# *Europe's Rail Joint Undertaking Multi-Annual Work Programme*

***Version 2.0***

***1 March 2022***

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## Abbreviations

| | |
|---|---|
| AC | Alternative Current |
| ACS | Adaptable Communication System |
| AGTU | Air Generation And Treatment Unit |
| AI | Artificial Intelligence |
| ALICE | Alliance For Logistics Innovation Through Collaboration In Europe |
| ATC | Automatic Train Control |
| ATO | Automatic Train Operation Or Autonomous Train Operations |
| 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 |
| CCA | Cross-Cutting Activities |
| CCS | Control Command And Signalling |
| C-DAS | Connected Driver Assistance Systems |
| CDM | Conceptual Data Model |
| CEN/CLC/JTC | Cen / Cenelec /Joint Technical Committee |
| CER | Community of European Railway and Infrastructure |
| COP | Coefficient Of Performance |
| CSM | Common Safety Method |
| DAC | Digital Automatic Coupler |
| DATO | Digital & Automatic Train Operation |
| DC | Direct Current |
| DCM | Digital Capacity Management |
| DT | Digital Twin |
| EC | European Commission |
| ECM | Entity In Charge Of Maintenance |
| EDDP | European DAC Delivery Programme |
| EECT | Era Extended Core Team |
| EIM | European Rail Infrastructure Managers |
| EMB | Electro-Mechanical Brakes |
| ENE | Energy |
| ENISA | European Union Agency for Cybersecurity |
| ERA | European Agency For Railways |
| ERRAC | European Rail Research Advisory Council |
| ERTMS | European Rail Traffic Management System |
| ESA | European Space Agency |
| ETCS | European Train Control System |
| EU | European Union |
| EU Rail JU | Europe’s Rail Joint Undertaking |
| EUG | Ertms Users Group |

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|---|---|
| EU-RAIL JU | Europe’s Rail Joint Undertaking |
| EUSPA | European Union Agency For The Space Program |
| FA | Flagship Area |
| FC | Fuel Cell |
| FFFiS | Form Fit Function Interface Specification |
| FiS | Functional Interface Specification |
| FM | Founding Member of the JU |
| FRMCS | Future Railway Mobile Communication System |
| FTE | Forum Train Europe |
| GoA | Grade Of Automation |
| HDV | Heavy Duty Vehicles |
| HIL | Hardware In The Loop |
| HMI | Human Machine Interfaces |
| HOF | Human and Organisational Factors |
| HPC | High Performance Computing |
| HVAC | Heating, Ventilation, And Air Conditioning |
| iCCTV | Closed-Circuit Television |
| IDS | International Data Space |
| IFC | Industry Foundation Classes |
| IM | Infrastructure Manager |
| INF | Infrastructure |
| IoT | Internet Of Things |
| IP | Innovation Program (Of Shift2Rail) |
| IP | Intellectual Property |
| IPCC | Intergovernmental Panel On Climate Change |
| IT | Information Technology |
| JU | Joint Undertaking |
| KPI | Key Performance Indicator |
| LCC | Life Cycle Cost |
| MaaS | Mobility As A Service |
| MAWP | Multi-Annual Work Programme |
| ML | Machine Learning |
| MOD | Mobility On Demand |
| MP | Master Plan |
| MS | Member State |
| OPE | Operations |
| OPEX | Operational Expenditure |
| OSI Model | Open Systems Interconnection Model |
| PEM | Polymer Electrolyte Membrane |
| PIS | Passenger Information System |
| PoC | Proof Of Concept |
| PRM | Persons with Reduced Mobility |
| PTO | Public Transport Operator |
| RAMS | Reliability, Availability, Maintainability And Safety |
| RES | Renewable Energy Sources |

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|---|---|
| RFC | Rail Freight Corridors |
| RFF | Rail Freight Forwarder |
| RST | Rolling Stock |
| RTM | Railtopomodel |
| RU | Railway Undertaking |
| S2R | Shift2Rail |
| SBA | Single Basic Act |
| SERA | Single European Railways Area |
| SOFC | Solid Oxide Fuel Cells |
| SP | System Pillar |
| SRIA | Strategic Rail Research And Innovation Agenda |
| SRS | Software Requirement Specification |
| SSBD | Safe and Sustainable by Design |
| STP | Safe Train Positioning |
| TCMS | Train Control Monitoring System |
| TCO | Total Cost of Ownership |
| TIMS | Train Integrity Monitoring System |
| TMS | Traffic Management System |
| TOD | Transit Oriented Development |
| TP | Transforming Project |
| TRL | Technology Readiness Level |
| TSI | Technical Specification for Interoperability |
| TT | Transversal Topic (On Digital Enablers) |
| TTD | Trackside Train Detection |
| TTR | Time Table Redesign |
| UIC | International Union Of Railways (Union Internationale Des Chemins De Fer) |
| UIC | International Union of Railways |
| UIP | International Union of Wagon Keepers |
| UITP | International Association of Public Transport |
| UNIFE | Union des Industries Ferroviaires Européennes |
| UNISIG | Union industry of signalling (UNIFE committee) |
| UNITEL | Union industry of telecom (UNIFE committee) |
| V&V | Verification And Validation |
| V2X | Vehicle To Everything (Vehicle \| Infrastructure \| Pedestrian \| Etc.) [IEEE 802.11p And 3GPP R14 And Above] |
| VHSDT | |
| VPP | Virtual Power Plant |
| WHO | World Health Organisation |

