCS tasks – such as design, testing, inspection, or maintenance – into a DT, including tasks traditionally performed on-site at different life cycle phases. This will allow potential integration issues to be identified and addressed at early stages of projects. Scope of FA6's work: limited to demonstrations, providing requirements and the development of regional specificities, in coordination with FA2. Link with other FAs: • all development is conducted in FA2.	4	5	7
CCS and operations	**New propulsion train fuelling/charging stations** Decarbonised fuelling and charging solutions for regional railways using hydrogen or electric energy (dynamic and static charging). Activities should focus on developing solutions for multimodal road and rail fuelling/charging stations, taking into account their optimised locations along regional lines. A methodology for new energy management solutions for the propulsion and energy system of the vehicle. Scope of FA6's work: limited to providing requirements and the development of design concepts for regional specificities, in coordination with FA4. Link with other FAs: • technical exchange with FA4.	3	3	4
Sustainable rolling stock	**Virtualisation in RS design** Virtual solutions for the replacement of selected hardware functions with software and electronics: design aimed at replacing hardware functions (pneumatics, electro-pneumatics and mechanics) with software and electronics as this has a positive impact on cost, including maintenance cost. Conducted in close cooperation with or based on FA4.	3	4	4/5

Cluster	TE	TRL		
		2026	2028	2030
Sustainable rolling stock	**Cost-efficient and modular RS system design** Overall cost-efficient and modular RS system design (virtual model with a focus on the following subsystems). • Specify and methodically develop a design concept of a lightweight vehicle base and various modular concepts to be adapted for flexible rail passenger services (up to 100 passengers). The focus will be on creating a light, modular vehicle architecture, prioritising mechanical and propulsion architecture, while also considering interiors for easy layout customisation, suitability for various operators and line characteristics, and the integration of on-board information systems. • Efficient electric traction design: single energy source and hybrid power-train design (battery and hydrogen) with high-power-density converters (possible reuse of FA4 technology, if relevant). • Wireless solutions: design aimed at reducing cabling, both inside the car and along the whole train (reuse for demonstration purposes already achieved in S2R IP1).	3	4	4/5
Sustainable rolling stock	**Innovative materials** Lighter, more cost-efficient or more sustainable materials (e.g. natural fibres in composites).		3	4
Sustainable rolling stock	**System integration into a new vehicle demonstrator of the sustainable rolling stock above**			
Customer service	**PIS** Comprehensive regional travel planning multimodal transportation incorporating external data sources (e.g. touristic data sources) and holistic passenger information. This may contribute to further development of the ontology networks produced in previous Shift2Rail projects, aligning them with CEN standards (Transmodel, FSM, OSDM, TRIAS, etc.) and with the connections to national access points.	6	7	7
Customer service	**Congestion rate monitoring and flow optimisation** Applications at stations and intermodal hubs, such as the management and integration of people and goods through the gathering of real-time flow data, using advanced technologies (e.g. IoT, machine vision) for applications such as congestion rate monitoring and passenger flow.	5	6	7

7.6.2.3. Demonstration implementations

Regional lines connect rural areas to larger rail transportation hubs typically situated on main lines or in urban areas, transporting passengers and/or freight. They typically have, with some exceptions, low capacity needs. Regional lines can be grouped (notwithstanding different national line categories) according to their level of connectedness to the main line:

- group 1: regional lines with a significant connection to main-line traffic or to urban areas;
- group 2: regional lines with no or limited connection to main-line traffic.

While group 1 has the same safety requirements as main lines, group 2 can – due to lower traffic density and different traffic patterns – adapt interoperability and safety requirements to suit its needs, when permitted under national and European rules. This can lead to traffic management (radio systems and CCS functionalities) and rolling stock specifications being different to those in group 1. Due to the requirements regarding interoperability and compatibility between connected regional lines (group 1) and main lines, this group offers more potential to develop a European solution with added value. On the other hand, group 2 lines also bring added EU value, provided that solutions are scalable and ensure standard interfaces with components from other FAs (e.g. the simplified TMS in group 2 should respect the protocols defined in FA1 to exchange data with the larger TMS controlling broader geographical networks). The approach and prototypes developed can be demonstrated in several geographically different locations. In this way, several issues can be addressed and demonstrated simultaneously, including:

- the feasibility of proposed technical solutions;
- operational adaptation challenges of the proposed solutions in different settings;
- the potential for scaling up as a Europe-wide solution.

The aim is to demonstrate all solutions under real operational conditions across different European regions. The regional railways used to demonstrate the results under real operational conditions in FA6 may also be used for other demonstrators whose main focus concerns other FAs. Hence, a strong involvement of all relevant stakeholders (RUs, IMs, industry and R & D) is crucial.

Demonstration under real operational conditions (at high TRL) is crucial for verifying feasibility and evaluating the impact on the future operational and technology solutions for regional lines, bearing in mind existing installations and relying on feasible and realistic plans for migration to the new solutions.

Since several TEs depend on the output of other FAs, the demonstration plan is also linked to the other FAs, in particular at the TRL implementation level, as FA6 will need to integrate those enablers within infra/RS assets for the demonstrations.

The following table ([28]) gives an overview of a timeline for demonstration implementations. The demonstrations which have been defined for 2026, 2028 and 2030 for both group 1 and group 2 of regional railways are as follows.

([28]) The aim of the FA6 demonstrator is to integrate and characterise the main components in order to achieve a flexible and low-cost regional system solution for regional lines. This implies the implementation and testing of products/systems developed in other FAs. Therefore, the detailed list of demonstrators requires an accurate analysis of the systems/products developed in the related FAs, and of the TRLs and their suitability for implementation in the regional framework. Consequently, the final definition of the demonstrators and of the related essential and necessary implementations is expected to be produced once this analysis has been performed.

TABLE 44. **Link between the demonstration plan and the TRL implementation level**

Demonstrator	2026	2028	2030
Demonstrator cluster 1: regional lines with a significant connection to main-line traffic or to urban areas (group 1) Based on the current CCS TSI and ERTMS specifications (**(TE) system specification for regional lines**), but also using technological developments and new specifications coming from other FAs and the SP, which might be introduced in upcoming CCS TSI and OPE updates, this cluster will demonstrate how these technologies can be used in European regional/low-density lines that are connected to the main railway network to reduce the TCO. Topics include but are not limited to: • the use of radio-based ETCS with a special focus on field element reduction (e.g. signals, track circuits), supported by **(TE) Hybrid train detection, moving block and relative braking distance**; • the use of **(TE) ATO over ERTMS adapted to regional operations up to GoA4** to optimise energy consumption and improve punctuality; • the use of **(TE) cost-effective fail-safe train positioning** systems and virtual balise concepts based on sensor hybridation, including GNSS, to minimise the use of eurobalises; • the use of cost-effective multi-bearer platform radio communication technologies (**(TE) cost-effective communication**) allowing the transition towards future FRMCS specifications for critical, performance-related and passenger services, along with wireless connections with various field elements; • the application of harmonised and simplified operational rules from the SP to significantly reduce engineering costs; • the use of **(TE) interlocking/RBC for regional lines**, explore new architectural and technological proposals such as interlocking/CCS virtualisation, with attention to applicability and migration paths for regional lines and current infrastructure; • the interface of the solutions with TMS, exploring the benefits of multimodality, dynamic regulation, smart conflict resolution, etc., in line with **(TE) TMSs** and **Cooperative Intelligent Transport Systems (C-ITS) for regional lines.** • the application of CDM and DT concepts in the project life cycle to facilitate the exchange of information between stakeholders, data preparation, validation and testing (**(TE) digital platforms for CCS validation and TSI certification in the regional line domain**). • the implementation of a digital process for data preparation, validation, and operational and End-to-End System Certification (ESC) testing (**(TE) Digital platforms for CCS validation and TSI certification in the regional line domain**); • the exploration of energy self-sufficient and/or wireless-enabled components for **(TE) wayside elements**, and/or the applicability of **(TE) SWOC**; • the use of **(TE) PIS** to offer value-added services and enhance the attractiveness of regional railways; • the use of **(TE) cost-effective fail-safe on-board train integrity** to ensure train integrity; • the use of **(TE) cost-effective fail-safe train length detection** to detect train length, which can be used, among other things, for the autonomous operation of wayside elements, such as level crossings, to reduce the TCO; • the implementation of a cost-effective solution for sending level crossing status information to the ETCS trackside.	n/a	TRL 6	TRL 7

Demonstrator	2026	2028	2030
Demonstrator cluster 2: regional lines with no or limited connection to main-line traffic (group 2) Regional lines in cluster 2 require the most significant reduction of CAPEX and OPEX costs (40 %). For this reason, a more aggressive approach towards simplification, addressing interoperability, is needed. This aggressive approach is made possible by the fact that there is no need for interoperability, since the trains in question do not exit these regional lines. Key elements include but are not limited to the following. • A simplified architecture to complement the SP architectures. This architecture may differ from the interoperable main network one only if it provides real added value supported by business case analysis; otherwise results/solutions from other FAs will be used (**(TE) System specification for regional lines**). • The demonstrator will guarantee standardisation, including protocols and interfaces for data exchanges with the systems deployed on main lines, maintaining full alignment with other FAs and the SP. For example, the regional line operation control room should be able to exchange data with the large national TMS and this also in a multimodal environment. The intermodal interface will cover primary traffic management based on the rail system and connect rail traffic management with existing regional mobility centres. • Zero wayside elements, except wireless-controlled switches (**(TE) wayside elements**). • Energy self-sufficient components that do not need an external power supply and/or cabling for power transmission (**(TE) wayside elements**). • Low-cost train positioning based on radio technologies, such as GNSS and xG (**(TE) cost-effective fail-safe train positioning**). • Low-cost wireless communication using public networks or satcom systems; **(TE) cost-effective communications** for FRMCS critical, performance-related and passenger services. • Tailor-made and integrated regional interlocking/ATP system designed specifically to address the requirements of regional railways in a moving block signalling environment (**(TE) interlocking/RBC for regional lines**). • Autonomous or remote-controlled movements (e.g. in shunting and the last mile) to reduce operational costs and human intervention.	n/a	TRL 6	TRL 7

Demonstrator	2026	2028	2030
Sub-demonstrator: The flexibility of key components integrated into the Cluster 1 and Cluster 2 demonstrator • Demonstration of part of a concept for modular (light) rail vehicle architecture with an alternative propulsion system, and a detailed simulation model of the main systems embedded in the vehicle. • Application of the relevant part of a force-flow-optimised modular lightweight design for load-bearing structures, based on a methodical approach and partially using sustainable natural materials. • Development of novel energy management solutions, demonstrated using simulation models. • Implementation of a system in a simulation model for **(TE) multimodal on-board facilities** and personal thermal comfort. • Testing of weight and track force reduction in simulation, ensuring tolerance to greater track unevenness. • Demonstration of **(TE) cost-efficient and modular RS system design**, featuring a reduction of wiring and pneumatic components on trains, replaced by electronic and software functions. • Demonstration of safety using an appropriate safety assessment methodology. • Demonstration of cost-effectiveness, showcasing the impact of the above-mentioned innovations. • **(TE) Virtualisation of hardware functions**. • Early mock-up demonstrators of components and subsystems, potentially available by 2028. • **(TE) New propulsion train fuelling/charging stations**.	n/a	TRL 3/4	TRL 4/5

The locations for the test lines for demonstrator clusters 1 and 2 are to be chosen in a manner that guarantees geographical balance. This, in connection with the vehicles meeting the needs of demonstrator cluster 3, will enable simulations of various scenarios and cross-testing under different socioeconomic conditions.

7.6.3. Impacts

7.6.3.1. Description of the impacts on existing rail services

Regional railways provide an important public service through transportation and the provision of goods and services. They connect rural areas to larger rail transportation hubs typically situated on main lines transporting passengers or freight. In order to ensure feasible long-term operations, costs must be reduced and economic viability and competitiveness enhanced. The development of technological and innovative solutions using information and communications technology and other mainstream and emerging technologies makes the operation of regional railways more cost-efficient. The technologies and tools developed should not remain limited to regional railways. They may also be applied in main lines, reducing the overall cost of operation and investment. We expect to further reduce costs by decreasing the need for field staff through digitalisation and automation, which consequently improves operational safety. On the customer side, it is essential to offer better services adapted to current and future needs in order to increase the attractiveness of regional lines in the multimodal context and make the regional rail services economically viable. Real-time train positioning, for instance, can be used to offer customers real-time data services. Such services improve the predictability of regional railways, thereby increasing their attractiveness to customers.

This FA will have a positive impact on competitiveness, sustainability and LCC.

As highlighted in the previous sections, the challenge lies in the status quo, which calls for innovative solutions to improve state-of-the-art safety and develop more attractive customer solutions – ultimately leading to affordable LCC, increased customer demand and more frequent services.

TABLE 45 **Descriptions of FA6 impacts in relation to the intended impacts laid out in the master plan**

	Meeting evolving customer requirements FA6 developments, such as new vehicle design and a cost-efficient signalling system, will lead to improvements in the safety, performance and capacity of existing lines, while making the solutions more affordable for the customers. Services using the TMS system will adapt to demand in real time, delivering improved service quality.
	Reduced costs The main goal of this FA is to ensure the long-term competitiveness of regional railways by supporting their economic viability and reducing costs. The main indicator of success is a reduction in the TCO per km, which should not include only implementation costs (CAPEX) but also operational costs (OPEX). This FA will assess the different technology enablers and propose a cost-efficient and tailor-made solution for regional services.
	More sustainable and resilient transport Revitalising regional rail services will promote the use of more sustainable transport for both passengers and freight and reduce the CO_2 end exhaust emissions of the transport sector at the European level. The technologies developed will improve the energy performance of the system by introducing lighter and more adapted rolling stock designs for regional services.
	Reinforced role for rail in European transport and mobility Revitalising regional lines will provide a sustainable solution for multimodal transport mobility and enable economies of scale and cost reductions, while also creating seamless links with the rest of the rail network and other modes of transport. It will create competitive solutions by providing more affordable and attractive solutions for passengers, while adapting services to meet demand.
	Improved EU rail supply industry competitiveness The sustainable and smart mobility rail objectives require a transformation promoting sustainability not only on the trans-European networks, but across the whole rail network. These lines promote social cohesion and inclusiveness, extend the reach of public transport to a broad population and create opportunities for businesses to emerge across Europe. A coherent, unified, interoperable vision of how to seamlessly connect those capillary lines to the rest of the European network and to other modes of transport is needed.

7.6.3.2. Quantitative KPIs demonstrated in this FA

To ensure the delivery of the aforementioned impacts, close monitoring will be implemented using KPIs. The definition of the KPIs will also take into consideration possible frameworks from which to extract the relevant indicators needed.

A set of high-level KPIs has been identified for FA6, targeting the main impacts envisaged for the programme. It is worth noting that KPIs related to enablers in other FAs are deliberately excluded from FA6 to avoid overlaps and misalignments. The baseline for KPIs is 2018–2022, subject to availability and taking into account the need to offset the effects that COVID-19 has had on data.

Demonstrator 1 and 2: regional system solutions, CCS and operations, regional railway assets and customer services

- 25 % reduction in the CAPEX of the CCS system, while maintaining or increasing the present safety level.
- 15 % reduction in the CAPEX of the radio network achieved through the use of the less costly public radio network on low-density lines.
- 10 % increase in system availability, with fewer trackside asset failures and more reliable CCS (average time of delay in minutes per asset and signalling failure).
- 15 % increase in reliability and 15 % reduction in OPEX and CAPEX achieved through the use of reliable cost-effective fail-safe on-board train integrity, train length detection and train positioning.
- 10 % reduction in energy consumption and 15 % increase in punctuality achieved through the use of ATO over ERTMS targeting GoA4.
  a. 30 % reduction in OPEX costs/km for trackside railway assets achieved through the use of fewer assets.
  b. 15 % increase in energy efficiency for trackside railway assets (as part of the OPEX reduction above, not in addition).

Sub-demonstrator: rolling stock

50 % reduction in vehicle CAPEX and OPEX achieved through innovative, modular and lighter design. The vehicles for low-density lines must be designed to deliver the service on these lines at a significantly lower CAPEX and OPEX.

Aside from the previous KPI, passenger vehicle development should aim to reduce weight by up to 30 % and track force by up to 60 % for some parts of the vehicle, ensuring tolerance to higher track unevenness.

It should be noted that the KPIs need to be estimated ahead of the implementation of the innovations, therefore a forecast is needed. Effects will be quantified at regular intervals during demonstrator projects and the effects on a broader European scale will be measurable after 2030, once the technology has been deployed. To set the right priorities, it is essential to clearly establish how KPIs improve with the use of new technologies compared to current operations. They must show how regional rail services as a whole will be transformed to significantly reduce costs.

7.6.3.3. Exploitation, deployment and migration considerations

The use of new technologies developed, demonstrated and validated in FA6 will benefit infrastructure owners, operators, passengers and freight customers. This will be demonstrated in use cases for new and untested signalling systems that are safe and can support cost-effective services, flexible traffic management with remote-controlled meeting stations, and track infrastructure tailored to the history and needs of these types of lines. Vehicles and digital solutions that are suited to low-density rural lines with low OPEX and CAPEX and still attractive to end customers.

FA6 will build on R & I conducted in other FAs and collaborate with them to seek solutions that are simpler and more affordable while at the same time meeting the safety requirements that apply to railways. Solutions should be up scalable or use down scaled main line solutions.

The implementation of technologies tested and proven in FA6 occurs in several different ways. Manufacturers of tracks, switches, signal safety systems and vehicles will be able to offer operators and infrastructure managers new products at lower system costs that match customers' expectations and willingness to pay.

The FA6 demonstrators should also be viewed as early implementations of the new system approach, anticipating the upcoming TSIs revisions, where the FA6 outcomes may be incorporated. In this way, the viability of new solutions can be demonstrated, facilitating an accelerated migration. This will also be supported by a set of proposals to update relevant standards, reflecting new regional system approaches and the concept of modularisation.

On the side of RUs, deployment will occur not only when operators procure new vehicles, but also in conjunction with the regional line traffic management system (CCS) overhaul.

Travelers and freight customers will take advantage of digital aids that support and facilitate mode integration, trip tracking and sharing solutions.

FA6 will also actively seek cooperation with roll-out funding stakeholders, such as the CEF, to ensure that solutions are implemented on schedule.

7.7. Flagship area 7 – Innovation on new approaches for guided transport modes

7.7.1. Objective and level of ambition

7.7.1.1. Targeted objective, opened opportunities and associated risks

The long-term vision for rail transport envisages rail transport as the backbone of future mobility in a multimodal context, as presented in the ERRAC's *Rail 2050 Vision* ([29]). Furthermore, it anticipates that there will be new opportunities for radical changes in the transport system. These changes range from the development of railway systems based on shorter but more frequent trains that can couple together virtually, to multimodal shared-mobility solutions volving full integration with other modes of transport. The anticipated changes even include totally new types of railway-based transport, such as ultra-high-speed trains and/or personalised vehicles or 'transport vessels' (hereinafter referred to as pods) capable of being transferred across modes via pod carriers on rail, road, water and even air transportation. Two conceptual examples – a pod-based passenger system and a vacuum-tube-based freight system – are illustrated in the artists' renderings shown in Figures 15 and 16.

([29]) ERRAC, *Rail 2050 Vision*, 2017.

FIGURE 15. **Concept of a pod-based multimodal mobility hub by Siemens Mobility. Source: Siemens**

FIGURE 16. **Concept of a vacuum-tube-based freight system**

Source: Virgin Hyperloop.

The objectives of FA7 are to explore non-traditional and emerging flexible and/or high-speed guided transport systems, and to provide innovators with opportunities to introduce ideas for shaping those future systems through a scientific approach within the existing rail framework. This will provide socioeconomically efficient and long-term, sustainable transport for citizens and businesses throughout Europe. Key aspects for such systems include reducing energy consumption, noise and pollutant emissions, and land consumption; using sustainable raw materials and energy sources; and ensuring the sustainable use of existing infrastructure. This work will highlight that innovation is both vital and economically significant for the evolution of rail transport and mobility, achieved through engaging in and responsibly generating new ideas while maintaining technological neutrality with a diligent and consistent programmatic approach. This includes identifying solutions to the main obstacles and estimating the necessary time and resources to facilitate the evaluation of feasibility and development of these emerging concepts.

The vision of the FA is to develop the next generation of railway and guided transport systems based on a fully automated, multimodal mobility network for passengers and goods that is sustainable, interconnected, digital, on-demand, standardised, scalable and compatible with all transport modes. It should consider the actual needs of the end user and the actual traffic situation across different modes (Figure 17 shows an example of this idea). While FA7 is generally open to all innovations in new approaches for guided transport modes, the focus will be on solutions that enhance flexibility through multimodality – such as transitioning to intermodally connected moving infrastructures with centrally coordinated, innovative purpose-built vehicles – and on ultra-high-speed, energy-efficient and environmentally friendly train systems. Any innovation in FA7 must fulfil the requirement of being an open platform built on common standards and standardised interfaces, connecting all transport modes and enabling the creation of disruptive operational and business models.

FIGURE 17. **Use case 'Living & Working'**

Source: Siemens.

The innovations should enable seamless operational and physical integration across different modes of transport. This is hereby proposed as one of the key elements for future mobility networks to deliver reliable and convenient passenger and freight transport, which remains the backbone of sustainable development in both urban and rural areas. It provides safe, sustainable, energy-efficient and affordable low-noise mobility options for everyone, day or night, ensuring accessibility and ease of use.

Maximum convenience through unique journeys and maximum reliability by using all available transportation modes with moving infrastructures are key advantages for passenger and freight transport brought forward by FA7 in a future where climate adaptation will be essential to establish a robust railway system. Further, the adoption of higher-speed technologies, such as maglev-derived and vacuum tube systems – either in conjunction with or in synergy with the railway infrastructure – can pave the way for upgrading the railway and mobility network. This will enable high-quality connections among cities and towns not only along high-speed railway corridors but also along current secondary lines, fostering the socioeconomic development and territorial integration of the areas concerned, with the aim of creating a single European mobility area. Such advancements will provide the foundation for a modal shift from private to public transport for passengers, and from road-based to multimodal transport for freight.

As a result, positive effects on the environment are expected, as the journey will be fully decarbonised, and a reduction in land usage can be reached through a more efficient exploitation of railway resources. By taking on the challenge of developing a new balanced, organised and well-thought-out transition, maximum efficiency can be reached within 8 to 10 years. An increased degree of automation in terminals, ports, logistic centres and parking facilities and at borders will contribute to more efficient freight handling, fewer operational errors, and reduced costs. The integration of railways with other modes of transport, along with the combination of passenger and freight traffic, will shape the future of mobility. For this to happen, a broader focus on other transport solutions (and their development), standardisation and implementation are included in a well-organised transition programme.

New approaches for guided transport modes – operating on disruptive modes like moving infrastructures, pods, magnetic levitation, air levitation, and vacuum tube systems – offer numerous advantages and can be an important, and possibly unavoidable, component of future mobility. However, as with most disruptive technologies, these innovations may also introduce potential gaps and associated risks that should be addressed in advance to ensure the system's effectiveness.

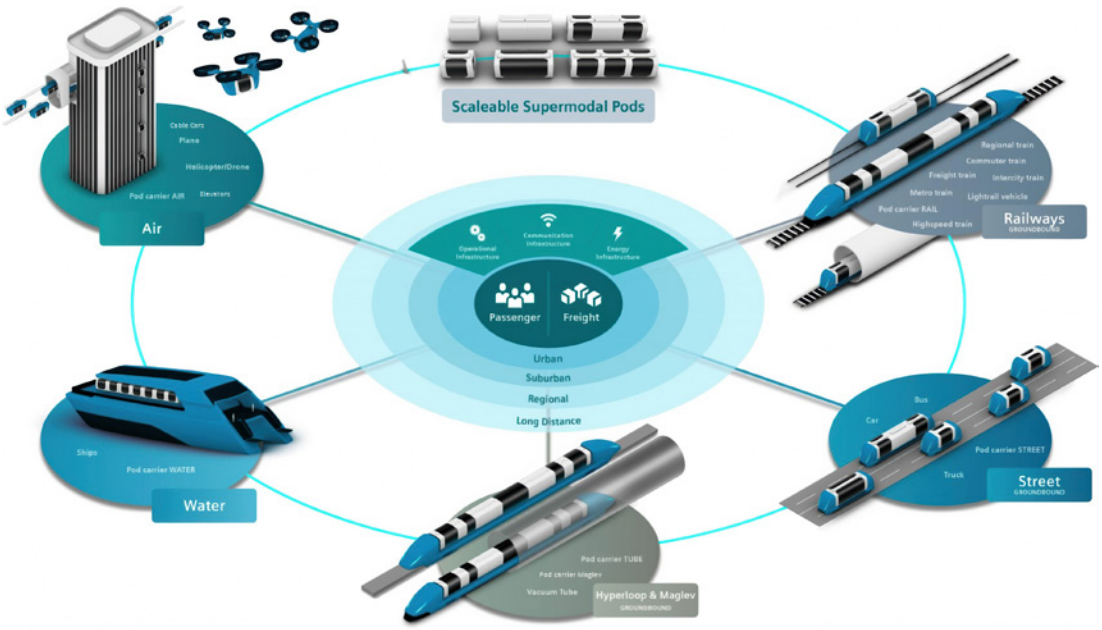
Firstly, achieving technological maturity is more challenging for such innovative systems compared to the evolution of existing ones. For example, although disruptive in their operational concept, pods as transportation units can reach a TRL up to 7/8 due to their adaptability to existing railway infrastructure. The same applies to maglev-derived systems. In contrast, vacuum tube vehicles – being the most disruptive technology – can be developed up to TRL 6. Regarding operations and traffic coordination of the innovations addressed in FA7, simulation tools will be essential for developing guidelines and evaluating performance, as the full systems will not yet be operational for real-world testing. Therefore, a TRL up to 5 can be anticipated in this area.

Additionally, in due time, migration plans must be established to ensure continued operations during transition periods. One of the main challenges lies in converting existing land use and infrastructure from today's modes and railway mobility to future solutions. A practical solution has to be found to create an implementable transition, as new techniques will be needed in the near future. These new techniques must, in one way or another, connect with the existing daily train operation system to enable the construction of sustainable intermodal transportation and robust transportation lines. Since these new forms of transport require significant infrastructure investments, initial demonstrators should preferably be implemented on a small scale – using an agile approach – to assess the PoC and overall feasibility of the solution.

Further, if this system is intended to be deployed across Europe as a sustainable and seamless means of transport for a connected EU, technological challenges emerging from cross-border transport must be addressed.

Secondly, as the technologies addressed in FA7 are rather disruptive, many gaps remain regarding the creation, establishment and consolidation of relevant legislation. A delicate balance needs to be found between allowing the technologies mature enough to define standards and regulations, and setting up a regulatory framework as soon as possible to ensure that developments comply with safety requirements and achieve maximum compatibility, interoperability and intermodality. Main aspects to be considered include safety and security, international travel – including issues such as border crossings and fees for infrastructure exploitation – legal frameworks for operations, interoperability and standardisation, and evaluation of conformity, including certification. For instance, pods are multipurpose elements that inherit risks associated with the regulatory status of autonomous vehicles, as illustrated in Figure 18. The EU's adoption of Addendum 78 to UN Regulation No 79, which concerns the development of autonomous vehicles, could serve as a catalyst for adapting legislation to technological synergies in this field ([30]).

FIGURE 18. **Concept for podimised multimodal mobility**



Source: Siemens.

The CEN and CENELEC (Comité Européen de Normalisation Électrotechnique [European Committee for Electrotechnical Standardisation]) Joint Technical Committee (CEN/CLC/JTC 20), dedicated to the standardisation of vacuum tube ('hyperloop') systems, has published its first set of standards. Also, a dedicated working group on safety was recently formed. However, many aspects regarding standardisation still need to be addressed. In addition, a first normative base or certification model can only be expected in the medium term, once the hyperloop system reaches a certain level of maturity. The cooperation between CEN/CLC/JTC 20 and the EU-Rail JU is robust, and all the progress made by the technical committee will be taken into consideration by the EU-Rail JU.

And thirdly, several difficult issues are linked to the sustainable construction of intermodal transportation and robust domestic or cross-border transportation lines. They include, for example:

- how to handle the many different domestic legislative and national processes involved in changing land-use or implementing infrastructure modifications within the European railway system;
- balancing the need for high-speed transportation, such as hyper-speed systems, with the requirements of local, regional, national or European societies;
- how transportation methods will adapt to the challenges posed by future climate changes.

([30]) UN Regulation No 79, Revision 3 – Agreement concerning the adoption of harmonized technical United Nations regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these United Nations regulations, Addendum 78, 14 September 2017.

7.7.1.2. Innovation beyond the state of the art, including the integration of S2R results

This FA builds on several references and results derived from S2R and EU R & I programmes.

Because of the technological openness in FA7, it is not possible to predict exactly which Shift2Rail results will be needed to enable a transition from the current state of the art to the desired goal. Nevertheless, there are some results from Shift2Rail, and from other projects outside Shift2Rail, which are likely to be used within the scope of FA7. These include, but are not limited to the following.

- Results from Shift2Rail:
  a. development and demonstration of energy-efficient drives, alternative energy supplies with batteries and fuel cells, etc.;
  b. development and demonstration of ATO, virtual coupling/platooning, etc., and integrated information systems for passenger services;
  c. In2Rail ([31]) – smart infrastructure, Intelligent Mobility Management (I2M), and power supply and energy management systems;
  d. X2Rail3 ([32]) and MOVINGRAIL ([33]) – virtual coupling;
  e. RAILS – Roadmaps for A.I. Integration in the Rail Sector ([34]) – AI approaches in the rail sector, and roadmaps for next-generation signalling systems, operational intelligence and network management;
  f. IMPACT-2 ([35]) – analysis of future needs, markets, trends and customer requirements, identification of key obstacles, development and assessment of trends and scenarios, and creation of system platform demonstrators.

- The emergence of enabling technologies, such as AI, the IoT, robotics, vehicle-to-vehicle and vehicle-to-infrastructure communications, autonomous driving and blockchain, will offer a wide range of opportunities for innovation in the rail system, transforming the way it operates. Success depends on the flexibility, practical implementation capacity and consistently high efficiency of the proposed key elements, while also integrating the development and deployment of other innovative vehicle combinations that pursue the same objectives in a complementary manner.
- Interdisciplinary projects, including the InSecTT – Intelligent secure trustable things project ([36]) (concerning IoT and AI), the i4trust project ([37]) (boosting innovative services around new data value chains in multiple sectors) and the SNCF Tech4Mobility innovation accelerator (concerning new collective and shared mobility solutions, with a focus on ultralight modular trains and door-to-door trains for sparsely populated areas).

([31]) Innovative intelligent rail (In2Rail, GA ID: 635900) (2015), accessed on 7 July 2020, www.in2rail.eu/.
([32]) Advanced signalling, automation and communication system (IP2 and IP5) – Prototyping the future by means of capacity increase, autonomy and flexible communication (X2Rail3, GA ID: 826141) (2018), https://projects.shift2rail.org/s2r_ip2_n.aspx?p=X2RAIL-3.
([33]) Moving block and virtual coupling next generations of rail signalling (MOVINGRAIL, GA ID: 826347) (2019), https://movingrail.eu/.
([34]) Roadmaps for AI Integration in the rail sector (Rails, GA ID: 881782) (2019), https://projects.shift2rail.org/s2r_ipx_n.aspx?p=S2R_RAILS.
([35]) Indicator monitoring for a new railway paradigm in seamlessly integrated cross modal transport chains – phase 2 (IMPACT-2, GA ID: 777513) (2017), https://projects.shift2rail.org/s2r_ipcc_n.aspx?p=IMPACT-2.
([36]) Bringing internet of things and artificial intelligence together (InSecTT – Intelligent secure trustable things, GA ID: 876038) (2019), https://www.insectt.eu/.
([37]) Incubator of Trusted B2B Data Sharing ecosystems of collaborating SMEs linked to Digital Innovation Hubs (i4Trust, GA ID: 951975), https://cordis.europa.eu/project/id/951975.

- Several concepts for small railway units, similar to the pods discussed in the SRIA's transforming project 8 'Non-traditional and emerging transport models and systems' ([38]), have been presented recently. These include separate pod carriers for different infrastructures, such as those designed by Siemens ([39]), Doppelmayr ([40]), A-Train ([41]) and the German Aerospace Centre (DLR) ([42]), and integrated solutions designed by the Max Bögl Group ([43]) or the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen University ([44]).
- The Hypernex project ([45]) is a key reference for vacuum tube technology. It provides an observatory to clarify roles across Europe, covering vehicles, infrastructure, energy supply and management, communications, levitation technology, and the minimum common understandings for hyperloops regarding intermodality, urban development, long-distance development and integration within existing infrastructures. Hypernex also compiles available technical information, which will allow the different scenarios that may arise during the startup phase of new transport technologies, including safety and operation considerations, to be analysed.

Furthermore, one major task in FA7 will be the continuous scouting of new potential solutions that can fulfil the objectives of the FA. A mechanism to ensure a structured scouting process should be organised for each FA7 project. These project-based mechanisms can be complemented by an overarching mechanism, such as a dedicated tender or working group within the Scientific Committee (SC).

7.7.1.3. System integration, interactions with System Pillar and with other Flagship Areas

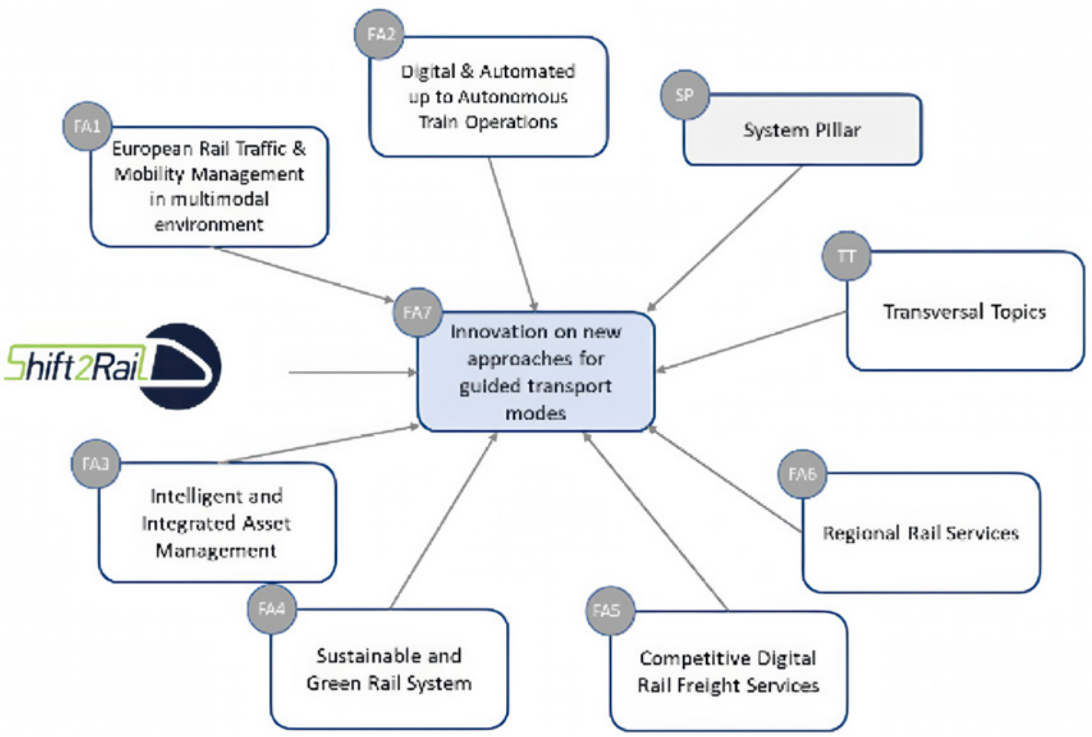
As FA7 is focused on innovative systems with lower TRLs, which means the interaction with other FAs is less intensive. Also, because of the openness of FA7, interactions with other FAs cannot yet be specifically identified. Nevertheless, there are certain topics where alignment between FA7 and other FAs is quite likely. Cooperation with FA1 will be necessary regarding the introduction of the specific capabilities of the innovative systems in the overall TMS. A close link with FA2 is also expected, as a number of technologies developed in FA2 will be used for solutions developed in FA7 and may require adaptions. For example, as long as the solutions targeted in FA7 operate on regular lines, they fall under the control of the DATO from FA2 – or, for high-speed solutions, both DATO and virtual coupling would need to be adapted. Additionally, to integrate FA7 solutions into a holistic mobility approach, continuous alignment with FA5 and FA6 will be required.

Naturally, there will be also a connection to the System Pillar (SP), which will define the requirements and architectures to be used in FA2, and consequently, for FA7 solutions as well.

However, the strongest connection of FA7 will be with the exploratory research. A direct link to the exploratory research must be ensured, so that recent developments or results from projects can be addressed as soon as possible.

([38]) ERRAC, *Rail Strategic Research and Innovation Agenda*, December 2020.
([39]) 'Disruption/conference "Future of multi-modal mobility: One4All pod system"', SIEMENS, https://www.youtube.com/watch?v=jDc5MSqI7JU&t=158s.
([40]) 'Doppelmayr/Garaventa Future concept urban (2021)', Doppelmayr, https://www.youtube.com/watch?v=bUKgkLSsAWI.
([41]) A-Train, http://www.railahead.nl.
([42]) 'Futuristic vehicle concept U-Shift', DLR, https://www.youtube.com/watch?v=ZJtopEtaGeU.
([43]) 'TSB – die Zukunft des Nahverkehrs' ['TSB – the future of public transport'], Max Bögel Group, https://www.youtube.com/watch?v=hwz2aaaSrvM.
([44]) Institut für Schienenfahrzeuge der RWTH Aachen, Artikel (rwth-aachen.de).
([45]) Ignition of the European hyperloop ecosystem (Hypernex, GA ID: 101015145) (2020), http://hypernex.industriales.upm.es.

FIGURE 19. **Interaction with other FAs, the TTs and the SP**



The details on the interaction between the SP and the Innovation Pillar are outlined in Annex A to the present MAWP, as a proposal from the SP based on the initial identified needs.

By the ramp-up phase of the relevant projects of the SP and the Innovation Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- As early as possible, the SP and each FA will review together Annex A to facilitate the ramp-up phase of the future activities.
- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the Single Basic Act (SBA) and master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to SP outputs, and vice versa.
- In accordance with the governance established in the SBA, the EU-Rail GB, based on the input from the SP Steering Group via the ED, with the support of the SIPB, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

Details of the exchange between the FAs can be found in Annex B.

The advanced solutions developed in FAs will ultimately be integrated to implement innovative operational processes at the rail system level. The availability of a digital representation of the rail system, with its constituent elements expressed as data, makes it possible to integrate FA results in a convincingly cohesive manner.

Therefore, the FAs generate a set of requirements and specifications of the data resources needed for:

- system integration,
- system interoperability,
- application processing within the FA.

These data resource specifications are developed in accordance with guidelines established by the SP at the overall rail system architecture level, and by TT in terms of:

- the Conceptual data model,
- the reuse of common foundation libraries of digital models,
- cybersecurity provisions.

The common tooling developed by TT on the basis of these specifications will be used by FA solutions for automated discovery and access to the digital resources, with the appropriate data access policies safeguarding the interests of the data owner.

7.7.1.4. Who does what by stakeholder group

The roles of the **IMs and RUs** with regard to R & I are as follows:

- developing understanding and relations between solutions and performed operations for new mobility solutions;
- providing information related to the required infrastructure and a virtual test bench for the feasibility of proposed solutions;
- developing business models predicting the technical/economic feasibility of new mobility solutions, evaluating the sustainability of the initiative;
- exploring future functional requirements and operational models of new mobility solutions under development by the market and helping with the collection of requirements and demonstration of results, carrying out safety analyses for authorising bodies where possible, and testing the developed products
- analysing interoperability as a service to ensure the continuity of services for passengers and freight, maximising intermodal connections with other transportation systems, such as planes, cars, local public transportation, and other freight and delivery services.

Suppliers contribute to research and development in the following ways:

- researching and developing relevant hardware and software components;
- designing, constructing and producing necessary prototypes;
- equipping the test modules with the necessary equipment.

The following may be relevant for all parties involved, including **research institutions**:

- participating in studies in the field of feasibility, profitability, technology and standardisation, etc. (e.g. identification of the technical and regulatory aspects to be standardised for a fully automated moving infrastructure, and the preparation of initial concepts for their standardisation process);
- developing a viable and risk-free transition strategy;
- defining scenario simulations (e.g. of transport coordination systems);
- defining and compiling safety and test specifications

- standardising technical and regulatory aspects, including the approval process;
- defining test sites, test procedures and test set-up design and implementation;
- active involvement in and securing of the relevant test sites;
- training of the relevant personnel carrying out the tests;
- compiling the test results and reports;
- evaluating impacts on assets, investments, operations, the normative/regulatory framework and on the organisation and processes of the railway system, based on technical results obtained from tests;
- involving relevant stakeholders – particularly from national/regional/local institutions – to disseminate the technical evolution of mobility solutions and jointly evaluate the potential implementation of the most innovative and mature solutions, along with related migration plans and the assessment of socioeconomic impacts and economic development induced by the introduction of new technologies in the region.

7.7.1.5. Interaction with other programmes, European and/or national

As already described in Section 7.7.1.2, several national and European projects and programmes are linked to the objectives of FA7. All described test tracks and labs are available or planned to be made available for projects under the EU-Rail JU. Some major programmes identified in Europe include the following.

- Over the next few years (2022–2029), Spain plans to promote the construction of a vacuum-levitated hyper-speed test track at a reduced scale of 1:2. The length of this test track will be around 4–5 km and it is expected to reach a speed of 600 km/h ([46]). The ADIF/Cedex hyperloop test track is planned to be made available to the EU-Rail JU for testing auxiliary vacuum tube train systems developed by EU-Rail JU partners.
- The Norwegian hyperloop test site will be implemented in Trondheim, Norway. The length of the test track is 140 meters. It can be used to test vehicles and various environmental materials, such as aluminium. It will be made available to other projects as well.
- Air levitation carrier ([47]) (A-train) scaled and tested in laboratories at Dutch technical universities. Floating on pressurised air and running on existing infrastructure with extra concrete plates between the rails and on the existing concrete sleepers makes it possible to achieve high-speed train connections. A full-scale demonstrator carrier is proposed by the Netherlands, to be built at Railcenter in Amersfoort, the Netherlands. This test field will be available as an open platform to all EU-Rail JU parties.
- Dutch pod designs combining freight (e.g. super express postal packages delivered within a few hours) and passengers within currently operating passenger trains. Turboplan2030 investigates using seats and passenger space – which are mostly not occupied throughout the whole day – for freight pod transport ([48]).
- The Italian railway test circuit, Bologna San Donato, and related assets. Full-scale tests (in stages/phases) of upgrades to existing railway infrastructures with maglev-derived technologies are made possible on this circuit.
- The Siemens Test Ring Wegberg-Wildenrath contains 28 km of test tracks in two loops and three test tracks, and is open to innovative test projects such as the Cargomover initiative or FlexCargoRail.
- The German test site 'Digital Rail Living Lab' in Saxonia is also open to innovative projects, as demonstrated by past remote-control and hybrid level 2 tests.

([46]) National Spanish Hyperloop program
([47]) www.youtube.com/watch?v=0zNxBxFD7K4
([48]) https://mission-innovations.com.

- Hyperloop Development Program ([49]) is a public–private partnership in the Netherlands. It is an open platform (e.g. Hardt Hyperloop is involved). The first phase began in 2022 in Groningen, the Netherlands.
- In October 2021, the European Innovation Council awarded Hardt Hyperloop ([50]) EUR 15 million as Brussels' first-ever hyperloop investment package, based on the Dutch Hyperloop Development Program. The funding from the European Innovation Council will accelerate the development of a fast and cost-effective, pan-European, emission-free hyperloop network to supplement cars, trains and planes, and decarbonise mobility. It also enables the realisation of the European Hyperloop Center, which carried out its first test in 2024. Public sector leadership is essential for the hyperloop to become a reality. This endorsement from the European Commission is a great acknowledgment for the hyperloop as a sustainable alternative for transportation, and will significantly accelerate securing additional backing and support from local and national governments across Europe and beyond.
- Land bridges dimensioned for speeds up to 435 km/h using prefabricated elements are being developed in Sweden ([51]).

7.7.2. Results/Outcomes

Because of the openness of FA7, detailed targeted results for the whole area cannot be given. A detailed description of results and outcomes should be included in every proposal answering to project calls of FA7. Nevertheless, a couple of broader aspects will be described, and examples for certain possible solutions to be targeted in FA7 can be found in Section 7.7.4.

7.7.2.1. Operational solutions outcome

As described in Section 7.7.1.1, even though FA7 should maintain openness with regard to the innovations developed, solutions for more flexibility through multimodality, and solutions for energy-efficient high-speed rail systems and guided systems are anticipated to be the main focus points.

Those could be reached through moving infrastructures, pods, magnetic levitation, air levitation, and vacuum tube systems, but also through other solutions that the rail sector might not yet be aware of. As these solutions vary widely in their technical implementation, no general assertions about their operational outcomes can be made.

7.7.2.2. Technical enablers: capabilities to achieve the targeted operational outcomes

Depending on the targeted solution, required capabilities and TEs can vary greatly. As described in Section 7.7.1.2, there are certain enablers that are more likely to be used by FA7 innovations, for example, autonomous train operation, virtual coupling and AI.

Also, as explained in Section 7.7.1.1, the TRL reachable within the programme's time frame will highly depend on the targeted innovation, its degree of independence from the existing railway services, and developments of the same concept outside the EU-Rail JU.

([49]) https://hyperloopdevelopmentprogram.com.
([50]) https://www.hardt.global/.
([51]) Trafikverket, 'Rambroar – ett koncept för industriell byggd landbro och längrebroar' ['Viaduct – a concept for industrially built land bridges and longer bridges'], TRV 2021/122214, 27 October 2021.

Thus, for FA7, close cooperation with other rail-related programmes and with programmes outside the rail sector (e.g. the IT or aeronautic sectors) will be key to its success.

7.7.2.3. Demonstration implementations

Throughout the duration of EU-Rail JU, complete demos or demos in collaboration with other projects/programmes (e.g. at the national level, providing test sites, infrastructure and vehicles) will be carried out depending on available resources. Particular attention should be given to demonstrations targeting issues of interoperability and those that offer advantages through EU-cooperation in comparison to national activities.

7.7.3. Impacts

A thorough analysis of the impacts should be included in every proposal submitted in response to FA7 project calls. Because of the openness of FA7, a detailed impact description for the whole area is not feasible. Nevertheless, some broader aspects will be described and examples for certain potential solutions to be targeted in FA7 can be found in Section 7.7.4.

7.7.3.1. Description of the impacts on existing rail services

Depending on the innovation regarding new approaches for guided transport modes targeted in FA7, both integration into existing rail services and infrastructure and the construction of new infrastructure to either supplement or substitute existing rail offers are possible. However, to advance guided transport modes there is a fundamental need for a smooth transition strategy.

When using existing infrastructure, implementation is feasible only if modifications are kept to a minimum and supported by standardisation, regulation and cross-mode integration. A full system approach to fit in the train mobility must be a fact to be successful.

In either case, it is especially important for the FA7 innovations to maintain a strong focus on shifting transport to rail. Developing new guided transport modes that simply cannibalise the existing rail services should be avoided.

7.7.3.2. Quantitative KPIs demonstrated in this FA

As the blue-sky FA in the EU-RAIL JU, FA7 has a broader scope and is particularly focused on technological openness and the interoperability of new approaches for guided transport modes within Europe. As described in Section 7.7.2.2, FA7 will focus more on bringing different technologies that were developed in other programmes (including other FAs of the EU-Rail JU) to form new guided transport modes than on targeting the development of new components. Thus, KPIs for FA7 can only be focused on the performance of the ensemble of the final system. As FA7 is aimed at developing several promising or interesting approaches, rather than bringing a single technology to a high TRL, defining quantitative KPIs for FA7 would be misleading and hinder technological openness. Studies to further understand the impact of different concepts on relevant KPIs should be included in FA7's projects.

7.7.3.3. Exploitation, deployment and migration considerations

Generally, considerations for deploying FA7's innovative solutions include adapting the current framework, for example, regarding regulations, standardisation, climate change adaptation, long time frames for land-use planning and inventory of relationships where the technology is profitable and can be introduced.

These considerations will provide a future-oriented approach for introducing innovative solutions that support the EU Green Deal.

7.7.4. Potential research fields in FA7: Innovation on new approaches for guided transport modes

In principle, many innovations may fall within the scope of FA7. Three notable examples are described below: automated multimodal mobility systems using moving infrastructure to transport multimodal pods; maglev-derived transport systems combining track-bound transport systems with elements of maglev technology; and unconventional fast track-bound transport systems, such as vacuum tube systems.

7.7.4.1. Automated Multi-Modal Mobility-System

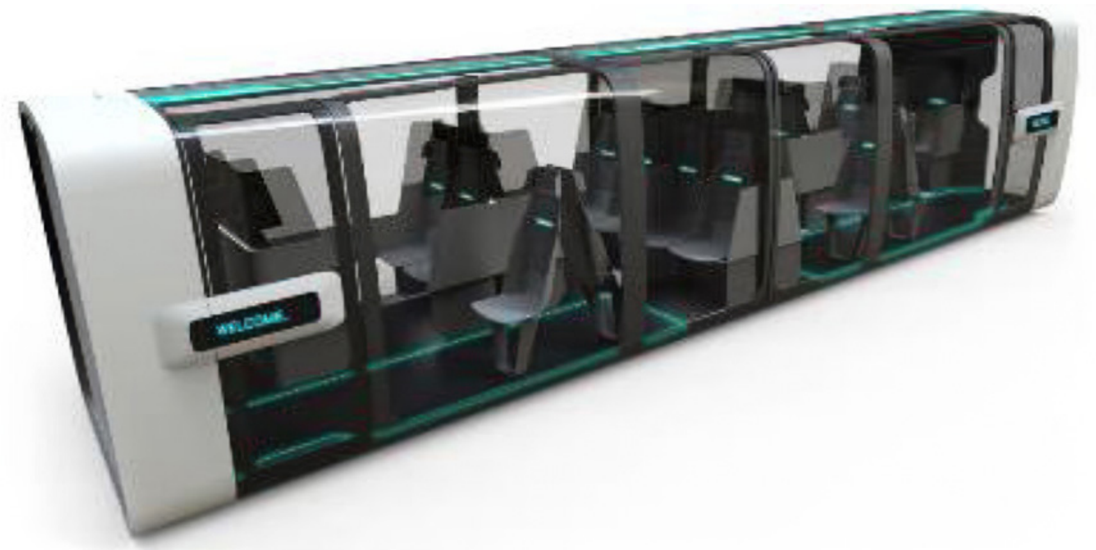
7.7.5. Results/Outcomes

7.7.5.1. Operational solutions outcome

The essential element is the transport of people and goods from door to door without changing the 'transport vessel' (hereinafter referred to as a pod), achieved through the use of standardised pods tailored to the different needs of the passengers or goods being transported. Pods are transported on standardised pod carriers.

The pods have standardised main dimensions and mechanical and, if applicable, electrical interfaces. Depending on the application, pods are designed for the transport of people and/or goods and have all the necessary facilities. For passenger transport, in addition to appropriate flexible interior equipment, there are also facilities for communication and passenger information, ticket recognition and/or autonomous payment systems, HVAC, safety and emergency systems, diagnostic equipment and autonomous repair processes (see Figures 20 and 21). The pod will also provide the capability for long-distance travel during the night. For freight services, the pods can be understood as innovative containerised solutions.

FIGURE 20. **Use case 'Podimised Passenger Transport' outside view**



Source: Siemens.

FIGURE 21. **Use case 'Podimised Passenger Transport' inside view**

Source: Siemens.

The pod carrier itself is the 'moving infrastructure'. The pod carrier contains all the functionalities that are necessary for transport on existing rail networks, such as running gear, energy supply and drive units, devices for autonomous driving (sensor technology, communication technology, vehicle control, etc.), braking devices, and global and local transport coordination. All of this is also adapted to all climate and adverse weather conditions (e. g. winter). The pod carrier should be able to carry out completely autonomous operations on the rail network with low noise emissions and the ability to communicate with the latest railway safety systems, in order to allow mixed operation if necessary.

The outcome of this system is a completely autonomous operation, ensured by the facilities on the pod carriers, and their communication with each other, with any available infrastructure-side devices (for example, to secure road crossings rail traffic), with the pods as well as with the necessary systems for the disposition of the pod carrier and/or monitoring of the pod carriers, since all operational logic would be located on board.

FIGURE 22. **Mock-up of intermodal passenger and freight pods**

Source: DLR.

The 'transport vessel' pod can quickly switch from a pod carrier (for example, on roads or cable cars) to another via a reloading device which is to be developed (see Figure 22). Consequently, stations and mobility hubs will require adaptations to accommodate the continuous loading and unloading of pods on and from pod carriers, and new concepts will need to be designed and developed. Standardised interfaces should thereby ensure the mechanical securing of the pods on the pod carrier, along with any necessary connections for power supply, communication technology, etc.

In order to implement a transport chain from door to door, similar vehicles are also available for transporting the pods, such as those used on roads (example in Figure 23), cable cars or water transport. Similar development activities are to be coordinated in cooperation with related transport organisations and industries.

FIGURE 23. **Intermodal passenger pod with road pod carrier**

Source: DLR.

The objective here is to produce flexible and performant operational models. Flexibility is necessary in order to provide a highly adaptive response to time-varying operational scenarios throughout the entire service period. The idea is to avoid predetermined fixed operational scenarios and to ensure compatibility with a pseudo on-demand service. The transport of freight should also be addressed and integrated into the overall system. Currently, passenger trains have significant unused capacity, especially outside rush hours. During off-peak times, capacity utilisation is low or very low, resulting in what can be described as 'almost only warm air' being transported by passenger trains (e.g. during the COVID-19 period). Hence, by providing tailor-made transport solutions, efficiency can be improved, making the system economically superior to other transport modes.

Another objective is to propose a scalable and modular system structure that aligns as close as possible with user needs while minimising resource allocation by providing small autonomous units which can be combined into virtual trains if needed. This is particularly essential on secondary lines, where it is crucial to challenge existing operation models which are not demand-oriented enough for low-demand periods. For rolling stock, this is achieved through a disruptive change of scale to the smallest units, and the same approach should also be applied to the supervision system.

Furthermore, alternative multimodal concepts could be developed, such as seamless travel on existing rail tracks or loading and unloading on trains as moving infrastructures. This FA will maintain a continuous effort to identify promising multimodal concepts to assess whether they can achieve the objectives more efficiently in terms of time and cost.

7.7.5.2. Description of the required capabilities and technical enablers

The introduction and operation of moving infrastructures or pod carriers within a multimodal mobility system involving arbitrary vendors requires the integration of existing and additional infrastructure, rolling stock, service providers, stations, yards, platforms, etc. To achieve this open standardised platform and interface concept, along with standardised development, testing and certification processes and platforms are essential.

The following challenges must be addressed within the context of enablers.

- Interfaces between moving infrastructures and technical open concepts for pods and pod carriers, and the full array of operational aspects.
- Different operating modes should be supported, allowing flexibility in use – such as during off-peak hours and the cohabitation of passengers and freight – with varying speeds and standardised dimensions for pods and pod carriers, whether for passengers or freight.
- Pod carriers should be developed for operation across main lines, secondary lines, tramways and both existing and emerging rail system infrastructures, while meeting all relevant conditions and safety requirements.
- Sensing, operations, control and communication systems, and monitoring technologies are required to enable fully autonomous driving in the near future. Additionally, the transition and migration to this next phase must be carefully managed.

Besides the capabilities directly enabling operational objectives, displayed in Table 46, several preparatory related tasks need to be carried out, including the following.

- Studies to examine existing transport systems, their interfaces, legal frameworks, transitions, etc., both within the respective transport system and between different transport systems. These studies will serve as a basis for further work and for creating methods to evaluate appropriate solutions.
- Inventory and evaluation of communication systems, which play an important role in direct communication between modules and also between modules and residual trackside components.
- Definition and development of interfaces with other modes.

- Obtaining developments concerning virtual coupling and autonomous driving should be operational as a technical key to bring the targeted operational flexibility.
- Investigation of loading and unloading technologies and facilities, alongside necessary adaptations to stations and mobility hubs to support automatic and seamless loading and unloading of pods on and from pod carriers.

An estimation of the TRL of the capabilities for 2025, 2027 and 2031 is provided in Table 46.

TABLE 46. **Estimation of the TRL of the capabilities for 2025, 2027 and 2031**

Capabilities enabling operational objectives	TRL in 2025	TRL in 2027	TRL in 2031
Development of Coupling System for connecting pod carriers to pods	2 – 3	3 – 4	
Development of loading and unloading technologies	2 – 3	3 – 4	
Development of pod carrier	2 – 3	3 – 4	
Development of pod and capsule	2	3 – 4	
Development of a fully automated multimodal mobility system	2	3 – 4	5
Prototype of an autonomous pod and pod carrier in a test environment, including loading and unloading			5

Analogously, in the case of interoperable pods with integrated pod carriers capable of operating on both roads and railway lines, or being loaded and unloaded on trains as moving infrastructures, the corresponding vehicles, infrastructures (including stations/hubs and switches) and interface technologies (e.g. CCS systems and/or TLC systems) must be identified in order to guarantee the safe and seamless access of the vehicles to the network.

A constant screening of the latest developments should be established to ensure the goals of interoperability and technological openness are met, while avoiding the duplication of development efforts.

7.7.5.3. Demonstration implementations

The demonstration of the system should expediently take place in several independent steps:

- demonstration of the functionality of the standardised interfaces for transfer devices and the coupling system between pod and pod carrier in a dedicated test site area;
- demonstration of the functionality of the coupling system between pod and pod carrier and cable cars in a dedicated cable car test area;
- demonstration of prototypes addressing key aspects of a fully automated multimodal mobility system in a virtual environment or simulation;
- demonstration of the transport coordination system in a virtual environment or simulation;
- demonstration of a prototype of an autonomous pod and pod carrier within a defined test area (e.g. test and validation centres in Germany or Czechia);
- demonstration of a prototype of a fully automated multimodal mobility system implementing standardised hardware and software concepts within a defined test and automation environment;
- first trial run on a selected branch line for freight traffic with a change of transport modes transport between rail and road;

- first trial run on a selected branch line for passenger traffic with a change of transport modes between rail and road.

7.7.6. Impacts

7.7.6.1. Description of the impacts on existing rail services

TABLE 47. **Descriptions of FA7 impacts in relation to the intended impacts laid out in the master plan**

	More flexibility and punctuality for passengers and freight The guided pod system will enable a more flexible and demand-oriented service for passengers, reduce transfers during trips and improve the overall economic efficiency of the system by operating trains only when needed, particularly on regional lines with low demand. This will instil a sense of security in users: 'When I need a pod, one will come and pick me up'.
	Reinforced role for rail in European transport and mobility If the development of the goals outlined in the R & I project has been successfully completed, a variety of positive effects are imaginable, but because the *Pod* solution is rather disruptive, predictions of positive effects are rather vague. Nevertheless, promising positive effects include improved service availability and quality through increased transport flexibility and higher degree of interlinking of the modes of transport which leads to a greater traveller satisfaction altogether.

7.7.6.2. Quantitative KPIs

To be defined based on the specific objectives of each project.

7.7.6.3. Exploitation, deployment and migration considerations

The aspects of the Automated Multi-Modal Mobility System described in Section 7.7.2.1 offers a multitude of potential use cases that can create new opportunities for rail, allowing for gradual integration into an existing railway system and implementation in cooperation with other transport modes.

Primarily, an initial introduction of the system is advisable when reactivating and continuing to use branch lines to revitalise and upgrade transport in rural areas through fully autonomous operation. Additionally, the proposed solution should be made more readily available by improving its economic viability, providing continuous door-to-door connections and extending mobility beyond railway infrastructure, even in remote regions, in conjunction with road traffic or cable cars. The transport of freight could also be addressed using dedicated pods. This first step with dedicated railway routes will make the deployment easier.

Another opportunity for applying the R & I results is the integration of such a system into inner-city public transport for cities and municipalities with challenging terrain. Systems could be implemented that combine aspects of tram, bus, shipping or cable car services, offering users greater comfort and door-to-door solutions.

In both scenarios, the necessary technology must be integrated into the railway lines and the corresponding logistics systems (booking, use, payment, route planning, disposition, depot, maintenance, etc.) to ensure safe, fully autonomous operation, along with the installation of the reloading technologies required for transfers from one type of transport to another at designated points.

Subsequently, mixed operations on main lines, combining conventional trains and autonomous systems, along with the introduction of the corresponding required technologies, can be implemented. Feeder routes connecting larger junctions and branch lines represent ideal candidates for this phase.

In any case, legal requirements for autonomous operation and for modal intersections – addressing the overlapping regulations specific to each transport mode – must be established to ensure legal certainty. Additionally, the normative and regulatory standards necessary for system approval must be met.

Last but not least, necessary adaptations to existing railway stations must be taken into account.

7.8. Maglev-derived transport systems

7.8.1. Results/Outcomes

7.8.1.1. Operational solutions outcome

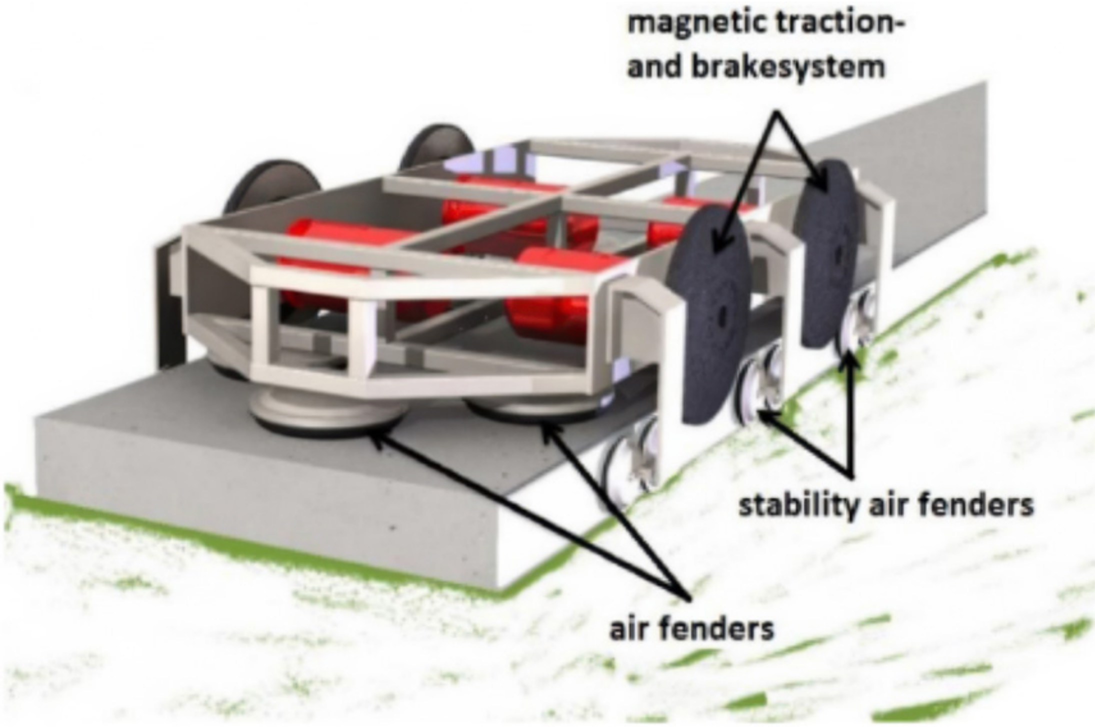
Maglev-derived transport systems refer to systems that use conventional rail systems in combination with technologies derived from stand-alone maglev transport systems, such as the Transrapid maglev train in Germany. These systems could use normal rails combined with either an additional maglev rail or with another kind of guiding track, as shown in Figure 24. They share the basic principles of conventional rail systems but provide enhanced performance in certain domains (e.g. higher speed or acceleration, reduced (power system) noise emissions, reduced energy consumption and CO_2 emissions). Another example can be seen in Figure 24. Since these systems share the same conceptual principles as rail, their development should be conducted within a railway program.

FIGURE 24. **Example of a magnetic or pressurised air levitation system.**

Source: A-train.

Having the ability to move passengers and freight very quickly can be of great interest in the context of future mobility within Europe, especially in a combined and integrated system that could provide new mobility solutions. This expands the application of such systems in future. More specifically, they could be seen as a tool to upgrade the performance of conventional railways in both freight and passenger domains – especially on regional and secondary lines – and/or as a low-emission alternative to high-speed transport modes, such as continental aviation (which is obliged to find ways to reduce emissions). This transport system is anticipated to outperform aviation in terms of comfort and environmental friendliness while being economical and at least as attractive. Maglev-derived transport systems, combined with existing high-speed and conventional rail, could provide the backbone of a fully green European transport system in the future.

FIGURE 25. **Schematic concept of a bogie from the A-train project**



The aim of FA7 is to evaluate the technical feasibility and effectiveness (from the perspective of safety, economic viability and performance) of the introduction of these new transport systems in Europe, along with the systems and technology needed to implement them (infrastructure, signalling, communications, etc). There are other examples on other continents that can provide useful information for carrying out feasibility analyses.

One important first step must be the development of a business case, taking into account the needs and requirements of the end customers and stakeholders involved. The pros and cons of the approach will then be highlighted, along with the business model to be adopted.

Another step is to identify and draft the system requirements. Following the definition of the SRS, the process for the realisation of the entire system will be described, and stakeholder interests will be investigated accordingly.

Following these initial steps, the FA will deliver the following main outcomes:

- build a system architecture;
- create appropriate testing environments;
- define and develop technical solutions for sensing, communications, safety and integrated data processing;
- define SRS;
- develop a socio-economic assessment to explore where transportation lines with maglev-derived transport systems generate socioeconomic value and where results could be established with on-site validation/testing;
- draft business cases;
- identify needs for standardisation, safety and security legislation, and interoperability;
- identify needs for testing infrastructures;

- identify specific technologies and subsystems derived from maglev-derived transport systems that could be reintroduced into the railway system, offering benefits in the form of increased performance and reduced operational costs and impacts;
- identify technical solutions and their costs;
- produce feasibility studies and use cases;
- conduct reduced-scale and/or full-scale testing in relevant or operational environments, which can only be done by leveraging infrastructures, test sites and assets made available outside the EU-Rail JU, such as those proposed in Section 7.7.1.5, for which the EU-Rail JU can provide additional resources to support further development through the implementation of innovative technologies and systems.

7.8.1.2. Description of the required capabilities and technical enablers

Maglev-derived transport systems further develop the existing stand-alone maglev system by adopting a 'best of both worlds' approach, integrating state-of-the-art railway technology. In combination with traditional railway systems, magnetic levitation approaches can be used as an overlay, for example, in limited sections of track or as a new independent system in isolated areas. The first step is to identify suitable use cases and conduct their economic assessment.

By nature, the main focus of this area is on maglev technology and the interaction between the vehicle and infrastructure. On the vehicle side, the emphasis is on dimensioning and adapting the maglev components, including their interaction with conventional propulsion, braking and suspension systems. Power supply availability will also influence operation, including in degraded scenarios. On the infrastructure side, the scope includes the design, specification, demonstration, testing and validation of necessary technologies to advance development towards commercial maturity. Furthermore, these new systems may sometimes require new infrastructure, while in other cases they can coexist with traditional railway systems by sharing infrastructure. Reusing existing infrastructure and civil structures like bridges and tunnels would reduce costs and time spent on the construction of new infrastructure. In addition, guidelines and traffic coordination concepts will be established to facilitate the application of such technologies.

Another important area is compatibility with CCS and communication systems, safety equipment and automation systems – including sensors, communication, data processing, etc. – to ensure safe, efficient operation and cost-effective maintenance. Virtual coupling and autonomous driving will be key technologies to achieve the desired operational flexibility. Given that maglev-related technologies use strong magnetic fields, special attention must be given to electromagnetic compatibility, for example with ERTMS, which must be validated through extensive testing under normal and degraded conditions. Traffic coordination concepts are also an important enabler for realising the activities in this area.

A collaboration is expected to be established with other areas of FA7 automated multimodal mobility systems and unconventional fast track-bound transport systems, and with other transport programmes and initiatives leveraging test sites and assets built outside the EU-Rail JU, such as those proposed in Section 7.7.1.5, for which the EU-Rail JU can provide resources to support further development through the implementation of innovative technologies and systems.

An estimation of the TRL of the capabilities for 2025, 2027 and 2031 is provided in Table 48.

TABLE 48. **Estimation of the TRL of the capabilities for 2025, 2027 and 2031**

Capabilities enabling operational objectives	TRL in 2025	TRL in 2027	TRL in 2031
Command, control and communication systems, safety equipment and automation systems	2 – 3	4 – 5	6-7
Full-scale fully automated maglev-derived system	2 – 3	4 – 5	6-7

The developments in this area are expected to be aligned with the work done in complementary initiatives, and could be tested in the facilities mentioned in Section 7.7.1.5.

A constant screening of the latest developments should be established so that the goals of interoperability, technological openness and not duplication development work are ensured.

7.8.1.3. Demonstration implementations

Demonstrations will address operability aspects and challenging topology across Europe to show and assess the full impact of maglev-derived transport systems. The demonstration of maglev-derived transport systems should proceed expediently through several independent steps:

demonstration of the technical, regulatory and safety-related aspects to be standardised for a maglev-derived system, at least within a virtual test environment;

demonstration of the integration of technical solutions for systems, components, sensing, communications, safety and integrated data processing, along with validation of the whole system at scale and within a relevant environment;

demonstration of a prototype maglev-derived system and validation of the full-scale system within a relevant or operational test environment.

Another possible scenario for a demo could take place on unused railway assets or on a railway test track/ring. For example, a demo of maglev-derived systems could be carried out on a secondary line or on a test track/ring that is adequately equipped for maglev-derived technologies, in terms of both infrastructure and vehicle requirements, to assess compatibility with the existing underlying railway system. Since the basic technologies for maglev-derived applications are already available at various stages of development, the demo will be the chance to test them, along with the TEs (in particular switches), in a full-scale and systemic application within a relevant environment.

7.8.2. Impacts

7.8.2.1. Description of the impacts on existing rail services

TABLE 49. **Descriptions of FA7 "Maglev-derived transport systems " impacts related to the intended impacts in the master plan**

	Improved performance and capacity Thanks to the maglev systems, both capacity and performance on existing lines – such as acceleration under challenging conditions – could be increased by operating with more trains on a given line, shorter headways or better overall performance. As a result, this would enable higher traffic volumes and improved operational reliability on these lines. Improved vehicle dynamics during acceleration and deceleration, higher speeds and reduced travel times. For freight services, maglev technology enables the use of lines with steeper inclines, providing access to more routes. Levitating pods with comparable performance when carrying both freight and passengers could also enhance operations, maximising capacity utilisation and improving the overall efficiency of the transportation system.
	Reinforced role for rail in European transport and mobility The most promising positive effect is reduced travel time and increased system performance, which not only enhances customer satisfaction in both passenger and freight transport but also boosts competitiveness against air and road transport, resulting in a positive modal shift towards rail.
	More sustainable and resilient transport Maglev-derived transport systems will help reduce environmental impact as they are fully electric and reduce traction system (or its cooling) noise emissions. They also enable greater use of existing infrastructure, thereby avoiding the need to build new tracks or lines.

7.8.2.2. Quantitative KPIs

To be defined based on the objectives of the specific projects.

7.8.2.3. Exploitation, deployment and migration considerations

As related to the *maglev-derived transport systems* deployment, there are still many details to be developed. The main point is the identification of suitable locations and applications as well as the related matching solutions. The technical performance of these demonstrators will help address the uncertainties related to the challenges of these transport technologies. Additionally, these test sites will provide more accurate data on the current and actual costs of the infrastructure and all associated subsystems.

Determining these costs is essential for developing a business model based on real data rather than on insufficiently substantiated hypotheses. This business model should consider not only the associated cost but also the positive effects on the underlying conventional rail system, such as reduced investment requirements for increased performance.

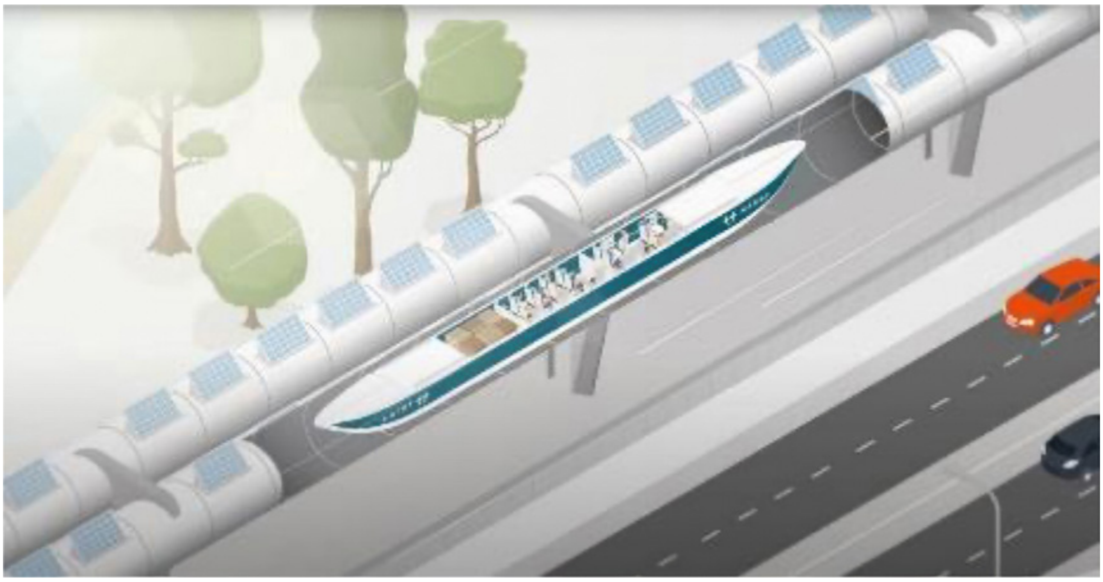
7.9. Unconventional fast track-bound transport systems

7.9.1. Results/Outcomes

7.9.1.1. Operational solutions outcome

Unconventional fast track-bound transport systems refer to a mode of land transportation capable of high-speed and driverless operations for passengers and freight, in which a vehicle is guided along a fast track. It shares the basic principles of conventional rail systems but provides enhanced performance in certain domains (e.g. higher speed, reduced noise emissions, reduced energy consumption and CO_2 emissions). Since these systems share the same conceptual principles as rail, their development should be conducted within a railway program.

FIGURE 26. **Hyperloop concept by Hardt Hyperloop**



Source: Hardt Hyperloop.

FIGURE 27. **The hyperloop test track in Castilla la Mancha (Spain) will be built at a 1:2 scale**

Source: CED.

Having the ability to move passengers and freight very quickly can be of great interest in the context of future mobility within Europe, especially in a combined and integrated system that could provide new mobility solutions. This expands the application of such systems in future. More specifically they could be seen as an alternative to high-speed transport modes such as continental aviation (obliged to find a way of reducing the level of emissions) to eliminate CO_2 emissions in very high-speed transport modes. This transport system is foreseen to outperform aviation in regards to comfort and environmental friendliness while being economical at least as attractive. Unconventional fast track-bound transport systems, combined with existing high-speed and conventional rail, could provide a fully green European transport system in the future.

The aim of FA7 is to evaluate the technical feasibility as well effectiveness (under the safety, economic and performance related perspective) of the introduction of these new transport systems in Europe and the systems and technology needed for their implementation (infrastructure, signalling, communications, etc). There are other examples on other continents that can provide useful information for carrying out the feasibility analysis.

One step must be the development of a business case, considering the needs and requirements of the end customers as well as and the involved stakeholders involved. The pros and cons of the approach will then be highlighted together with a business model to be adopted.

Another step is to identify and draft the system requirements. Following the definition of the SRS, the process for the realisation of the entire system will be described and therefore interests on the part of the stakeholders will be investigated.

Following these two initial steps, the FA will deliver the following main outcomes:

- Define a common System Architecture
- Define System Requirement Specification
- Develop Socio-economic assessment in order to explore where transportationlines with *unconventional fast track-bound transport systems* generate socioeconomic value and where results could be established with a on-site validation / testing can be carried out

- Draft Business Cases
- Identify needs of standardisation, safety and security legislation, interoperability
- Identify needs of testing infrastructures
- Identify potentially, specific technologies and subsystems derived for *unconventional fast track-bound transport systems* that could be imported back into the railway system itself, with benefits in terms of increased performance and reduction of costs and impacts related to operations.
- Collect Technical solution and their cost
- Produce feasibility studies and use cases
- Run full-scale testing at least in relevant environment (this can only be made by leveraging infrastructures, test sites and assets built outside the EU Rail JU, such as those proposed in 7.7.1.5, for which EU Rail JU can provide resources for further development through implementation of innovative technologies and systems)

7.9.1.2. Description of the required capabilities and TEs

New high-speed transport systems (passenger and cargo) are emerging due to the adoption of (passive/active) magnetic and air levitation technologies. Equivalent to traditional railway systems, magnetic levitation or air levitation approaches (e.g. hyperloop) can involve three areas of innovation, each with corresponding TEs.

- The vehicle/pod/capsule (hereinafter referred to as a capsule) refers to the structure comprising the aerodynamic fuselage, a flexible and comfortable interior for passenger or freight transport, and the power supply system. Although the construction of the capsule lies outside the scope of this FA, collaboration is expected with other unconventional fast track-bound transport programmes and initiatives (see Section 7.7.1.5) in which the capsule is or will be built.

The focus of this FA is on the interaction between the capsule and the infrastructure.

- The infrastructure includes the support and guidance structures through which the capsules move, along with the systems needed for levitation and propulsion, switches, and – for the vacuum tube approach – the tube itself, pressure maintenance systems, etc. This also encompasses necessary climate adaptations of the tube and other infrastructures to ensure a robust mode of transportation. As with the capsule, the construction of the infrastructure, levitation and propulsion systems for commercial lines lies outside of the scope of this FA. Collaboration is expected to be established with other unconventional fast track-bound transport programmes and initiatives leveraging test sites and assets built outside the EU-Rail JU, such as those proposed in Section 7.7.1.5, for which the EU-Rail JU can provide resources for further development through the implementation of innovative technologies and systems. The availability and reliability of the power supply will be a critical factor for operational continuity, in both regular and degraded scenarios.

The scope of this FA is focused on the design and specifications for the necessary infrastructures, along with the testing and validation of these infrastructures to support development towards commercial maturity. In addition, guidelines and traffic coordination concepts will be established to promote the implementation of such technologies.

- Command, control and communication systems, safety equipment and automation systems – including sensors, communication, data processing, etc. – are essential to ensure safe, efficient operation and cost-effective maintenance. Virtual coupling and autonomous driving will be key technologies to achieve the desired operational flexibility.

- Especially, those TEs related to **sensing** at ultra-high-speed are particularly important. These are needed, for example, to locate the capsules and collect data from the infrastructure, such as temperature, deformation, vibration, etc. These systems must account for the specific requirements resulting not only from the high speeds but also from the materials used to build the tube and the capsule. The sensors and all the information generated should be managed in an integrable way. To support this integration, the main proposed TE is an IoT platform capable of **monitoring, supervising and managing** the sensors, and integrating all the collected data. This includes the use of predictive algorithms to, for example, detect potential equipment failures in advance. Regarding **safety and signalling systems**, TEs will also address the automation of operations, such as Automatic Train Protection (ATP) systems and safety systems, to prevent accidents. Traffic coordination concepts and CCS systems (both centralised and distributed) are important enablers for the activities under FA7. These will be supported by the required automation and communication systems to overcome challenges such as those related to the operational environment (i.e. a metal low-pressure tube) and the extremely high speeds involved, particularly with respect to latency.

Furthermore, these new systems may sometimes require new infrastructure, while in other cases they can coexist with traditional railway systems by sharing infrastructure. Reusing existing infrastructure and civil structures like bridges and tunnels would reduce costs and time spent on the construction of new infrastructure.

An estimation of the TRL of the capabilities for 2025, 2027 and 2031 is provided in Table 50.

TABLE 50. **Estimation of the TRL of the capabilities for 2025, 2027 and 2031**

Capabilities enabling operational objectives	TRL in 2025	TRL in 2027	TRL in 2031
Dedicated and stand-alone CCS systems, safety equipment and automation systems	2 – 3	4 – 5	6
Scaled 1:1 fully automated vacuum-tube-based system		2 – 4	5 – 6

The developments in this area are expected to align with work carried out in complementary initiatives and may be tested at the facilities mentioned in Section 7.7.1.5. They should also align with the business plan of the Chairman of the CEN/CLC/JTC 20 N 78 ([52]).

A constant screening of the latest developments should be established so that the goals of interoperability, technological openness and not duplicating development work are ensured.

7.9.1.3. Demonstration implementations

Demonstrations will address operability aspects and challenging topology across Europe to show and assess the full impact of unconventional fast track-bound transport systems. The demonstration of vacuum-tube-based systems should proceed expediently through several independent steps:

([52]) CEN/CLC/JTC 20 N 78, Updated Businessplan of the Chairman. CEN/CLC/JTC 20 'Provisional: Hyperloop systems'. 5.10.2021

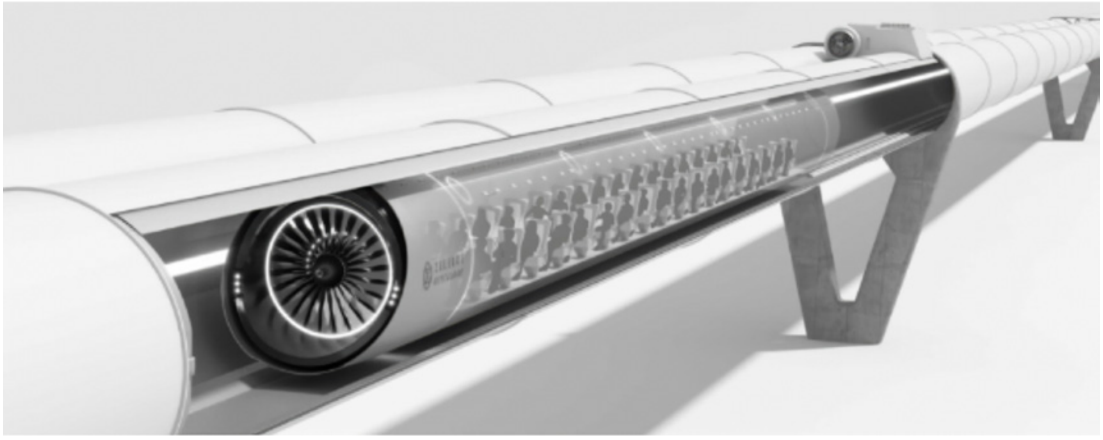
- demonstration to verify some aspects of signalling and automation within a laboratory simulator;
- demonstration of the functionality of the technical aspects – such as systems requirements, system architecture, sensing, communications, safety, integrated data processing and regulatory compliance – to be standardised for a fully automated vacuum-tube-based system, at least within a virtual test environment in a lab and, if possible, on site;
- demonstration of the integration of components and validation of the system, at least in a laboratory or relevant test environment;
- on-site validation of a scaled prototype, which can be carried out within complementary projects and initiatives, as previously mentioned.

Having available areas in which to carry out tests in real environments would be ideal (Figures 28 and 29), but it is necessary to evaluate the feasibility of these scenarios within the duration of the FA. Therefore, testing and demonstrations of other unconventional guided systems that can be set up within shorter timeframes should also be considered.

FIGURE 28. **Inside view of a future passenger capsule**

Source: Hardt Hyperloop.

FIGURE 29. **Tube and capsule view of a vacuum tube system**



Source: Zeleros.

7.9.2. Impacts

7.9.2.1. Description of the impacts on existing rail services

TABLE 51. **Descriptions of FA7 "Unconventional fast track-bound transport systems" impacts related to the intended impacts in the master plan**

	Improved performance and capacity The R & I projects outlined above focus primarily on the preliminary development of a completely new transportation system. While a variety of positive effects are imaginable, predictions remain uncertain due to the disruptive nature of unconventional fast track-bound transport system solutions.
	Reinforced role for rail in European transport and mobility Nevertheless, the most promising positive effect is reduced travel time, which not only enhances customer satisfaction in both passenger and freight transport but also boosts competitiveness against air transport.

7.9.2.2. Quantitative KPIs

To be defined based on the objectives of the specific projects.

7.9.2.3. Exploitation, deployment and migration considerations

There are still many questions to be answered regarding the deployment of unconventional fast track-bound transport systems. The foremost is the technical feasibility of this kind of transport, which should be addressed through the development of test sites like those considered in this FA. The technical performance of these demonstrators will help address the uncertainties related to the challenges of this transport technologies. Additionally, these test sites will provide more accurate data on the current and actual costs of the infrastructure and all associated subsystems.

Determining these costs is essential for developing a business model based on real data rather than on insufficiently substantiated hypotheses. This business model should consider not only the associated cost but also the external benefits of this transport mode, such as the reduction of direct CO_2 emissions from very-high-emission transport modes like aviation.

The future success of these unconventional fast track-bound transport systems, at least in Europe, depends on three key conditions:

- demonstration of technical feasibility;
- a firm political decision to ban CO_2 emissions from transport;
- that other solutions, such as electric or hydrogen aircraft, are not widely introduced before unconventional fast track-bound transport systems.

If these three conditions are met, unconventional fast track-bound transport systems will become a feasible solution for very-high-speed transport and, combined with current high-speed trains, could help achieve the goal of a zero-emission high-speed transport system.

Innovation must respond to future challenges; therefore, the development of test tracks for unconventional fast track-bound transport systems is justified, not only for addressing these challenges but also for developing numerous parallel technologies that justify the high investment required.

7.10. Transversal Topic: Digital Enablers

7.10.1. Objective and level of ambition

7.10.1.1. Targeted objective, new opportunities and associated risks

When the railway system becomes fully digital and connected, the availability of real-time and historical data from across the whole system will unlock a whole range of new possibilities. However, 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 an edge–cloud continuum / railway digital enabler environment for the entire rail system, supporting the development of advanced transformational digital capabilities, such as DTs.

Digitalisation is of major importance for all FAs; therefore, it is organised as a TT to ensure that all elements of the system work together coherently and interoperably. The digital enablers from this work area – mainly digital engineering and DTs, along with innovative processes enabled by interoperable data sharing, including conceptual data model (CDM) will support suitable demonstrations within the FAs.

Therefore, the establishment of a holistic integrational element, such as the railway digital enabler will create an ecosystem in which data from all applications will be aggregated in a standardised manner. This will enable applications to increase their performance levels and to be combined with application data or DTs from other domains within the railway sector (e.g. combination of railway operation data with maintenance information). These digital enablers manifest as federated and distributed edge and cloud components, serving as an environment for the creation, modelling, editing and processing of data within one of the railway sector's most important digitisation concepts: a new dimension of DTs of railway assets. This digital infrastructure creates an edge–cloud continuum where complex digital objects can exist. The main objective of this FA remains the creation of standardised concepts for DTs that enable users to employ them interoperably. DTs from one part of the railway system should be fully compatible with DTs from other railway applications (e.g. operations, maintenance, passenger services) to enable co-simulation. Through this approach architectures with different scopes are created and coupled together via respective interfaces, such as:

- architectures of digital environments for DTs;
- architectures describing the inner structure of a DT, including data structures, service APIs and application logic;
- modular descriptions of interfaces that link this digital environment with the overall system architecture from the SP.

Furthermore, the railway digital enablers will facilitate integration with other technological initiatives and support collaboration across various rail applications.

A DT is a virtual representation capable of imitating the behaviour of a physical system throughout its entire lifecycle. Within the railway sector, DTs will integrate knowledge on the fundamental behaviour of systems and subsystems into its digital simulations for both predicted and operational regimes. A DT offers a more efficient means of predicting and controlling the present and future performance of assets, thereby holding the potential to transform various aspects of the business. A digital representation of any part of the real railway system – be it infrastructure, vehicles or operations – will enable visualisation, simulation and prediction of the current and future status and behaviour of the system. This will improve safety and availability while reducing operational costs for the entire transportation system by forecasting future events and supporting the development and faster deployment of innovations through low-impact, virtual testing. DTs will encompass all rail market segments and their subsystems, including urban transit. The comprehensive representation of the entire railways system will emerge from the aggregation of multiple DTs at appropriate levels of granularity and detail, tailored to their intended applications.

The created feedback loop builds a bridge between the design phase (calculations and estimations) and the real world (measurement of the behaviour on the field for a given system or subsystem). Since measured data may be inconsistent or contain information gaps, mathematical tools such as statistical analysis must be developed to ensure the best possible data is fed back to the DTs. Adopting standardised statistical methods and tools as an integral part of transversal functions will enable the different FAs to use suitable datasets – conforming to a stable and standardised framework – to test and validate their DTs effectively.

The development of a railway digital enabler framework will encompass the entire railway sector to ensure efficient implementation in the real world as a subsequent step. Developing a DT within each railway/stakeholder's domain/subdomain would instead lead to potential incompatibility of assets or processes once applied together in the network, resulting in a need for further patches and adaptations.

The TT on digitalisation will support the operational processes and activities of the FAs and, in particular, their implementation of the related use cases. It will take into account the SP's rail system concept of operations, along with definitions of SP architectures and SP interfaces. DT requirements, implementation and data are the FA's responsibility. The TT on digital topics will support this through the following three measures.

- Firstly, the DTs support for operational processes of the FA by composition of re-usable, blackbox, compiled, digital interoperable model units of components, subsystems, executing in a federated simulation runtime environment the DT to provide suitable analysis tools (e.g. root-cause analysis).

- Secondly, the TT will develop and provide a DT design toolbox (design-time) to model development tools for design, validation, verification and testing; registry and discovery services; and interoperability validation tools.
- Thirdly, TT will provide a federated rail data space to feed DTs, ensuring a common ontology, identity and trust management, federation services, data asset registry and discovery services, data distribution services, data stream management, cybersecurity, etc. In addition, the TT will address transversal topics relevant to all FPs and to the SP, such as support for digital engineering, CDM and the application of AI within the digital enablers.

It is of upmost importance to understand that the TT architecture and its associated interfaces need to be broader than the architecture provided, for example, for CCS+, in order to ensure the proper functioning of the DT environment. Hence, all the results and definitions from the SP will be taken into account and comprehensively represented.

7.10.1.2. Innovation beyond the state of the art, including the integration of S2R results

The work builds on all IPX , IP1 , IP3 and cross-cutting S2R activities related to the virtualisation of assets. It will use the data structure provided by FA1 and may also incorporate new elements into its models, particularly regarding connection interfaces with other transport modes, drawing on the work carried out in FA1 and FA6. As the TT, it provides the tools for simulation and prediction to all other FAs.

Recent European collaborative efforts carried out within the S2R programme have already paved the way for the use of DTs across various applications.

This approach aims to enable the development of a global and shared railway digital enabler, within which DTs of different areas of the railway environment can operate.

TABLE 52. **Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail**

State of the art	Shift2Rail results	Further innovation needed and covered by this FA
Virtual testing, transferring testing from on-site to lab environments	Zero on-site testing for the CCS domain (X2Rail-3 (X2Rail-3, 2018), X2Rail-5 (X2Rail-5, 2020)	Fully digital test generation and execution in lab
Certification approaches based on digital models	General specifications and developments for virtual certification; virtual certification of cross-cutting activities (PLASA (PLASA, 2016)	General approach to virtual certification / homologation based on the aggregation of suitable DTs (granularity and level of detail); use of digital enablers for improvement of testing
Certification approaches based on digital models for rolling stock and associated components	Specific activities for the virtual certification of S2R IP1 rolling stock (PIVOT (PIVOT, 2017) with respect to bogies, PINTA (PINTA) with respect to traction systems)	General approach to the virtual certification / homologation of rolling stock, based on the aggregation of suitable DTs (granularity and level of detail) and accepted tools

State of the art	Shift2Rail results	Further innovation needed and covered by this FA
Field measurement of noise emissions and subsequent certification	Noise auralisation and visualisation (FINE1 (FINE1, 2016), FINE2 (FINE2, 2019)	General approach to virtual certification / homologation based on the aggregation of suitable DTs (granularity and level of detail) and accepted tools
Planning, certification and approval of planning based on expert knowledge; certification and approval of infrastructures through field measurement	Virtual certification for infrastructures IP3 infrastructure (In2Smart2 (IN2SMART2, 2019), In2Track (IN2TRACK, 2016), In2Track2 (IN2TRACK2, 2018), In2Track3 (IN2TRACK3, 2021)	General approach to the virtual certification / homologation of the planning and implementation of infrastructures, based on the aggregation of suitable DTs (granularity and level of detail) and accepted tools
Planning, certification and approval of planning based on expert knowledge; certification and approval of infrastructures through field measurement	Virtual certification for CCS systems	General approach to the virtual certification / homologation of the planning and implementation of infrastructures, based on the aggregation of suitable DTs (granularity and level of detail) and accepted tools
Planning, certification and approval of planning based on expert knowledge; certification and approval of infrastructures through field measurement	Virtual certification for energy management systems (IN2Stempo (IN2STEMPO, 2017)	General approach to the virtual certification / homologation of the planning and implementation of infrastructures, based on the aggregation of suitable DTs (granularity and level of detail) as well as accepted tools
Individual, but partially incompatible, digital data models and ontologies, tailored to the specific purpose or application	The S2R IPX (IPX) LinX4Rail (LinX4Rail:, 2019) project, starting end of 2019, lays the groundwork for a shared vision of railway system architecture and for the development of a CDM; UIC projects rail system model and ontology for rail (Ontorail), associated with LinX4Rail (LinX4Rail:, 2019) activities, also significantly contribute to a converging sector approach to defining the railway CDM and all the necessary elements developed by major initiatives, such as the industry foundation classes rail project and EULYNX; combined, they will enable various simulation or operational subsystems to run together, paving the way for shared and interoperable architecture	Development of a conceptual data model for the entire railway system, including the required data structures and functionalities; the CDM results from LinX4Rail-1and -2 will be further developed and deployed

As described before, a key objective is to enable the integration of individual DTs in a shared environment, the railway digital enabler. Consequently, several risks arise from a lack of consensus, alignment, data access and system interoperability. Thus, already within the EU-Rail JU, there is a risk that consolidation with other FAs may not be achieved in a timely manner or to a sufficient extent across all necessary areas.

Additionally, the lack of an agreed framework on rights, obligations and governance associated with the use of DTs and federated data could hinder the effective utilisation of the developed digital environment. In particular, for rolling stock and CCS virtual certification, it shall be required at least that the models are kept open or are verified by third parties.

Another risk associated with DT development is finding the right balance between complexity and granularity. On one hand, creating a simple DT may result in a digital model that cannot accurately represent the real system. On the other hand, creating an overly complex DT requires substantially greater effort and can result in a model that is so intricate it becomes almost impossible to understand, maintain and debug.

The final purpose of developing a railway DT is for it to serve as an enabler for other FAs. An example of this would be the creation of predictive and prescriptive maintenance algorithms within FA3, based on data generated by DTs. However, this major opportunity also presents the challenge of ensuring effective coordination and specification with the other FAs. A lack of clear specifications and coordination may result in a DT that is only partially usable, thereby limiting the ability to realise the full potential of the supported FA. Using one specific DT in two areas can lead to similar functional requirements but differing levels of complexity. To reduce this complexity, some railway-specific standards could be developed within the TT. These standards (for specifications and interfaces), encompassing model-based operational requirements and the validation of system models, would facilitate the creation of the DTs. Such efforts need to be carried out in a moderated, transversal manner, in collaboration and coordination with the relevant FAs.

Transversality, in itself, presents a risk. Requirements and functionalities must be collected from the FAs, and the architecture developed in LinX4Rail (LinX4Rail:, 2019) and further developed in the SP needs to be taken into account. In addition, requirements from various stakeholders and FAs need to be accommodated and integrated. Besides the content-related challenges, this also poses issues for project management and governance.

7.10.1.3. System integration, interactions with System Pillar and with other Flagship Areas

As the railway DT represents all physical assets (through their respective DTs) and their interactions, some processes and rules for specific cases will be incorporated to enhance the prediction of failures and other potential events. Once there is a common system of systems framework with easily interpretable operational rules, the complexity of use cases and processes to be included in the DT simulation framework is reduced and the synergies found across subsystems could increase, also digitally, through simulation. The TT creates value only when used in the other 'vertical' FA. This comprehensive and distributed TT architecture with the ability to leverage networked digital resources will optimise the development of the digital environment for the overall railway system.

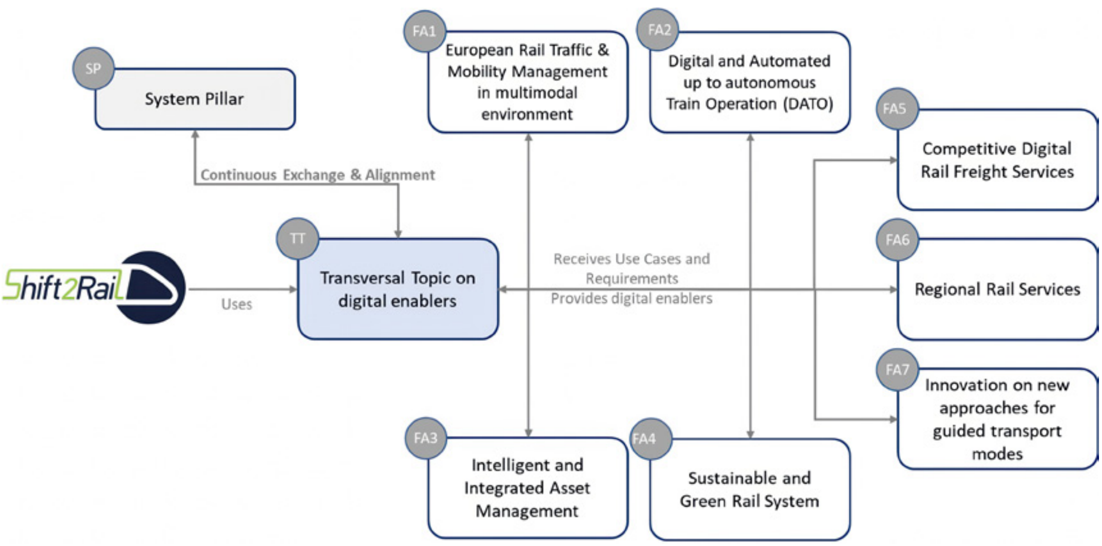
The separation of application logic, which is specialised to support specific use cases (addressed by the FAs), from the core digital resource management functions provided by the digital enablers, which are shared across EU-Rail JU FAs and potentially also across partnerships in the Horizon Europe programme (automotive, aviation) and other industries, is a key principle in pursuing synergies with S2R outcomes and market-ready solutions. This separation is an overarching principle adopted in the development of the EU-Rail JU MAWP.

Inherent digitalisation use cases require a holistic approach that relies on the following pillars:

- enabling digital **data sharing** throughout the entire supply chain to support the specification, tendering, design, manufacturing, planning, automated V & V of planning, maintenance, testing, validation, certification, homologation, operation, refurbishment, recycling and disposal of rail assets – facilitated through the use of DTs, digital models and the associated services and interfaces;
- integrating **virtual simulation and testing** – using DTs and models fed by high-quality datasets – as part of the system (including services, manufacturing processes, operations and assets) during the introduction of changes and innovations;
- using **prediction and visualisation** of the state of the system (or its components, including services, manufacturing processes, maintenance, operations and assets) and of the flow of passengers and goods.

The TT will provide a common set of core digital resource management functions to other FAs, while the FAs will provide the specific use cases, as outlined in Annex 1. Close cooperation between all FAs and the TT is envisaged to identify, detail and describe the use cases. The TT will support the demonstrations planned within the FAs with the TEs that have been developed. A strong interaction with the SP is planned too, particularly in relation to architecture and standardisation, among other things.

FIGURE 30. **Interaction with FAs and the SP**



During the ramp-up phase of the relevant projects of the Innovation Pillar and System Pillar, the detailed interaction shall be refined and finalised, based on the following principles.

- The two pillars will interact in a closely synchronised process to define dependencies, detailed architecture, operational concept and other system outputs based on the provisions of the Single Basic Act and master plan.
- Annex A already identifies certain relevant elements of the interaction, such as specifications, (for example, system requirements and interface requirements), detailed architecture, operational considerations and associated outputs that require the Innovation Pillar future activities to plan for the necessary resources to deliver the

relevant results. The requirements for the Innovation Pillar will be defined in the calls and associated grant agreements, based on the finalised annex.
- There will be a need for continued interaction and flexibility within projects for the Innovation Pillar projects to adapt to System Pillar outputs, and vice versa.
- In accordance with the governance established in the Single Basic Act, the EU-Rail Governing Board, based on the input from the System Pillar Steering Group via the Executive Director, with the support of the System and Innovation Pillar Programme Board, shall be the decision-making body responsible for the granularity of the architecture and resultant specifications and the associated system outputs to be delivered by the programme.

Details of the exchange between the FAs and TT can be found in Annex B.

The following FA use cases are the focus of the TT and will be used for system integration.

- Network management planning and control and Mobility Management in a multimodal environment (FA1):
  a. machine-readable ontology of an interoperable connected TMS;
  b. provide a data space connector as a standard interface for data exchange with legacy TMS;
  c. holistic real-time simulation platform for transport and traffic management, optimisation and planning.

- Digital and automated up to autonomous railway operation (FA2):
  a. AI training and certification on digitalised real and emulated/simulated operational scenarios;
  b. digital maps for both train localisation and environment perception systems;
  c. exchange between, for example, trackside and on-board subsystems;
  d. remote control and command network (based on results from the technologies for autonomous rail operation project);
  e. automated planning, generation of planning and engineering, automated V & V of planning, auto-corrections, certifiable proofs for certification, for example, by applying AI on the ERTMS test generation, execution and evaluation;
  f. virtual certification.

- Intelligent and integrated asset management (FA3):
  a. machine-readable ontology of assets life cycle domain;
  b. cybersecure networking (cabled, Wi-Fi or satellite) of distributed IoT sensors and devices, both mobile and stationary;
  c. data collection and aggregation from networked assets, sensors and devices;
  d. statistical methods and tools to support the solution of data inconsistencies;
  e. providing DTs for predictive, prescriptive and condition-based maintenance;
  f. construction site surveillance, inspection and project management;

- A sustainable and green rail system (FA4):
  a. holistic energy management, including the monitoring and metering of energy production, recovery, distribution and consumption, and the monitoring and metering of emissions;
  b. environmental monitoring in and around the infrastructure (noise and vibration levels, meteorological conditions, electrical aspects, pollutants);

- Fully digital green logistics (FA5):
  a. digital capacity management;
  b. digitalisation of cross-border freight traffic and the freight logistics chain;
  c. DAC as an enabler for digital freight transport and upgrade for locomotives;

d. digital customer interfaces and services;
e. goods data-sharing platform;
f. data harvesting and digitalisation of freight operations;
g. integration of last-mile services and digital shipment consolidation.

- Seamless rail freight (FA5):
  a. telematics data.

- Innovative freight assets (FA5):
  a. freight train status supervision.

- Regional rail services / innovative rail services to revitalise low density/rural railway lines (FA6):
  a. data sharing and integration;
  b. Passenger Information System
  c. virtual certification of rolling stock;
  d. virtual certification of the CCS.

- New and emerging transportation systems (FA7);
  a. defining digital interconnections and interfaces between existing offers in the field of public transport, mobility services, logistics and future mobility-on-demand systems;
  b. customer-oriented services supporting automation and unstaffed transport through internet closed-circuit television and PIS for automatic handling of passengers and goods;
  c. development and demonstration of a distributed security mechanism enabling the exchange of data and models between transportation modes.

7.10.1.4. Who does what by stakeholder group

The **IMs and RUs** can provide a detailed understanding of solutions and rail operations and how they are linked. Hence, they can provide data structures and content, along with processes – such as certification – that are suitable for digitalisation.

Suppliers will develop digitalisation solutions and provide innovations based on state-of-the-art technologies in the area of digitalisation. The group of suppliers represents the core of the rail supply industry, enabling the application of digital technologies during the development phase. They are mainly responsible for providing system solutions, related data and/or models of the products and tools, based on the operating community's requirements and specifications, including the development of prototypes and equipment necessary for demonstrating the use cases.

Research centres are responsible for supporting IMs, RUs and suppliers by providing methodologies and addressing scientific or methodical issues that may arise during the development of digital enablers. With their support, a new generation of technologies can be matured into market-ready solutions in collaboration with the suppliers.

7.10.1.5. Interaction with other Programmes, European and/or National

It is essential to establish connections with sectors beyond the railway domain. Besides synergy-enabling activities with related topics in other Horizon Europe partnerships, the Gaia-X initiative is of special interest. The TT of digital enablers focuses on a holistic integration of the digital railway ecosystem across three layers: data, services and edge–cloud infrastructure. This naturally creates a strong link to other EU programmes centred on edge–cloud technologies and broader information technologies. Thus, the Gaia-X initiative emerges as a central point for both adoption and cooperation. Within this initiative, several technologies needed in the rail sector are already under development and can be adopted by the rail sector. Since these developments are carried out in a very abstract and generic way – with the ambition to address as many industries as possible, including finance, healthcare, industry and mobility – they cannot be used directly in the railway domain without being adapted. Nevertheless, the principles, guidelines and concepts developed can be leveraged for synergies with the rail sector.

7.10.2. Results/Outcomes

7.10.2.1. Operational solutions outcome

The rapid development of digital technologies offers numerous opportunities for creating new value-added services in the railway industry. To seize these opportunities, action is required on three levels.

1. Data needs to be shared among all sector members, including railway undertakings, suppliers, contractors, and between various manufacturers.

To exchange this data effectively up to fully automatically it is mandatory to have open and standardised data structures to form a data ecosystem that meets the requirements of the railway industry, especially regarding the exchange of DTs. The requirements to exchange data focus on high data security, integrity, sovereignty and privacy, along with access, control, transparency and traceability. As an outcome, the members of the working group shall establish a blueprint architecture that enables all railway stakeholders to participate digitally in common data space ecosystems, both within the railway and across other domains. This blueprint is primarily based on data relationships among trusted partners, governed by a system of standards (e.g. Gaia-X, International Data Spaces Association) for secure and sovereign data exchange, certification and governance for business and industry across Europe. Successful uptake depends on the ongoing involvement of experts from both the FAs and the SP.

2. The need to properly process data using standardised services.

The available data is meant to be utilised by powerful tools and application-specific logic. Here, digital services and software are used to accomplish this.

Generic software tools and services are developed to provide basic functionality to data processing, preparation and visualisation as generic data services for reuse in all applications and for all kinds of DTs. This software might be used to handle data objects or DTs, regardless of the specific application that they are intended for. Examples of these generic functionalities include compression of DT data, encryption, efficient data transport and data transformation. The services shall therefore include a generic platform minimum architecture (such as a data dictionary and a common standardised railway ontology) and functionalities for distributed platform architectures. Here, the blueprint architecture for any kind of DT is developed to link to the work of the other FAs, where the respective applications are worked out in detail. Accordingly, the software and services – including potential application logic – are compiled.

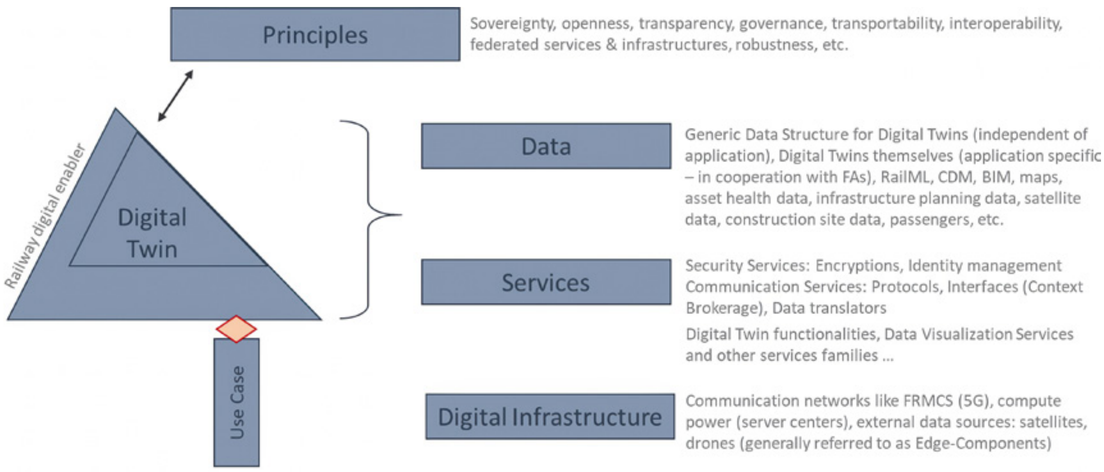
3. Powerful data and communication infrastructure.

The above-mentioned software and data assets require a digital infrastructure to operate in. This includes not only sensor hardware (satellites, drones, etc.) but also backend technologies such as high-performance computing centres and digital edge components (on-board systems and interfaces), which must be adopted for use in a federated railway digital edge–cloud continuum. Furthermore, the data transfer technologies between these infrastructure elements (5G connectivity, protocols for encryption, data protection, etc.) shall be adopted for use within the railway sector. Most of these technologies are already in use in other sectors and it is envisioned to adopt and transfer them for use in rail.

Together, they form a concept known as the **railway digital enabler** – or **edge–cloud continuum** – featuring appropriate interfaces and the transfer of core principles.

The concept of DTs is of great importance within the railway sector. Figure 31 displays the details of the above-mentioned concept in more depth and presents the relationship between DTs and the surrounding ecosystem.

FIGURE 31. **Railway DT ecosystem**



Here, the railway digital enabler is meant to be considered as a set of concepts, models, technologies and methods addressing the three levels of action – data, services and digital infrastructure. It relates to the concept of the DT in that the DT exists within this larger digital environment of data, services and digital infrastructure, while the twin itself carries its own data, service methods and application logic. The railway digital enabler is therefore an abstract construct that needs to be filled with real technology and architectures at a later, more specific stage of the work programme. For clarification, some examples of possible work areas that might be addressed or adopted are presented in the figure. In connection with this concept, it should be emphasised that, in addition to a common standardised/well-documented data space, a common standardised/well-documented semantics framework and standardised/well-documented protocols are also necessary and will need to be worked out in detail.

Core results of the TT will therefore be:

- the above-mentioned open, trusted and sovereign data space architecture for railway DTs and the identification of technologies needed for its implementation;

- the elaboration of principles and standards for developing generic and reusable software and services for rail applications, with the overall goal of balancing CAPEX and OPEX;
- the definition of concepts for the development and use of data infrastructures, such as communication technologies (e.g. 5G, FRMCS) and high-performance computing centres, to meet specific data requirements.

It is of key importance for the opening of the market that access to rolling stock models is kept open, in order to promote design and validation independence.

7.10.2.2. Technical enablers: capabilities to achieve the targeted operational outcomes

Federated Data Spaces

Across the European rail system, data is generated, stored and processed in hundreds of networked heterogeneous devices and systems owned by multiple organisations. This network must be allowed to grow as the digitalisation of the overall system progresses and becomes increasingly interconnected with other mobility and industry sectors in the European digital economy.

There is, therefore, a need to build a mechanism to make all these data available to specialised digital applications in multiple domains while at the same time:

- allowing incremental extensions and avoiding the rigidity of synchronised and centralised deployment timelines;
- providing data owners with the ability to retain control of their assets.

Conceptual data model (CDM)

The importance of high quality data and its accessibility is key to the success of the next generation of railway application and services. Therefore, data must not only be of high semantic quality but also formatted using a standardised, high-quality syntax. This is where data formats come into play, and the TT emphasises continuing the excellent work done in recent R & D activities on the CDM.

Not only shall the underlying concepts and principles of the CDM be respected, but they shall also be further developed to add additional value (e.g. transparency, sovereignty or governance) and to enable the use of fully interoperable DTs in both syntax and semantics.

Digital Twin Design-time environment

The availability of data resources in the federated data spaces allows the development of DTs, digitally replicated versions of real-world rail system entities and processes, synchronised at a specified frequency and fidelity. These DTs consist of logico-mathematical models of the entities' behaviour created by their designers, possibly embodying intellectual property that must be protected. Data available on the federated data space are then used as the coefficients and/or variables in the model's logico-mathematical expressions. These models may be created through the composition or coupling of sub-models of constituent components.

A DT design-time environment consists of a set of software tools and procedures allowing domain model experts to develop entity models, and to store them as compiled 'black-box' units with standard interfaces for reuse in the composition of higher-level models. The developers of these compiled units retain control over the reuse of models, which can only be accessed through the standard interfaces without the need to expose the models' encapsulated knowledge. Tools that automatically assess compliance with the standard interfaces are also part of the design-time environment to ensure interoperability when deployed in the DT run-time environment.

Digital Twin run-time environment

Compiled model units are used in simulations using instance-specific coefficients and variables data available on the federated data space. Simulations may involve multiple independently developed units connected through standard interfaces, both between themselves and with the underlying data federation spaces. The run-time environment provides mechanisms for deploying and configuring the simulation execution, initialisation, and executing and monitoring simulation runs. The results can be analysed in a powerful analytical visual interface for root cause analysis. The DT run-time environment will also have the capability to connect real-time streaming data from physical assets, enabling a real-time operational twin to assist operators in decision-making.

An estimation of the TRL of the capabilities for 2026, 2028 and 2030 is provided in Table 53.

TABLE 53. **Estimation of the TRL of the capabilities for 2026, 2028 and 2030**

Capabilities enabling Operational objectives	TRL in 2026	TRL in 2028	TRL in 2030	Allocation
Common Domain Ontology	6	7	7	Take advantage of the work produced in LinX4Rail. TRL 7 is justified based on the coverage of domains. Currently, CDM is focused on one source model of X2Rail4 of TMS. Based on the alignment with FAs, we need to prioritise the source models and improve coverage. If more coverage of source models such as BIM is required, the TT will need more time.
Identity and Trust Services	6	7	8	The design and implementation of IAM and cybersecurity systems is outsourced to an IT company. This company shall also specify how to maintain security for future enhancements.
Data Assets Registry and Discovery Services	5 or 6	7		Specified and outsourced to IT company. Based on initial usage and feedback from the FAs, the services are improved.
Data Assets Distribution Services	5 or 6	7		Specified and outsourced to IT company. Based on initial usage and feedback from the FAs, the services are improved.
Digital Twin Design-time Environment	5	6	7	The design-time environment is outsourced. TRL 8 due to missing features or enhancements, based on feedback from the FAs after initial use, and further ongoing enhancement to TRL 9.

Capabilities enabling Operational objectives	TRL in 2026	TRL in 2028	TRL in 2030	Allocation
Functional mock-up unit (FMU) (twin model) integrated development environment	5	6 or 7	7	The most common necessary twin models are prepared by the outsourced IT company, as specified by the FAs and TTs. This forms the foundational library of FMUs. The development environment provides these basic necessary twin models, which serve as a basis for FAs to develop their own light blue and blue models. 7 because of low coverage at the beginning and to make further improvements based on the usage and feedback.
Compiled FMU registry and Discovery Services	5	6 or 7	7	Reasoning is the same as above.
Automated FMU Interface compliance verification tool	4 – 5	5 – 6	7	
Digital Twin Run-time Environment	5	6	7	The run-time environment is outsourced. Not reaching TRL 8 due to missing features or enhancements, based on feedback from the FAs after initial use, and further ongoing enhancement to TRL 9.
FMU deployment and Configuration	5	6 or 7	7	Reasoning is the same as for FMU twin models.
Federated Data Spaces	6	7	7	The coverage of the federated data space could be low at the beginning, focusing on a specific FA demonstrator, such as FA1, to simulate real-time traffic just as an example. Based on experience, the TRL can be increased.
Federated data space interface and messaging infrastructure	6	7	7	Specified by the TT and delivered by the IT company.
Time management	7	8	8	Specified by the TT and delivered by the IT company
Simulation execution monitor	6	7	7	Specified by the TT and delivered by the IT company
Root Cause Analysis Tool	5	6	7	Specified by the TT and delivered by the IT company
Sustainable cybersecurity resilience (including ‘over-the-air’ security updates)		6	7	
Operational Technology Cloud Cybersecurity		6	7	
Post-Quantum Cryptography (as part of the shared security services for a Digital Twin)		6	7	

Capabilities enabling Operational objectives	TRL in 2026	TRL in 2028	TRL in 2030	Allocation
Advanced data-based tooling for automated risk assessment		6	7	
Creation of the Shared Cybersecurity Services (SCS) demonstrator		6	7	

The TRLs in Table 53 will be updated following feedback from the FAs regarding the needs of their use cases.

The operational solutions outcome requires TEs to be used to develop, implement and support the solutions described.

The edge-cloud continuum or the rail digital enabler as well as the DT outlined above, is essentially just an architectural pattern that requires further detailed specification. Technological components or building blocks can be identified to show probable cause of a later implementation. Some of these TEs are listed below.

- Generic ML/AI tools to:
  a. aggregate and analyse data from different data lakes;
  b. compare the predicted behaviour of a system with its observed behaviour (possibly with a physical model), and build a statistical model to more accurately predict the actual behaviour of the system;
  c. elaborate decision support systems for real-time traffic management, maintenance planning or rescheduling after incidents;
  d. explain the decisions made by other AI systems.

- Methodologies to ensure the trustworthiness of the algorithms and be certain that the algorithms act in accordance with legislation (especially the AI Act).
- Technologies to develop real-time fatigue or degradation models for strategic assets, or traffic management. The current models, being more design-oriented, often take a long time to run because real-time applications have not been required until now.
- Technologies to describe a **generic and standardised data space** for the railway domain, to create and access **DTs** of railway assets in an open, standardised, trusted and widely used data repository, including machine-readable ontologies. Technologies enabling this activity may include the international data space and/or FIWARE. The ontology-based approach of the CDM from LinX4Rail should be further developed, including ontologies related to architectures.
- Other necessary IT TEs include:
  a. a data exchange with standard interfaces,
  b. identity providers,
  c. individual data lakes,
  d. edge device extensions,
  e. data transfer and encryption technologies.

- From (model-based) operational specifications to the validation of system models, a range of standards (covering specifications and interfaces) would simplify the task of building a DT. This effort should be transversal and conducted in collaboration and coordination with the rest of FAs.
- Full process support by digital specification, development process, planning, support of digital and highly automated planning, engineering and V & V of planning, virtual certification assessment models and tools.

7.10.2.3. Implementation Approach

The ensure successful implementation, the work is carried out in close cooperation with the other FAs and, in particular, with the SP. To optimise shared results, the work is organised into two layers. In the first (blue) layer, the work on digital enablers is embedded inside the FAs. In the second (green) layer the transversal and generic works are executed. Note, that there is an embedded part (orange) within the green working layer, where useful inputs from outside the rail sector are explored and adapted if suitable. It is assumed that all FA projects have a dedicated work plan on digitalisation which implements the digitalisation enablers within the FA.

Embedded implementation (blue layer)

The idea behind this approach is to ensure that the knowledge and requirements of the respective railway applications – reflected in the different FAs – are effectively conveyed to the Digital Enablers within the TT. Since the FA experts know the best of what the digital needs are, to handle their application optimally. That is why digital enablers, like specific DTs, need to be developed in very close cooperation with their respective FAs. Here, the details of the data and algorithms that lead to a proper implementation of the inner logic and correctness of the digital assets (e.g. a DT of a maintenance activity, or part of a network or an algorithm logic for failure detection and similar) are discussed and developed.

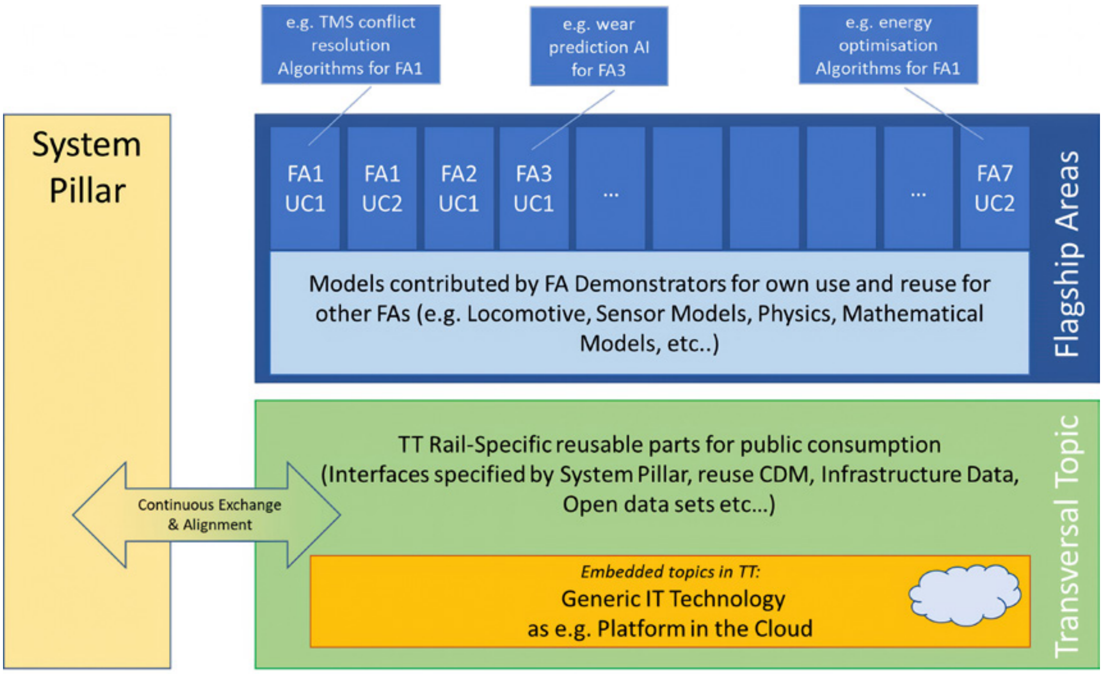
The traversal part (green layer)

Within the green layer, more conceptual work is carried out to support the work in the FAs in a way that creates specifications, tools and concepts on how the above-mentioned digital assets can be built to ensure interoperability. This approach aims to enable cross-application use of data, services and algorithms – often referred to as 'co-simulation'. Co-simulation makes it possible to use data and knowledge within railway applications that would usually be inaccessible due to barriers often found in large companies. This is the key added value of the TT: to describe how a federated ecosystem can be created and used by various applications and railway units in an interoperable way. The green layer, therefore, serves as the bridge between the FAs, the SP and the generic IT-specific parts of the work package.

Generic IT parts (orange layer)

While working on digital aspect of the railway system, it is necessary to include non-railway generic IT tools and concepts. The orange layer deals with aspects within the TT that will be outsourced or subcontracted to railway stakeholders interested in these topics or non-railway stakeholders and suppliers from the IT sector. Here, partners work with generic IT technology and concepts that are used (not developed) and adapted to support specific railway applications and their needs. Examples include communication protocols (TCP/IP), data encryption and compression, visualisation, service API specifications, and cloud technologies that might be used within the EU-Rail JU innovation programme.

FIGURE 32. **Implementation approach and interaction with the FAs**



The interaction between the TT and the SP is focused on achieving optimal outcomes for common railway architectures, since the resulting specifications and standardisation outputs are important deliverables for the overall program.

7.10.2.4. Demonstration implementations

The blueprint of the rail digital enabler for railway architecture has to be implemented in such a way that railway-specific digital value-added services can operate on this blueprint architecture based on the defined models for data exchange.

Peer-to-peer sovereign data exchange and/or participation in existing data spaces, such as Gaia-X's Common Mobility Data Space, can be used to deploy specific use cases in the area of distributed DTs among all stakeholders (train operators, infrastructure managers, entities in charge of maintenance, train manufacturers, suppliers of train components and systems, and suppliers of infrastructure components).

EU-Rail JU demonstrations for the rail digital enabler and the individual DTs within it shall fulfil the following requirements and conditions:

- demonstrate the system's ability to analyse signalling-specific communication protocols in a non-invasive and transparent manner, identifying potential cyber or physical safety and security anomalies;
- use the same data model for at least two different applications (ideally developed by two different entities) and ensure that they produce consistent outcomes;
- simulate in the laboratory specific behaviours (within asset management, traffic operations, etc.) using DTs, including the required physical models;
- virtual certification/homologation without the need for field validation;
- Use of Edge and Cloud Computing to run existing applications, achieving the same outcomes under the new constraints and/or conditions.

7.10.3. Impacts

7.10.3.1. Description of the impacts on existing rail services

The development of a railway digital enabler framework will encompass the entire railway sector to ensure efficient implementation in the real world as a subsequent step. Consequently, digital interoperability will increase. The use of digital enablers will enhance the harmonised approach to evolution and yield greater adaptability. This will reduce the costs of development, certification and operation, which in turn will improve the competitiveness of the EU rail industry.

TABLE 54. **Descriptions of TT impacts in relation to the intended impacts laid out in the master plan**

	Reduced costs To enable deployment on existing networks, the representation and detailing of DTs will be improved over time and in areas where positive effects are to be expected. The twin capability will not only help to understand historical and present situations, but also simulate scenarios with continuation and forecast alternatives for use and maintenance evolution/change. This approach will is expected to deliver significant benefits and drive impactfulevolution in the design of the railway system.
	Harmonised approach to evolution and greater adaptability Design and planning based on verified performance throughout the entire design cycle can be achieved by following the DT approach, rather than a design approach based on specifications. This enables a faster development cycle: under the current approach, if performance requirements are not met at the end of the development cycle, the process must restart from the beginning. The proposed DT approach allows for continuous performance verification throughout the development cycle.
	Improved EU rail supply industry competitiveness The reliance on real physical networks, data and systems for authorisation processes will be significantly reduced through virtual validation and certification processes. This virtual certification is an important step towards shortening the time-to-market for railway assets, such as rolling stock. Various initiatives have been underway for several years, some driven by stakeholders, others coordinated through European projects. The TT approach will consolidate them and increase their impact. DTs will provide a much more realistic framework for virtual certification – building on work already addressed in S2R – than individual subsystem simulations, especially when strong connections with other subsystems are needed (e.g. the hardware-in-the-loop testing philosophy).

7.10.3.2. Quantitative KPIs demonstrated in this FA

For the DT capability to be fully beneficial, it must support the automation of tasks that currently are still conducted in the field. Moreover, the availability of historical data about a 'twin' should enable not only the assessment of an asset's current status but also the prediction of its future behaviour. The first three KPIs are aimed at monitoring improvements in the number of tasks that can be executed in the laboratory, while the fourth KPI is oriented to monitor the improvements in predictive capability.

The fifth and sixth KPIs help to identify the most critical data types for modelling and assess the harmonisation of the overall process.

Another important aspect is data readiness for FA applications. Based on FA requirements, all data must meet application-specific data quality requirements. The seventh and eighth KPIs monitor improvements in the consistency and completeness of data, and the quality level expected for the specific FA application.

The adoption of digital infrastructures based on the edge–cloud continuum poses new challenges related to managing cybersecurity vulnerabilities and data transfers. The ninth KPI concerns data security, while the tenth and eleventh KPIs monitor improvements in response time and in the amount of time required to complete a data transfer.

TABLE 55. **Overview of the TT KPI improvements**

KPI description	Improvement
Digital Twin Capability	
1. Reduction in the number of physical infrastructure inspections required for the infrastructure design due to the implementation of a DT for CCS, track and electrical infrastructure on a specific trackside area. This reduction should be estimated while all other parameters, e.g., availability, risk level and traffic level, remain consistent.	% reduction in physical inspections
2. Number of rolling stock inspections that can be conducted in a laboratory without requiring field inspection.	% increase in lab
3. Percentage increase in simulation tasks for an equipment / prototype that can be performed using Digital Twin instead of a physical testing.	% increase in simulation tasks replacing testing
4. Reduction in routine maintenance activities for rail infrastructure due to the implementation of predictive behaviour enabled by DT models.	% reduction in routine maintenance activities due to the use of DT models
Data Modelling	
5. Number of times the same data type is managed in an isolated manner in a process using an independent system.	No. of use
6. Number or share of data entities that have been homogenised.	No. of use
Data Quality	
7. % of coverage of physical assets with related DTs (completeness).	% increase in coverage
8. % of errors present in the list of DTs (inconsistency).	% reduction against 2022 baseline
Cybersecurity	
9. Data Security – Role-based security of data in a DT environment, measured using a white hack test.	Increase in no. of survived tests
Time to respond and resolve a vulnerability	Reduced time
Connectivity	
Time to complete a data transfer task from the Edge to the Cloud.	Reduced time

KPIs need to be discussed, refined and agreed on with the FAs, based on their specific use cases and corresponding improvement needs.

7.10.3.3.Exploitation, deployment and migration considerations

A key aspect of the transversal topic on digital enablers will be the way to deploy and to migrate from the current railway system to the future digitalised railway system. To ensure an efficient switch to this future reality, TT results must support the deployment of digital enablers with benefits for all involved partners. A special focus is on the CMD as the results taken over and continued from LinX4Rail, which will be used by the TT and hence further deployed. The challenge is to come up with a generic migration path that can be applied by all operators, infrastructure managers as well as rolling stock and system manufacturers (or their partners), while assuring proper decision-making on the basis of the right business case inputs. That way, a generic deployment approaches could be provided. Overall, the business case on a system level must be already clear, but it must be noted that within the migration and transition, gains and investment for each involved party are different, and therefore additional measures and research could be needed. Insight into these aspects is crucial for a smooth transition and must be considered throughout the innovation and specification phase as well.

7.11. Exploratory Research and other activities

Europe's Rail will promote forward-looking activities by addressing disruptive technologies and thinking, conducting exploratory research to accelerate the pace towards radical system innovations in guided transport modes, and supporting the evolution of the Innovation Programme in both 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 with much higher speeds than currently available for distances over 1000 km. All exploratory research will be developed with a European system in mind and within a user-centred, multimodal setting.

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

- Study on upcoming enabling technologies and general/breakthrough innovations coming also from other sectors as well, that can be applicable to the rail systems and subsystems.
- Disrupting the innovation cycle itself by applying game-changing methodologies with the goal of significantly shortening time-to-market and significantly reducing costs of the innovation process itself and the cost of resulting solutions.
- Socio-economic and market-influencing factors analysis, including user-acceptance studies (reflecting changes in demand), taking various geographic settings into account (regional, intercity, urban, etc.).
- Research on emerging technologies or their critical subsystems, including maglev, magrail, aerodynamic propulsion and vacuum tube technologies, such as HyperloopTM solutions.
- Research on business, innovation and transport models.
- Research on emerging safety, security and certification issues.
- Personalised rail infrastructure and vehicle concepts moving over different transport modes infrastructures.
- Multimodal, customer-centric, sustainable, shared-mobility solutions including full integration with other modes of transport, including in urban environments.
- Studies of ultra-high-speed (beyond 500 km/h) trains and synergies with non-conventional and/or emerging new modes of transport (e.g. hyperloop).
- Impact of innovation on operations and human factors.
- Setting up networks bringing together different rail communities, such as in relation to regional hydrogen rail, rail research centre around specific concepts, etc.
- Programmes for PhDs focused on EU-Rail-related activities.

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

Other operational activities to support the Programme implementation and delivery will also be considered.

8. The Deployment group activities

The Single Basic Act establishes the Deployment Group to advise the Governing Board on the market uptake of 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 on its two pillars, is expected to further accelerate the introduction of innovative solutions. In order to complete the innovation cycle, the deployment of novel solutions requires a shift towards new ways of working within the sector, which would encourage the transformation of rail into one integrated European system. Only a strong and collective commitment may ensure reaching the milestones set out 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, which 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 that provide the capabilities needed to transform the European rail system. Only through a coordinated and integrated deployment of system integrated solutions can rail fully benefit from the investments made, accelerate its transformation and deliver new services to its clients. Notwithstanding these uncontested targets, the relevant adaptations to the legal framework – whether at EU or national levels, or in terms of standards – must not be overlooked. These changes must be developed in a well-coordinated manner to support the swift deployment of solutions, where the transition phase is of utmost importance.

In recent years, the deployment of innovative solutions has 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's rail systems to their legacy, missing the opportunity for a major transformation. The speed at which these obligations were implemented very often depended on the state of the legacy system, national transport policy priorities and the financial capacity of the relevant stakeholders. Therefore, the baselines among Member States may vary considerably and need to be taken into account when setting up a specific transition regimes and investment plans. Without the full support of the concerned stakeholder groups, swift deployment will not take place and the transformation failure may happen.

There is a clear and shared sector vision that accelerating the deployment of future technological and operational solutions requires decisions that will also shape the execution of future EU-Rail projects and call for 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 that are 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 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.), and including a representative from the state representative group.

- Examining and providing 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, (incl. investment plan if needed).
- Consideration of human factors as a result of deployment.
- Assessment of the relevant legal framework, its necessary adaptations, and the options for the transition phase.
- 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 considerations 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 life cycle and increase the performance of rail, maintaining the same level of safety or increasing it.

The composition of the Deployment Group may be variable, considering the scope of the activities.

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 TRL 9, in order to allow phasing in deployment as from 2025.

9. Financial resources of the Europe's Rail Joint Undertaking

The EU's financial contribution from the Horizon Europe programme to EU-Rail, including European Free Trade Association appropriations, to cover administrative costs and operational costs, shall be up to EUR 615 000 000. This includes contributions from non-EU countries associated with Horizon Europe (United Kingdom), i.e. EUR 29 000 000 and the reduction of EUR 14 000 000 following the multiannual financial framework mid-term review.

The R & I programme constitutes EUR 591 000 000, of which:

- at least EUR 50 000 000 is for the SP;
- EUR 541 000 000 is for the Innovation Pillar, of which:
  a. EUR 473 800 000 is for industrial research,
  b. EUR 67 200 000 is for exploratory research and other activities.

Running costs amount to EUR 24 000 000.

This amount may later be supplemented by additional EU financial contributions from other programmes, just as it has been increased with contributions from third countries associated with Horizon Europe in line with Article 16(5) of Regulation (EU) 2021/695 ([53]) and provided that the total amount by which the EU contribution is increased is at least matched by the contribution of non-EU members, or their constituent or affiliated entities.

The total value of the programme is estimated at EUR 1 273 387 000.

The R & I programme constitutes EUR 1 222 587 000; the SP, EUR 58 824 000, funded up to EUR 50 000 000; and the Innovation Pillar, EUR 1 167 043 000, which is divided into:

- EUR 1 087 987 000 for industrial research, of which EUR 302 342 000 is for additional activities (Article 2(9) of the SBA), funded up to EUR 469 245 000;
- EUR 79 056 000 for exploratory research and other activities, funded up to EUR 67 200 000

Running costs amount to EUR 48 000 000.

In terms of the total value of the programme, industrial research under the Innovation Pillar amounts to EUR 1 061 686 000, excluding the EUR 26 301 000 allocated to voluntary additional activities (Article 2(9) of the SBA), and is divided indicatively between the areas of priority and large-scale demonstrations listed in Table 56.

([53]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12.5.2021, p. 1, ELI: http://data.europa.eu/eli/reg/2021/695/oj).

TABLE 56. **Indicative split of Innovation Pillar Total Value per areas of priority**

	(EUR)
FA1: network management planning and control and mobility management in a multimodal environment	133 970 000
FA2: digital and automated up to autonomous train operations	255 656 000
FA3: intelligent and integrated asset management	227 271 000
FA4: a sustainable and green rail system	175 199 000
FA5: sustainable competitive digital green rail freight services	136 328 000
FA6: regional and innovative rail services aimed at revitalising capillary lines	75 984 000
FA7: innovation on new approaches for guided transport modes	15 687 000
TT: digital enablers	41 590 000

10. Multiannual programme implementation

In order to achieve its mission and objectives, EU-Rail will perform the tasks established in Article 5 of the SBA, complemented by those defined in Title IV.

In particular, EU-Rail shall provide financial support, mainly in the form of grants, to indirect R & I initiatives. These must be selected through open, transparent and competitive calls, except in duly justified cases specified in the annual work programme, where additional conditions may require the participation of JU members.

EU-Rail has opted to make use of lump sum grants, complemented as needed by procurement procedures or any other instrument envisaged in its financial rules.

The programme is implemented multiannually in instalments, allowing EU-Rail to launch calls and sign grant agreements beyond the limits of annual budget appropriations, in order to strengthen and integrate scientific, innovation and technological capacities, and facilitate collaborative links across the EU, supporting the creation and diffusion of high-quality new knowledge and skills, in particular with a view to successfully addressing global challenges, and securing and enhancing EU competitiveness, European added value, resilience and sustainability.

In this respect, on indicative basis, the EU-Rail programme is expected to be implemented as follows.

With regard to SP activities

Implementation via one or more framework contracts (procurement) appears to be the most appropriate approach, considering:

- the need to ensure that the initial elements of the functional system architecture and the concept of operations are in place before the commencing other R & I activities;
- the type of expertise required to carry out these activities;
- the advantage of maintaining a high degree of flexibility in implementation;
- to ensure that the results of the work are owned by the JU to be available to the rail sector, while, when needed, to protect information due to its nature or proprietary content, for example, in relation to its background,

The first call for tenders was launched by the end of the first quarter of 2022.

With regard to Innovation Pillar activities

This constitutes the core of the programme, where private members are expected to provide contributions of up to EUR 591 000 000.

In accordance with the SBA, as already mentioned, EU-Rail shall provide financial support, mainly in the form of grants, to indirect R & I initiatives. These must be selected through open, transparent and competitive calls, except in duly justified cases specified in the annual work programme, where additional conditions may require the participation of JU members.

To ensure a smooth ramp-up phase of the programme and especially to secure sustainability-driven global leadership and resilience in EU value chains for key technologies and industries, in line with the relevant EU policies, while also developing and accelerating the uptake of innovative solutions throughout the EU, addressing climate, environmental, digital and other global challenges contributing to EU strategic priorities, accelerating the economic growth of the EU and fostering the innovation ecosystem, thereby improving the quality of life of European citizens, this core part of the programme will be implemented via a series of calls for proposals.

- Call 2022, planned for Q1 2022, is expected to cover up to 50 % of the cost of R & I activities to be conducted between the end of 2022 and the middle to end of 2026, to reach TRL 5, and in some cases higher, building on the results of S2R.
- Call 2025/2026, planned for Q4 2025 / Q1 2026, is expected to cover around 30 % of the cost of R & I activities to be conducted between the middle to end of 2026 and 2029, largely to run large-scale demonstrations of sufficiently mature solutions while ensuring a continuous pipeline of research at lower TRLs.
- Call 2027, planned for Q1 2027, is expected to cover the remaining part of the cost of activities to be conducted by 2030/2031, to ensure that EU-Rail technological and operational solutions are ready for industrialisation and future deployment.

The overall objective is to ensure a virtuous cycle of R & I that would allow the rail system to be transformed through a modular and scalable approach.

In addition, from 2022 to 2031, EU-Rail intends to launch, on a regular basis or as needed, calls for proposals and/or for tenders to complement the core programme, to explore new areas of rail R & I in line with its master plan, or perform studies and any other relevant activities that would contribute to the achievement of its programme.

Finally, to ensure that the programme meets the evolving requirements concerning policy, technology and society, a midterm review will be conducted in 2025, along with a second one most probably towards 2028.

With regard to deployment group activities

These activities will support the process of bridging R & I with future coordinated deployment and will be defined in line with the programme's evolution.

11. Other operational activities and outreach

11.1. Stakeholder engagement

Institutional stakeholders

EU-Rail shall maintain close relationships with its key institutional stakeholders such as the European Parliament, the European Council and the European Commission, to ensure that its activities are aligned with and adapt to policy developments. It will also establish appropriate cooperation and coordination with the following organisations, including through formal cooperative arrangements where appropriate.

- **ERA**, to ensure an early exchange of knowledge on new technological and operational solutions being developed, thereby facilitating ERA processes with regard to TSI preparation, authorisation, etc., and ultimately accelerating the market uptake of innovative EU-Rail solutions. Also, EU-Rail will ensure it meets ERA needs in specific rail R & I activities, to maintain an integrated approach and maximise resources. EU-Rail will also support the ERA in European and international activities related to securing the necessary safety, security, interoperability and regulatory arrangements.
- **EUSPA**, to coordinate on the roles of EGNOS and Galileo in the next generation of rail operations.

Industry stakeholders

EU-Rail will foster collaboration with the following key European stakeholders.

- **ERRAC** – EU-Rail will participate in the advisory council as needed to ensure the coherence and consistency of activities and align with ERRAC's *Rail 2050 Vision*.
- **Alliance for Logistics Innovation through Collaboration in Europe** – EU-Rail will liaise with the platform to ensure that rail R & I solutions, in particular concerning rail cargo, meet the expectations of the logistics value chain.
- **CEN-CENELEC-ETSI** – EU-Rail's participation in standardisation activities is essential to ensure a faster uptake of innovative solutions. This includes close collaboration also between the members of the JU and the standardisation bodies. Alignment of priorities and coordination of work plans will be also considered.
- **Professional staff organisations** – EU-Rail will maintain close relationships with various professional staff associations to provide the necessary knowledge on the expected transformation of the rail system.
- **Passengers' associations** – EU-Rail will ensure that the needs of the passengers, including PRM, are duly take into account in its R & I efforts. A continuous and open dialogue will be maintained.
- **New entrants** – EU-Rail will liaise with representatives of various new entrants in rail and in guided land systems that will be part of its activities. The JU will promote integration and inclusiveness.

Relationships established with sector associations will continue, building on the progress made by the S2R JU.

The JU will also consider how to integrate the aforementioned relationships into specific work to be undertaken by industry stakeholders in support of delivering the programme.

11.2. Synergies

The EU-Rail JU will implement measures to maximise its impact by leveraging synergies with other European, national and regional programmes and activities. Beyond its involvement in the overall coordination of Horizon Europe, EU-Rail will particularly focus on capturing synergies across the following areas.

The 'climate, energy and mobility' cluster. The JU will reach out to other mobility JUs with the aim to build, where possible, consistent projects and demonstrators for climate-neutral mobility solutions. This may also address shared areas of intervention such as multimodal transport, automation in vehicles and other assets, decarbonisation and the use of alternative fuels. In particular, specific coordination with the SESAR 3 JU, Clean Hydrogen JU and BATT4EU co-programmed partnership is of key relevance.

The 'digital, industry and space' cluster. Considering the key expectations related to the digital transformation of rail, this cluster is expected to contribute significantly to rail-critical applications. AI, cybersecurity and high-performance computing are cross-sectorial issues that require close coordination, especially in developing use cases and applying European standards. European space policy is also highly relevant, considering ambitions to introduce a growing number of satellite-based solutions for localisation or data transmission, and possibly communication. Synergies with EUSPA (and ESA) and SNS will continue as well, building on past collaborations and creating new ones, in particular with Chip.

European Partnership on AI, Data and Robotics. This partnership could support access to these technologies, and relevant industrial partners and developers will be considered in the implementation of this work programme Additionally, inspection and maintenance was one of the four priority areas defined under the robotics Public-Private Partnership (PPP).

EU missions. EU-Rail will explore joint activities with the EU mission 'Climate-neutral and smart cities' to contribute to comprehensive climate-neutral and smart urban mobility solutions. Potential areas of collaboration include single ticketing and smart transport hubs integrating suburban and long-distance passenger rail traffic with urban mobility.

Major national (sectorial) policies, programmes and activities. It is estimated that around 15 % of the EU's Recovery and Resilience Facility stimulus package will be invested in various areas of national rail systems. Ensuring maximum levels of complementarity and impact, with a focus on future-proof investments, is essential. This will require leveraging local, regional and national investments to complement the R & I activities conducted at the EU-Rail level, and vice versa.In this respect, the SRG is expected to play a key role.

11.3. Cooperation with Third Countries and other organisations

In accordance with Article 85(3) of the SBA, in carrying out its activities, EU-Rail shall seek a geographically balanced involvement of members and partners in its activities. It shall also establish the necessary international connections in relation to rail R & I, in line with Commission priorities.

In this respect, EU-Rail strategy will be to conduct outreach activities with international partners pursuant to its strategy for cooperation with third countries and/or international organisations, in particular to contribute to the competitiveness of the European rail industry at the global level.

EU-Rail will continue the cooperation set up by the S2R JU with a number of key international partners, such as the European Union Agency for Fundamental Rights, the American Public Transportation Association, the United States Federal Transit Administration, the Canadian Urban Transit Research and Innovation Consortium, Gulf Countries, India and, in the near future, Australia.

In line with the Commission's policy priority on rail international relations, and keeping in mind the aforementioned objectives, it is expected that exchanges will take place with Australia, the Association of Southeast Asian Nations, Japan, South Korea and Mexico.

The collaboration with the EU neighbouring countries, in particular the Western Balkans, will continue and be enhanced, further exploring opportunities for joint activities and large-scale demonstrations.

11.4. Policy support to the Commission

EU-Rail will provide its input to the European Commission as requested to support policy-making, for example preparing technical documentation, conducting technical studies or supporting regulatory activities. It will also ensure the stewardship of the master plan, including monitoring, reporting and updating it.

12. Internal management, control and monitoring

12.1. Internal management and control

EU-Rail shall fully comply with the requirements of the financial regulation. In compliance with Article 71 of Regulation (EU, Euratom) 2018/1046, the JU will respect the principle of sound financial management. EU-Rail shall also comply with the provisions of the model financial regulation applicable to the JU. Any departure from this model financial regulation, required for the purpose of the JU's specific needs, shall be subject to the Commission's prior consent. Monitoring arrangements, including through the EU representation in the GB, and reporting arrangements will ensure that EU-Rail can meet the accountability requirements both to the College and to the budgetary authority. The internal control framework for EU-Rail is built on:

- the implementation of the internal control standards offering at least equivalent guarantees to those of the Commission;
- procedures for selecting the best projects through independent evaluation, and for translating them into legal instruments;
- project and contract management throughout the duration of every project;
- *ex ante* checks of claims, including receipt of audit certificates and *ex ante* certification of cost methodologies;
- *ex post* audits on a sample of claims as part of the Horizon Europe *ex post* audits;
- the scientific evaluation of project results.

Various measures shall be established to mitigate the inherent risk of conflict of interest within EU-Rail:

- independence of staff;
- evaluations by independent experts based on published selection criteria, together with appeal mechanisms and full declarations of any interests;
- a requirement for the GB to adopt rules for the prevention, avoidance and management of conflicts of interest in the JU in accordance with the financial rules of the JU and with the Staff Regulations in respect of staff.

The establishment of ethical and organisational values will be one of the key roles of the JU, and will be monitored by the Commission. The ED, as the authorising officer, will be required to introduce a cost-effective system of internal control and management. They will be required to report to the GB on the internal control framework adopted. The GB will monitor the risk of non-compliance through the reporting system that it will develop, and by following the results of *ex post* audits on the recipients of EU funds disbursed by EU-Rail, as part of *ex post* audits covering the whole of the Horizon Europe. There is a clear need to manage the budget in an efficient and effective manner, and to prevent fraud and waste. However, the control system needs to strike a fair balance between attaining an acceptable error rate and managing the control burden, and avoid lowering the attractiveness of the EU's research programme.

On the basis of the above, EU-Rail will implement its activities in accordance with the provisions of the SBA, its financial rules and other GB and ED decisions that will ensure sound management of the resources available. In this respect, the JU, as an EU body, is subject to internal and external assurance processes and has established agreements regarding the protection of the EU's financial interests, including with the European Anti-Fraud Office and, in the future, with the European Public Prosecutor's Office .

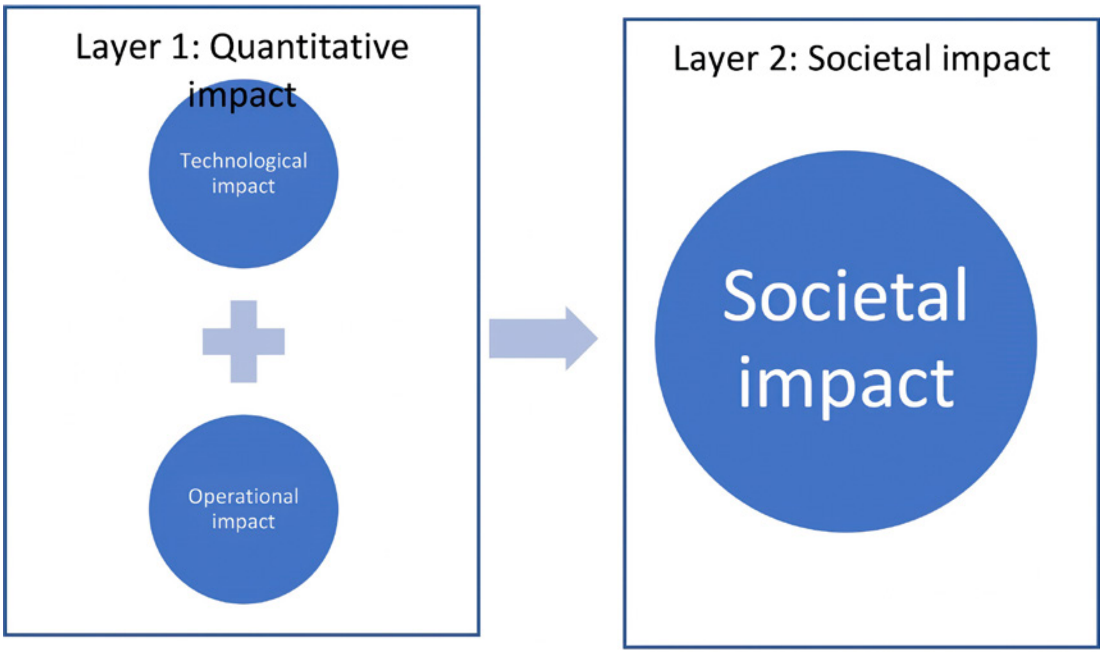
12.2. Indicators

The results of EU-Rail 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 KPIs shall cover the full lifecycle of R & I, from exploratory research to deployment coordination.

On the first layer, quantitative impacts will be evaluated, originating from technological and operational advancements generated by the R & I activities.

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

FIGURE 33.



232

The targets and achievements of the Shift2Rail JU have been revised in view of the definition of impact KPIs capable of assessing the performance of the innovative solutions once deployed.

The KPI model shall be based on input delivered by each of the JU projects and reported on a yearly basis through its annual activity report. Each project will be required to ensure that relevant quantitative and qualitative metrics that contribute to the JU's overall KPIs are provided.

In this regard, further to the past involvement of the Joint Research Centre (JRC) of the European Commission and, in particular, of the transport R & I monitoring and information system in the activities related to the development, monitoring and analysis of the KPIs of the S2R JU, the JRC will advise the JU on the development of the overarching assessment framework of EU-Rail, and the definition of the source of data and the process to collect them to feed the model. The JRC will also contribute to the annual activity report by drafting a specific section dedicated to KPIs. In addition, specific Horizon Europe implementation indicators are also defined and reported.

The deployment group will play a key role in establishing the elements to be taken into account to ensure the conditions required for successful market implementation. 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 in the identified priority areas and, even more importantly, will help identify and address critical issues, along with potential redevelopments and opportunities, in the most appropriate way.

12.3 Risk management

EU-Rail has an established risk management process that has been implemented within the S2R JU for the last five years. It involves providing clear communication to governance, staff and stakeholders on how EU-Rail positions itself in the management of risks and opportunities that can affect the achievement of its objectives, taking into consideration the assessment of the level of uncertainty that it is willing to accept (risk appetite). The ED approves the policy and sets the tone, and staff at various levels implement the policy. The GB endorsed the risk register brought to its attention as part of the annual activity report.

Annex A. System Pillar and Innovation Pillar interactions

This note sets out an indicative proposition regarding the requirements for the SP and the Innovation Pillar to assist in the development of the *Europe's Rail Joint Undertaking Multiannual Work Programme*. The deliverables may change throughout the ongoing EU-Rail preparatory work but should be regarded as a reference for the type of outputs required from the SP and the Innovation Pillar within EU-Rail, with resources planned accordingly. This document will be finalised as the foundation for the work to be carried out within EU-Rail.

EU-Rail, via the SP, aims to establish a coherent approach to the evolution of the European rail system through a system architecture approach.

The SP has a distinct work scope to set the system architecture of the rail system (task 1), with a particular focus on the CCS+ architecture (task 2), and coordinate the standardisation and TSI outputs of EU-Rail. While the main focus will be on these two tasks, the SP must also integrate and duly consider other key subsystems, such as DAC as an enabler of significantly more performant rail cargo, interfaces to urban mobility, and energy systems.

For CCS, EU-Rail will develop the operational concept(s) and functional system architecture for a genuine integrated European CCS system, with much greater standardisation, a wider scope (described as CCS+ at this time), and no variation compared to the present.

The Innovation Pillar will deliver, through R & I, advancements in areas such as advanced traffic management, digital and automated train operations, and rail freight.

A structured and continuous interaction between the SP and the IP will be necessary to achieve the overall objectives of EU-Rail, ensuring that the system work performed within the IP integrates with and remains consistent with the SP.

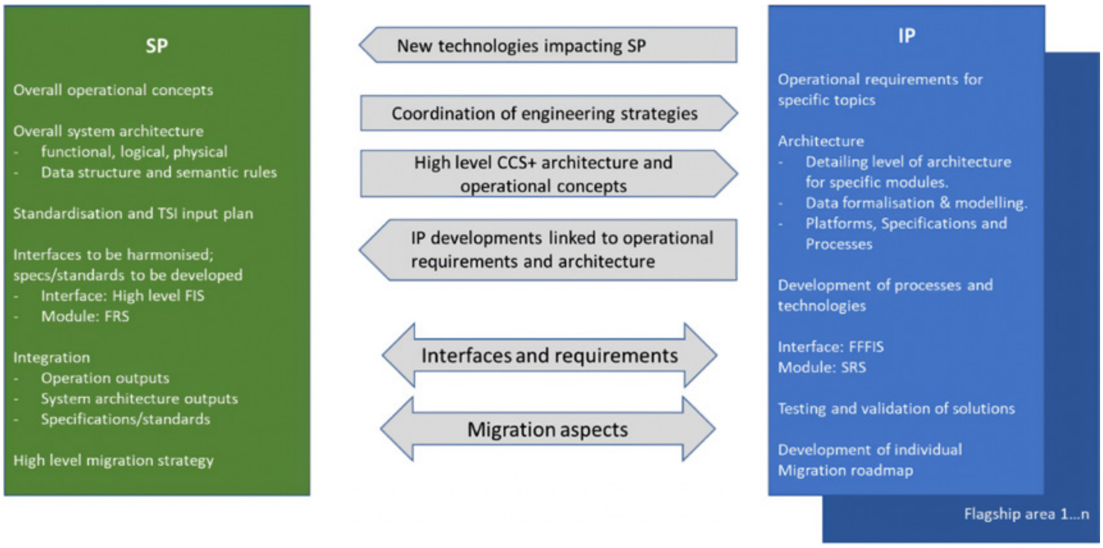
This note aims to set an approach for this detailed collaboration, taking into account the high-level functional architecture and principles included in the SP report, and the current proposals received from the IP FAs.

When existing TSI regulations or standards are available for these topics, the work of both the SP and the IP will be based on them, with updates or modifications proposed instead of new drafting initiatives.

As further definitional work on the system approach is carried out, additional system-led requirements may impact the work of the IP, and outputs from the IP may influence the system architecture. It is therefore necessary to allow flexibility in definition of IP and SP outputs throughout the time frame of the JU. Procedures and plans that include relevant milestones referring to the activities of the SP will be identified for each FA interacting with the SP and vice versa. In addition, the necessary supervision and change management will be anticipated, including the organisation of regular review meetings.

According to the SP report, the SP and the IP have different roles.

FIGURE 34. **Relationship between the SP and the Innovation Pillar**



The following describes the expected division of roles between the SP and the Innovation Pillar for the Innovation Pillar FAs.

FA1

This FA includes outcomes to improve the strategic and tactical planning of the rail network (planning), develop the resilience of a connected real-time rail network (operation) and integrate rail traffic within door-to-door mobility.

SP	IP
• Traffic management principles, top-level requirements and use-case scope. • Functional and non-functional requirements for network disturbance resolution. • Functional requirements for on-demand traffic management.	• Specifications for planning tools and interfaces for: a. rolling planning and TTR; b. decision support for short-term planning; c. optimisation methods for timetabling and railway planning; d. feedback loops from operations. • Technical specifications and functional/ non-functional requirements for operational tools and interfaces (including with the control and command layer) for: a. automation and decision support; b. improved real-time connection of the networks; c. real-time convergence between planning and operations; d. dispatching and incident management; e. disruption management; f. conflict detection and resolution; g. speed regulation and dynamic timetables; h. real-time crew / rolling stock dispatching.

It should be highlighted that this is the main layer that has been included within the extended scope of CCS+, so the outcome of EU-Rail's work in this area is expected to include sufficient regulations and standards for integrated European rail traffic management. The basis for this will be the existing regulations on telematic applications for freight and passenger service TSIs.

SP	IP
• Traffic management cross-border operational principles. • Operational and architectural concept for a European TMS, including operational requirements and CCS principles.	• System requirements for cross-border scheduling, traffic flow optimisation and deviation management. • Interface specifications and data set for an interoperable connected TMS. • Interface specifications and data set to integrate rail traffic within door-to-door mobility.

FA1 and FA2

FA2 also considers as a priority the interface of their outputs with the TMS and demand-orientation and network capacity improvement technologies. Also, FA2 includes outcomes related to route setting methodologies, which concern both the traffic management layer and the control trains layer. It is understood that there will be coordination between these FAs on these topics.

In terms of ERTMS, FA1 and FA2 shall design CCS trackside and on-board functionality as a simplified technical environment for an efficient ERTMS rollout in Europe based on the harmonised operational concept provided by the SP. This includes the simplification of the trackside architecture and its migration, and the implementation of higher GoA for the toolchain needed for CCS system planning, configuration engineering, monitoring, etc. It may require reconsidering the distribution of the 'intelligence' among on-board, trackside and European central oversight components as designed in FA1. The effort required to roll out ERTMS shall be strongly reduced by designing functionalities that do not require expert skills, extensive configuration or detailed, site-specific safety cases. Upgrades to trackside and vehicle ERTMS functions shall be simplified through operational, architectural and functional optimisation of the technical ERTMS environment or its components.

SP	IP
• Functional requirements and operational concept for the interface between operational railway system and control and command railway system layers. • High-level signalling principles, including the list of potential types of routes and what the rules are for locking, monitoring, releasing and blocking the routes. • Users requirements and physical and logical architecture to identify the correct level of modularity required for the related modules. • Harmonised operational concept and requirements for a homogeneous, economic and simplified use, roll-out or change of radio-based ERTMS applications.	• Technical specifications for planning tools and interfaces (including with the control and command layer) for: a. the integration of ATO/TMS to improve capacity; b. ATO journey profiles for timetabling. • Technical specifications for operational tools and interfaces between CCS and traffic management systems for automated and digital train operation. • System requirement specifications for the systems that define routes and consequently control train movements. • Interface specifications for the system: a. harmonised expected input from the timetable functions, b. harmonised expected outputs towards the trackside function that enables the control of trains, c. logical and physical interfaces based on SP architecture.

Also, strong collaboration is expected between FA1 and FA2 regarding the function to manage railway stations and depots. Greater standardisation and harmonisation of operations in stations and depots will enhance the performance of the railway system in its interface with customers. Both FA1 and FA2 have outcomes related to terminals.

SP	IP
• CCS principles, operational concept, functional architecture and requirements for specific railway areas like shunting yards, shunting zones in stations, depots, terminals and connected industry areas.	• FA1 – System requirements and dataset interfaces for the connection TMS & CTC, and automated yards. • FA1 – Dataset and interfaces for the integration with yard and station management. • FA2 – engineering rules for terminals. • FA2 – operational rules for movements in terminals.

FA2

This FA includes outputs for an overarching automation process and the evolution and optimisation of ATP. ATP and DATO are to be designed and developed based on the same supporting functions and infrastructure, such as high-precision localisation, digital topology information, safe computing platforms, on-board communication networks, and train-to-train and train-to-ground communication. In addition, combining ETCS hybrid level 2 or full moving block with DATO will be key to increasing the capacity of railway lines.

These outputs are part of the technical scope of the CCS+ function which contains the infrastructure and on-board functions to control the train movements. In line with the principles included in the SP report, the following deliverables are expected.

SP	IP
• Operational concept for digital ATO, for both nominal and degraded operations. • Further detailing in the architecture, concluding, for example, whether a direct link exists between TMS and ATO or how such a link could be established.	• Updated specifications for GoA3/4: a. system requirements, b. requirements for the communication channel, c. requirements for diagnosis, d. communication layers, e. ATO–ETCS, ATO–TCMS and ATO–trackside interfaces. • Unique set of engineering rules for deploying the different stages of DATO (see the demonstrators in FA2).

In particular, for the outcomes related to harmonised supporting functions for localisation, FA2 includes, for example, safe absolute near-real-time train positioning techniques.

SP	IP
• Architecture that implements the flexible combination of a mix of trackside sensor and on-board localisation systems. • Collection of the set inputs from the work related to the 2022 CCS TSI (e.g. from the TWG architecture). • Performance requirement targets for the next evolution of localisation systems.	• Develop solutions that enable high-precision localisation, digital topology information and safe absolute near-real-time train positioning techniques. • FFFIS odometry platform (enhanced train localisation interface between technology-independent sensors and the EVC).

FA2 also highlights that, to achieve the expected output, safe unattended operation must be ensured through the use of comprehensive, modular and scalable perception systems (on board and trackside) for both outdoor and indoor environments. This includes, for the on-board side, a new generation of braking systems and new methods for the qualification of brake performance under degraded adhesion conditions. In the draft CCS+ architecture, this pertains to the functions of control signalling devices and train management interfaces, which play a key role in several central interfaces of the CCS+ system of interest and the related systems. Hence, modularity and interface standardisation are expected within this scope.

SP	IP
• Operational model and requirements. • Functional, logical and physical architecture identifying the list of signalling devices that the CCS+ layer will control. • Operational concept for the signalling devices (signalling principles). • Open points of the topical working group architecture for the 2022 CCS TSI, including functional allocation between control command train and offer rolling stock (e.g. odometry, TDC, shared data services, cyber, DAC interface).	• Specifications for the interfaces between the trackside CCS system and the TMS, trains, trackside assets and trackworker safety systems. • FFFIS for signalling devices. • (Updated) system requirements for braking. • Revised FIS/FFFIS of the train architecture, based on the innovative solutions developed by EU-Rail.

FA3

This FA is linked to task 2 and includes results related to functional modules already identified in the SP report within the system of interest for the CCS+. This assumes that the maintenance and renewal functional module included in the operational railway system layer is FA3’s responsibility (to be confirmed).

SP	IP
• Maintenance and renewal principles (for hardware and software assets). • Identification of functionalities within this module of the CCS+. • Functional requirement for an interface between the traffic management function and the maintenance and renewal function. • Functional requirement for an interface between the control and command function (infrastructure and trains) and the maintenance and renewal function.	• FA3 system requirements for the CCS+ functionalities of the IAM system – linked to maintenance and renewal functional module. • FA1 and FA3 specifications for the interface between the IAM system and the operation and traffic management system. • Specifications for the interface between the IAM system and the TR CCS (ATP trackside, ATO, object controllers). • Specifications for the interface between the IAM system and the OB-CCS.

FA3 envisages an operational outcome related to the sharing of information across the supply chain and TMS. The identification of the necessary data and the best capture methods are expected from FA3 to input the conceptual data model in the SP and the complete data architecture in TT. This is further described in the section transversal to all FAs and that is also applicable to TT.

Task 1 linked: For other results expected in this FA, contributions to the rail system architecture and operational concept are expected for the task 1 of the SP.

SP	IP
• Functional, logical and physical architecture. • Overall operational concept.	• Description of the specific developments linked to operational requirements or system architecture, including unmanned and non-invasive monitoring and inspections; advanced and holistic asset decisions; advanced and holistic design and certification of assets; remotely controlled, unmanned and metadata-assisted interventions. • Economic assessments for some of these developments. • Global simulation results of some of the developments or specific results of the planned demonstrators.

FA4

This FA is linked to task 2 and includes outputs and results relevant for the systems related to the CCS+ identified within the proposed SP system architecture. This mainly involves the energy management considerations for the traffic management and train control functions. However, the expected inputs from the IP to the SP can be found both in FA1 and FA4, and it remains to be clarified whether the work will be done by a specific FA or handled by a combined taskforce.

SP	IP
• Energy savings principles and targets for traffic management. • Decisions on the levels of requirement and modularity necessary for the energy savings functionalities for any input to the standardisation and TSI input plan.	• Specifications for planning tools and interfaces for: a. optimisation methods for capacity efficiency and energy saving (FA1/FA4); b. feedback loops from operations (FA1/FA4) for the part related to energy. • Technical specifications for operation tools and interfaces (including for the control and command layer) for: a. automation and decision support, dispatching and incident management, disruption management, and conflict detection and resolution (FA1); b. Energy savings module specifications and interfaces for these functions, including for real-time timetabling (FA4).

The outputs related to advanced environmental data management envisaged in this FA are of interest to the data structure. These are described in the section transversal to all FA and that is also applicable to TT.

Europe's Rail

Task 1 linked: For other of the results expected in this FA, contributions to the rail system architecture and operational concept are expected for the task 1 of the SP.

SP	IP
• Functional, logical and physical architecture. • Overall operational concept.	• Description of the specific developments linked to operational requirements or system architecture, including alternative energy solutions for RS, enhanced energy management at stations, alternative fuels for railways, the improvement of systems aimed at reducing energy consumption, noise emissions and vibrations, and the development of systems supporting a healthier railway. • Economic assessments of these developments. • Global simulation results of the developments or specific results of the planned demonstrators.

FA5

This FA is linked to task 2; previous sections in this document include what is expected from FA1 and FA2 regarding the function to manage railway stations and depots. Greater standardisation and harmonisation of operations in stations and depots will enhance the performance of the railway system in its interface with customers. Outcomes included in FA5 will collaborate towards this objective.

SP	IP
• CCS principles, operational concept, functional architecture and requirements for specialised railway areas like shunting yards, shunting zones in stations, depots, terminals and connected industry areas.	• FA1 – System requirements and dataset interfaces for the connection TMS & CTC, and automated yards. • FA1 – Dataset and interfaces for the Integration with yard and station management. • FA2 – engineering rules for terminals. • FA2 – operational rules for movements in terminals. • FA5 – system requirements for automation components such as automated/automatic brake test systems or automated parking brake systems. • FA5 – system requirements and dataset interfaces for the wagon identity system and yard automation equipment and tools.

Linked to task 1, one of FA5's main objectives is to improve seamless rail freight. This has several outcomes relevant for the CCS+ system of interest in its layer or interface to the traffic management. The expectations between the SP and the IP are therefore built on the table included previously for FA1.

SP	IP
• Operational and architecture concept for an European TMS, including operational requirements and CCS principles.	• FA1 – system requirements for cross-border scheduling. • FA1 – interface specifications and dataset for interoperable connected TMS. • FA1 – interface specifications and dataset to integrate rail traffic within door-to-door mobility. • FA5 – system requirements for freight automatic cross-border slot finding. • FA5 – freight requirements for seamless traffic management planning and operation.

The migration towards the target system envisaged by EU-Rail for the freight sector is identified as a challenge in the FA5 document. The SP expects to deliver a railway system architecture migration roadmap; to achieve this, FA5 needs to produce a specific migration roadmap for the target system in specific for freight.

The outputs related to freight data envisaged in this FA are relevant to the data structure. These are described in the section transversal to all FA and that is also applicable to TT.

For other of the results expected in this FA, contributions to the rail system architecture and operational concept are expected for the task 1 of the SP.

SP	IP
• Functional, logical and physical architecture. • Overall operational concept.	• Description of the specific developments linked to the operational requirements or system architecture, including DAC types 4 and 5, and hybrid, new telematic solutions, checkpoints at borders or other operational stop points, and rostering concepts. • Economic assessments of these developments. • Global simulation results of the developments or specific results of the planned demonstrators.

FA6

This FA is linked to task 2 and, as mentioned in FA6, the survival of regional lines and fleets depends on their economic viability. It is therefore expected of the SP that this is evaluated at the rail system level, including both the infrastructure and the vehicles. Hence, the initial expectations from the SP to this FA focus on the identification of the architecture elements and operational principles that would allow this economic viability to be achieved.

SP	IP
• Functional, logical and physical architecture, including the list of signalling devices that the CCS+ layer will control and the different CCS+ modules on board: • (aa) (after interaction with FA6 economic assessment and migration considerations) target CCS+ regional architecture that includes the subset of the functions, interfaces and components included in the overall SP architecture that are sufficient for the regional operation and that optimise this economic viability. • Architecture migration roadmap. • Operational concept.	• Economic assessments for optimising economic viability with the SP architecture on regional lines: a. criteria to define the required functions, modules, interfaces and constituents that will optimise economic viability for regional services. • Asset life cycle, production process and device designs (including simplified configuration on board and trackside) that comply with the architecture interfaces and principles of FA1 and FA2, while meeting economic requirements. • As-is analysis of the current systems on regional lines for the traffic management and CCS layers, including a description of their characteristics that will support the next steps of the migration towards the identified target digital regional system: a. including, for example interface with the existing interlocking systems and the challenges of migrating them to the target regional CCS+ architecture.

Transversal to all FAs and applicable to Transversal Topic (TT)

Conceptual data model, process and architecture models

Building a conceptual data model for the railway system falls within the scope of EU-Rail. Regarding CCS+, the draft functional architecture identifies several interfaces between different functions within the system of interest yellow boxes, and between these functions and the related systems shaded yellow boxes. These would be the priority areas for data inclusion in the model.

SP	IP
• Conceptual data model at least for the interfaces between the different functions included in the CCS+ scope, and the interfaces of the CCS+ functions and related systems. • Functional, logical and physical architecture. • Standard framework for process specification and modelling for the integration of a centralised model (including assurance). • Principles and method for master data management, data flows and registries (e.g. functional track network topology).	• All the FAs should contribute with detailed data flows and the necessary structures. • TT supports the collection of data flows and structures for this set of data and provides an integrated conceptual data model for the functional, logical and physical architecture. For this, TT provides a modelling service and interface for the architectural process and ensures the integrity of the model. • Centralised ontology register and change management/governance process. • Centralised modelling platform (also as a extranet service). • TT solutions supporting the gathering, transmitting, storage and management of data done by the main IM and RU (including, where possible, automatic data acquisition). • Specifications and demonstrator for the digital register (important basis for DTs). • Standard DT framework regarding process specification and modelling for the integration of a centralised model (including assurance).

Continuous integration of results into a simulated architecture: model checking

In addition to the data model, which will include at least the interoperable data, a digital model (potentially also including simulations or implementations) that serves as a virtual representation capable of imitating the behaviour of the railway system throughout its life cycle is expected to be delivered by the TT. This model should enable continuous integration, maturity assessments, virtual certification and validation of systems or specifications. Requirements and results for these are also expected from the SP.

Mutual waiting for results between higher and lower architectural design levels or between different functions shall be avoided. A continuous integration process shall be defined, monitored by the SP and continuously simulated in TT that allows top-down and bottom-up integration of FA and SP results in parallel.

This continuous integration process will enable rapid development of individual functionalities as isolated models or prototypes (based on a standard TT framework). It will also ensure their subsequent integration into a testable model that simulates the overall CCS+ or railway system architecture. The depth and functional completeness of the model will correspond to the integration validation needs defined by the SP. The model shall be designed as a continuous laboratory that also supports the evaluation of change requests.

The centralised architecture model service, a necessary instrument for continuous integration, plays a key role in achieving the SP targets and ensuring end-to-end quality of the architecture. Therefore, the interaction between the SP and TT should be close and based on an agile workflow management approach.

SP	IP
Defines integration and validation needs and depth for the implementation of the DT. Continuously monitors the integration process, including the maturity of integration.	• TT defines a standardised framework for the development of prototypes that can be integrated into a full-system DT based on a continuous integration process. • TT provides a centralised DT laboratory (at least for CCS+) to validate the integration of prototypes that may initially be developed as isolated solutions. Through systematic test-driven development of the DT, the lab generates reports on integration problems. Test definitions are provided by FA1–FA6.

Additional considerations

These expectations from the SP and the IP are related to the anticipated deliverables within the technical scope of the system. However, there are other aspects that are expected from both the SP and the IP and that are essential to achieving the objectives set out in EU-Rail. The following are common to the various technical scopes within the CCS+.

- Regarding migration, the SP will deliver a target system / target systems together with stable intermediate steps to reach it/them. For this, it is expected that the IP will provide, in some cases, details of the current technical solutions. Also, the IP will review the stable intermediate steps to ensure alignment with the roadmap of their innovative solutions.
- Maturity records or pilots for different innovative solutions will be monitored by the SP. The design of such pilots should align with the operational concept and functional architecture of the SP, so iteration between pillars should be expected. In addition, as part of the results of these pilots, the IP is expected to develop the testing and validating requirements necessary to evaluate the success of the demonstrator, and to test and validate the innovative solutions once they are incorporated into regulations or standards. This includes testing requirements for newly developed functions and, if necessary, updated testing requirements for any development of existing functionality (e.g. with ETCS)
- The SP will define principles regarding data exchange, communication methods, function and service design and interface design for all standardised interfaces.
- The SP will derive top-level requirements from the operational concepts and the identified pain-points or opportunities and will break them down into process and architectural requirements. The IP will design compatible system requirements that fulfil these. As a part of the validation process, the correctness of this requirement derivation will be traced by the SP.
- To structure the architectural integration process, the SP will define integration milestones and their validation targets.

At this stage, there is no agreed detailed architecture, nor a logical or physical agreed architecture approach for CCS+. Therefore, when referring to an FFFIS, this should not be interpreted solely as a physical interface – this may also involve, for example, a software interface. Further analysis of the concept of a modular safety platform for several uses is also envisaged. The level of detail regarding interfaces and modularity needs to be discussed and agreed, taking business and economic impacts into account.

Once the deliverables proposed in this technical note have been discussed and agreed, they will be the first input for the standardisation and TSI input plan that the SP needs to develop. Also, in all the different points included in this note, a standardisation proposal or a change request to a TSI will be drafted by the SP, taking into account the input from the IP. These deliverables are key to the role of the SP as a 'generic system integrator' for EU-Rail.

Annex B. Flagship areas and transversal topic activities interdependencies

TABLE 57. **shows the expected interdependencies between the FAs and is subject to further changes based on the output of the respective FAs**

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
DAC-based digital applications for safety related applications	**FA5**		**Demonstration TRL 7**		**Demonstration TRL 8**		
	FA1/ FA2		Use FA5 data outputs.		Use FA5 data outputs.		Use FA5 data outputs.
DAC-based train operation concerning train integrity and length	**FA5**	Requirements/ feedback and adjustments that may become necessary for the use of DAC.	**Demonstration TRL 7**	Requirements/ feedback and adjustments that may become necessary for the use of DAC.	**Demonstration TRL 8**	Requirements/ feedback and adjustments that may become necessary for the use of DAC.	
	FA2	TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).		TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).		TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).	

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
DAC-based train operation concerning efficient driving and energy management	**FA5**	Requirements/ feedback	**Demonstration TRL 6/7**	Requirements/ feedback	**Demonstration TRL 7/8**	Requirements/ feedback	**Demonstration TRL 8**
	FA1		**TRL 6** Decision support and optimisation: optimisation methods for timetabling and railway planning.		**TRL 7** Decision support and optimisation: optimisation methods for timetabling and railway planning.		**TRL 7** Decision support and optimisation: optimisation methods for timetabling and railway planning.
	FA1		**TRL 5/6** Integration of energy management (electric traction system).		**TRL 6/7** Integration of energy management (electric traction system).		**TRL 7** Integration of energy management (electric traction system).
DAC-based yard operation: fully automated shunting loco movements (GoA4)	**FA5**	Requirements/ feedback and special functions for automatic and autonomous shunting operations / train protection system for shunting and reaction system (push/pull functions).	**Demonstration TRL 5/6**	Requirements/ feedback and special functions for automatic and autonomous shunting operations / train protection system for shunting and reaction system (push/pull functions).	**Demonstration TRL 7**	Requirements/ feedback and special functions for automatic and autonomous shunting operations / train protection system for shunting and reaction system (push/pull functions).	**Demonstration TRL 7/8**

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA2		**Development TRL 5/6** New ATO technology solutions for automated driving and decision-making, interoperable, and for all applications and segments, including freight-specific issues in commercial operations. Includes the already available integration of C-DAS and will include appropriate TMS interfaces for energy network management.		**Development TRL 6/7** New ATO technology solutions for automated driving and decision-making, interoperable, and for all applications and segments, including freight-specific issues in commercial operations. Includes the already available integration of C-DAS and will include appropriate TMS interfaces for energy network management.		**development TRL 7:** New ATO technology solutions for the automated driving and decision-making, interoperable, and for all application and segments, including freight specific issues for commercial run. It includes the already available integration of C-DAS and will include appropriate interfaces with TMS for energy network management
	FA2				**TRL 6** Full continuous supervision (cab signalling) in all normal modes, for freight stabling and for yellow fleet movements.		**TRL 7** Full supervision (cab signalling) continuously in all normal modes, also for freight stabling, or for yellow fleet movements.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
DAC-based yard operation: yard digitalisation for fully automated train composition and dispatching (ASO)	**FA5**	DAC-based automation functions: shunting-operation-specific function in FA5 ensuring interconnectivity with main-line systems (ATP, positioning, object detection, etc.). This especially includes DAC-based automation functions such as automatic uncoupling.	**Demonstration TRL 6/7**	DAC-based automation functions: shunting-operation-specific function in FA5 ensuring interconnectivity with main-line systems (ATP, positioning, object detection, etc.). This especially includes DAC-based automation functions such as automatic uncoupling.		DAC-based automation functions: shunting-operation-specific function in FA5 ensuring interconnectivity with main-line systems (ATP, positioning, object detection, etc.). This especially includes DAC-based automation functions such as automatic uncoupling.	
	FA2		**Development TRL 5/6** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.		**TRL 6** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.		**TRL 7** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
DAC-based yard operation: yard automation equipment	**FA5**	Yard automation equipment	**Development TRL 5/6**	Yard automation equipment	**Demonstration TRL 7**	Yard automation equipment	**Demonstration TRL 7/8**
	FA2		**Development TRL 5/6** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.		**TRL 6** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.		**TRL 7** Automating functions, such as train preparation, for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness.
Seamless planning of rail freight services	**FA5**	Requirements/ feedback	**Demonstration TRL 6/7**	Requirements/ feedback	**Demonstration TRL 7/8**	Requirements/ feedback	**Demonstration TRL 8**
Integration of cross-border timetable planning functions, management and path-ordering systems covering digital capacity management planning horizons and, in particular, the specific needs of short-term path requests for (international) freight services.	**FA1**		**TRL 6/7** Cross-border planning: Towards European cross-border scheduling Improved capacity allocation using rolling planning and TTR.		**TRL 7** Cross-border planning: Towards European cross-border scheduling Improved capacity allocation using rolling planning and TTR.		**TRL7/8** Cross-border planning: Towards European cross-border scheduling Improved capacity allocation using rolling planning and TTR.
	FA1		**TRL 5/6** Decision support for short-term planning.		**TRL 7** Decision support for short-term planning.		**TRL 7** Decision support for short-term planning.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Seamless planning of rail freight services **Integrating and connecting last-mile (e.g. accessionlines, shunting, yards and terminals) slot planning directly or via interfaces.**	**FA5**	Requirements/ feedback	**TRL 6** specific freight developments	Requirements/ feedback	**Demonstration TRL 7**	Requirements/ feedback	**Demonstration TRL 8**
	FA1		**TRL 5/6** Integration with yard capacity planning.		**TRL 6/7** Integration with yard capacity planning.		**TRL 7** Integration with yard capacity planning.
Dynamic dispatching tools used in last-mile operations **Harmonised real-time interfaces between TMS and, for example, yard/terminal management systems and agreed data structure/quality.**	**FA5**	Requirements/ feedback	**Demonstration TRL 6/7**	Requirements/ feedback	**Demonstration TRL 7/8**	Requirements/ feedback	**Demonstration TRL 8**
	FA1		**TRL 5/6** Integration with yard capacity planning.		**TRL 6/7** Integration with yard capacity planning.		**TRL 7** Integration with yard capacity planning.
Dynamic dispatching tools used in last-mile operations **Dynamic yard/terminal management systems upgrade with optimisation functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1).**	**FA5**	Requirements/ feedback	**Demonstration TRL 6**	Requirements/ feedback	**Demonstration TRL 7**	Requirements/ feedback	**Demonstration TRL 7/8**
	FA1		**TRL 5/6** Integration with yard capacity planning.		**TRL 6/7** Integration with yard capacity planning.		**TRL 8/7** Integration with yard capacity planning.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Dynamic dispatching tools used in last-mile operations	**FA5**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 6/7**	Requirements/ feedback	**Demonstration TRL 7/8**
Dynamic freight-specific real-time functions for interaction between various TMSs (FA1) and with other management systems.	**FA1**		**TRL 6** Cross border operation: Real-time connection of the networks Improved modelling for cross-border.		**TRL 6/7** Cross border operation: Real-time connection of the networks Improved modelling for cross-border.		**TRL 8/7** Cross border operation: Real-time connection of the networks Improved modelling for cross-border.
Dynamic freight-specific real-time functions for interaction between various TMSs (FA1) and with other management systems.	**FA1**		**TRL 6** Improved integration: connection TMS & CTC, and automated yards; integration with yard management; integration of station management.		**TRL 6/7** Improved integration: connection TMS & CTC, and automated yards; integration with yard management; integration of station management.		**TRL 7** Improved integration: connection TMS & CTC, and automated yards; integration with yard management; integration of station management.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
ATO over ETCS adapted to regional operations **Progressive evaluation and implementation of driver advisory systems and radio-based, all-weather ATO over ETCS up to GoA3/4 applicable and adapted to regional operations, including OD systems. Aspects to be considered include energy savings and the optimisation of driving schedules and remotely controlled trains, especially, though not only, in shunting areas or last-mile movements.**	**FA6**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 6**	Requirements/ feedback	**Demonstration TRL 7**

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA2		**Development TRL 5/6 New ATO technology solutions** for automated driving and decision-making, interoperable, and for all applications and segments, including freight- and region-specific issues. They should include, when relevant, the already available integration of C-DAS and should include appropriate TMS interfaces for energy network management.		**Development TRL 6/7 New ATO technology solutions** for the automated driving and decision-making, interoperable, and for all application and segments, including freight and regional specific issues. It should include when relevant the already available integration of C-DAS and should include appropriate interfaces with TMS for energy network management		**Development TRL 7 New ATO technology solutions** for the automated driving and decision-making, interoperable, and for all application and segments, including freight and regional specific issues. It should include when relevant the already available integration of C-DAS and should include appropriate interfaces with TMS for energy network management

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA2		**Safe environment perception TRL 5/6**, including signal reading and OD, supporting cooperative awareness, supported by virtual certification.		**Safe environment perception TRL 6/7**, including signal reading and OD, supporting cooperative awareness, supported by virtual certification.		**Safe environment perception TRL 7**, including signal reading and OD, supporting cooperative awareness, supported by virtual certification.
	FA2		**Remote driving and command solutions TRL 6/7**, for depots, lines with low traffic, fall-back operations and shunting.		**Remote driving and command solutions TRL 6**, for depots, lines with low traffic, fall-back operations and shunting.		**Remote driving and command solutions TRL 7**, for depots, lines with low traffic, fall-back operations and shunting.
Hybrid train detection, moving block and relative braking distance	**FA6**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 6**	Requirements/ feedback	**Demonstration TRL 7**
	FA2		**TRL 5/6** Mixed level 2, hybrid train detection, moving block and relative braking distance.		**TRL 6** Mixed level 2, hybrid train detection, moving block and relative braking distance.		**TRL 7** Mixed level 2, hybrid train detection, moving block and relative braking distance.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Regional cost-effective communications **Cost-effective use of dedicated railway mobile networks or third party communication infrastructures (e.g. 4G, 5G, satcom and IoT communications) for innovative information exchange between regional railway subsystems (e.g. train to train, train to trackside /wayside assets, trackside to trackside). Particular attention will be given to aspects of multi-bearer platforms and their use (building on Shift2Rail results on ACS and FRMCS), the transmission of vital CCS data over public networks, new communication service features and their application in regional railways, and cybersecurity aspects. The objective is to provide an effective communication tool for various potential applications, including ETCS, ATO (up to driverless operations), high-quality passenger services, smart maintenance, and support for innovative ways to connect rolling stock and wayside elements.**	**FA6**	Requirements/ feedback on dedicated railway mobile networks in the remit of FA2 and investigation regarding the use of public networks in FA6.	**Demonstration TRL 4/5**	Requirements/ feedback on dedicated railway mobile networks in the remit of FA2 and investigation regarding the use of public networks in FA6.	**Demonstration TRL 6/7**	Requirements/ feedback on dedicated railway mobile networks in the remit of FA2 and investigation regarding the use of public networks in FA6.	**Demonstration TRL 8**
	FA2		**TRL 5/6** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements).		**TRL 6/7** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements).		**TRL 7** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements).

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
TMSs and C-ITS for regional lines **TMSs for regional lines improving the resilience of a connected rail network, optimising train operations, including during disturbances. Multimodal timetable integration, such as tactical planning through simulation and optimisation with other transport modes, to ensure multimodality through the integrated management of rail and other services (buses, trams, metro, taxi, carsharing, bicycles, park and ride) from a single command post, in coordination with C-ITS services. Managing real-time on-demand optimised timetables, rescheduling and route setting.**	**FA6**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 6**	Requirements/ feedback	**Demonstration TRL 7**
	FA1		**TRL 6** Decision support for short-term planning.		**TRL 7** Decision support for short-term planning.		**TRL 7/8** Decision support for short-term planning.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA1		**TRL 5/6** Decision support and optimisation (operation): increased automation in decision support; real-time conflict detection and resolution (for regional and main lines and optimisation, different from S2R).		**TRL 7** Decision support and optimisation: increased automation in decision support; real-time conflict detection and resolution (for regional and main lines and optimisation, different from S2R).		**TRL 7** Decision support and optimisation: increased automation in decision support; real-time conflict detection and resolution (for regional and main lines and optimisation, different from S2R).

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA1		**TRL 5/6** Anticipate demand in order to improve resource utilisation: short-term demand forecast calculation; long-term demand forecast calculation; integrate demand forecast into DT to optimise offers; manage/ communicate disruptions across transport modes; optimise rail capacity to meet demand more efficiently.		**TRL 6/7** Anticipate demand leading to improved resource utilisation: Short term demand forecast calculation Long term demand forecast calculation Integrate demand forecast in digital twin to optimise offer Manage/inform disruptions across modes Optimise rail capacity to better match the demand		**TRL 7** Anticipate demand leading to improved resource utilisation: Short term demand forecast calculation Long term demand forecast calculation Integrate demand forecast in digital twin to optimise offer Manage/inform disruptions across modes Optimise rail capacity to better match the demand

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Regional cost-effective fail-safe highly accurate train positioning	**FA6**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 6**	Requirements/ feedback	**Demonstration TRL 7**
Cost-effective interoperable fail-safe highly accurate train positioning based on, among others, hybrid multi-sensor (including GNSS) technologies and on-board databases of digital maps, as a means to reduce the number of balise installations, increase operational efficiency and decrease the TCO in the context of regional lines.	**FA2**	Requirements/ feedback	**TRL 5/6** Absolute STP, highly accurate and safe, incorporating new sensors.	Requirements/ feedback	**TRL 6** Absolute STP, highly accurate and safe, incorporating new sensors.	Requirements/ feedback	**TRL 7** Absolute STP, highly accurate and safe, incorporating new sensors.
	FA2		**TRL 5/6 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.		**TRL 6 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.		**TRL 7 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.
	TT		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM
Regional cost-effective fail-safe on-board train integrity	**FA6**	Requirements/ feedback	**Demonstration TRL 4/5**	Requirements/ feedback	**Demonstration TRL 5**	Requirements/ feedback	**Demonstration TRL 7**
Cost-effective fail-safe on-board train integrity to verify the completeness of the train while it is in operation. **Cost-effective fail-safe train length detection to determine the beginning and end of the train and detect its length.**	**FA2**	TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).	**TRL 5/6** Mixed level 2, hybrid train detection, moving block and relative braking distance.	TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).	**TRL 6** Mixed level 2, hybrid train detection, moving block and relative braking distance.	TIMS to match the ETCS EVC (CCS TSI) (class 3, which is currently the state of the art).	**TRL 7** Mixed level 2, hybrid train detection, moving block and relative braking distance.

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Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Digital platforms for CCS validation and TSI certification in the regional line domain **Technology infrastructures available to the stakeholders involved in regional line APIS (authorisation for placing into service) processes will provide integral solutions to speed up related activities and reduce associated costs, focusing in particular on the application of digital certification in this line typology.** **Inspired by the Commission's zero on-site testing initiative, these platforms aim to bring a range of CCS tasks – such as design, testing, inspection, or maintenance – into a DT, including tasks traditionally performed on-site at different life cycle phases. This will allow potential integration issues to be identified and addressed at early stages of projects.**	**FA6**	Requirements/ feedback	**Demonstration TRL 4**	Requirements/ feedback	**Demonstration TRL 5**	Requirements/ feedback	**Demonstration TRL 7**
	FA2		**TRL 5** Testing, validation and (virtual) certification platforms and facilities.		**TRL 6** Testing, validation and (virtual) certification platforms and facilities.		**TRL 7** Testing, validation and (virtual) certification platforms and facilities.
	FA2		**TRL 5 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.		**TRL 6 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.		**TRL 7 Digital register** acting as a central data source for STP, ATP, TMS and DATO, among others.
	TT		Support by TT available w.r.t. DT and virtual certification		Support by TT available w.r.t. DT and virtual certification		Support by TT available w.r.t. DT and virtual certification

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Regional new propulsion train refuelling/recharging station **Alternative fuelling solutions for regional railways, such as hydrogen, e-fuels and battery fuelling (dynamic and static charging). Development efforts should concentrate on identifying solutions for road and rail fuelling and charging stations along regional lines.**	**FA6**	Requirements/ feedback			**TRL 3** Requirements, adaptation of concept design for multimodal application based on FP4.		

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA4		**TRL 5/6** Railway strategic hydrogen demonstrator. Application of solutions addressing the production, storage and refuelling of hydrogen for railway vehicles, demonstrated on a prototype refuelling station. Development of a standard refuelling interface using algorithms to ensure optimal timing and safety throughout the process. Provide scalability and future growth of the refuelling station to meet the demand for hydrogen.				
Virtual coupling, including self-driving freight wagons, supporting cooperative awareness	**FA2**		**Development TRL 5**		**Development TRL 6**		-
	FA5	Requirements/ feedback		Requirements/ feedback			

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Operational feedback for planning: planning using feedback loops from operations **Integration of feedback loops with ATO/TMS for higher capacity** **Using ATO journey profiles for timetabling**	**FA1**		**Development TRL 5/6**		**Demonstration TRL 6/7**		**Demonstration TRL 6/7**
	FA2	Provide parameters for planning and simulation tools to calculate the capacity benefits.		Requirements/ feedback		Requirements/ feedback	
	TT		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM
Optimisation methods for timetabling and railway planning	**FA1**		**Development TRL 6**		**Demonstration TRL 7**		**Demonstration TRL 8/9**
	FA4	DAS/C-DAS and energy management experts input.	**TRL 5–7** Innovative energy management models and systems that can be integrated into subsequent energy optimisation models and systems considered by FA1 (e.g. C-DAS) and FA2 (ATO driving curve).	DAS/C-DAS and energy management experts input.	**TRL 6–8** Innovative Energy Management models and systems that can be integrated in further energy optimisation models and systems considered by FA1 (e.g. Connected DAS) and FA2 (ATO driving curve).	DAS/C-DAS and energy management experts input.	**TRL 7/8** Innovative Energy Management models and systems that can be integrated in further energy optimisation models and systems considered by FA1 (e.g. Connected DAS) and FA2 (ATO driving curve).

Capabilities that require input/output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	FA2		**TRL 5/6**: **New ATO technology solutions** for automated driving and decision-making, interoperable, and for all applications and segments, including freight-specific issues. Includes, when relevant, the already available integration of C-DAS and will include appropriate TMS interfaces for energy network management.		**TRL 6/7: New ATO technology solutions** for the automated driving and decision-making, interoperable, and for all application and segments, including freight specific issues. It includes when relevant the already available integration of C-DAS and will include appropriate interfaces with TMS for energy network management		**TRL 7: New ATO technology solutions** for the automated driving and decision-making, interoperable, and for all application and segments, including freight specific issues. It includes when relevant the already available integration of C-DAS and will include appropriate interfaces with TMS for energy network management
	FA5	Requirement input.		Requirement input.		Requirement input.	

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
Real-time convergence between planning and operations	**FA1**		**Development** **TRL 5**		**Demonstration** **TRL 6/7**		**Demonstration** **TRL 7**
Cooperative planning multi-actors **Dispatching, incident management and customer information** **Disruption management** **Speed regulation, precise routes and target times for ATO and dynamic timetables**	**FA3**		**TRL 6** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation) and to enable high-performance computing with the data.		**TRL 7** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation) and to enable high-performance computing with the data.		**TRL 8** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation) and to enable high-performance computing with the data.
	FA2		**TRL 5/6** Automated maintenance and inspection solutions.		**TRL 6** Automated maintenance and inspection solutions.		**TRL 7** Automated maintenance and inspection solutions.
	FA7		**TRL 2/3** Specific capabilities of the innovative systems (e.g. operational characteristics) based on operational concept.		**TRL ¾** Specific capabilities of the innovative systems (e.g. operational characteristics) based on transport coordination system.		**TRL 5/6** Specific capabilities of the innovative systems (e.g. operational characteristics) based on prototype.

Capabilities that require input/ output from other FAs	FA	Before 2026	Currently written in 2026	Before 2028	Currently written in 2028	Before 2030	Currently written in 2030
	TT		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM		Support by TT available w.r.t. digital maps and CDM

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HI-01-25-000-EN-C

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Publications Office
of the European Union

ISBN 978-92-95215-30-6