# 1 About the Europe's rail Multi-Annual Work Programme

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

In accordance with the SBA, EU-Rail has defined in its Master Plan[2] its priority research and innovation activities, overall system architecture and harmonised operational approach, including large-scale demonstration activities and flagship areas. These are required to accelerate the penetration of integrated, interoperable and standardised technological innovations necessary to support the Single European Railway Area. The Master Plan provides an overview of the ambitions and the objectives of EU-Rail and defines a systemic, long-term and result-oriented delivery strategy for research & innovation in the railway sector.

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

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

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

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

a) Changing customer requirements: demographic, technological, market and political trends are changing the needs of passenger and freight customers. These shifts, along with disruptive events like the COVID19 pandemic, require rail to be more flexible than in the past.

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1 Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R2085https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R2085

2 Adopted by the European Commission on xx/02/2022 and by the EU-Rail Governing Board on 01/03/ 2022.

b) Need for improved performance and capacity: in order to deliver an overall more sustainable transport mix, rail must be able to accommodate increased demand.
c) High cost: rail is currently often more expensive compared to other transport modes. To be more competitive and support future increased usage, rail must deliver more cost-efficient solutions and services compared to today.
d) Climate change: rail is the most sustainable motorised mode of transport, as indicated in a recent report of the European Environmental Agency. Increased use of rail is necessary to fulfil European climate objectives and rail assets need themselves to be climate resilient.
e) Legacy systems and obsolescence: rail system assets are procured assuming very long lifecycles and are based on national approaches, which makes fast and interoperable transformation difficult.
f) Interaction with other modes: rail networks and the services associated to them in some contexts link well with other transport modes. But such integration must be improved to better serve the needs of customers, and make rail central to future mobility and a more attractive mode overall.
g) Increased competition. The European rail supply industry is world leading. However, it faces many challenges at 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 has to:

- bring to completion and deliver the ongoing S2R Programme and Projects, that will also set the baseline for the new Programme, including fostering the market uptake of mature solutions, e.g. those being part of the TSI 2022 package, etc. These activities will continue to be performed under the H2020 regulatory framework. In order to ensure Projects monitoring at JU level, the S2R Innovation Programme Steering Committees will be convened on a regular basis;

- implement the EU-Rail Research and Innovation 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 Union policy objectives and international commitments;

- set up an internal management and control system to ensure the sound financial management and the legality and regulatory 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 SBA, details the tasks to be performed by EU-Rail to deliver its objectives.

# 2 The Vision and Mission Statement of Europe’s Rail JU

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 Europe's Rail JU

In addition to the General and Specific Objectives established in Chapter 1 of the SBA, EU-RAIL is entrusted with the following:

***General Objectives***

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

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

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

***Specific objectives***

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

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

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

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

(e) develop demonstration projects in interested member states;

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

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

In carrying out its activities, the Europe's Rail Joint Undertaking 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 research and innovation, in line with the Commission priorities.

***Additional tasks***

In addition to the tasks set out in Article 5, the Europe's Rail Joint Undertaking together with the Commission shall also prepare and, after consultation of the states' representative group, 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 detailed in EU-RAIL Master Plan, complemented by the MAWP.

This section, it is not exhaustive and highlights the relevant element of the legal framework and governance of the JU in relation to the Programme Management.

## 4.1 SBA

Council Regulation (EC) 2021/2085[3] (hereinafter the SBA) sets out the legal basis of EU-RAIL and its Programmes. The Other 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 total contribution defined in Article 87 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 Other Members' Letter of Commitment*

Other Member's Letter of Commitment details the scope of the membership in terms of content, activities and their duration, the concerned Member contributions to the JU, including an indication of the envisaged additional activities referred to in point (b) of Article 11(1) SBA. The Letter of Commitment does not contain conditions regarding its accession

[3] OJ L 427, 30.11.2021, p.17

other than those set out in the SBA. Hence, the Other Members shall contribute to the proper implementation of the EU-RAIL Programme in accordance with the objectives and requirement set out in the SBA.

## 4.2 GB and GB Decisions

The Governing Board is the decision-making body of the Joint Undertaking. It shall have overall responsibility for the strategic orientation, coherence with relevant Union objectives and policies, and the operations of the joint undertaking and shall supervise the implementation of its activities. In accordance with Article 17 of the SBA, the GB shall, among others:

- take measures to implement the joint undertaking's general, specific and operational objectives, assess their effectiveness and impact, ensure close and timely monitoring of the progress of the joint undertaking's research and innovation programme and individual actions in relation to the priorities of the Union and the Strategic Research and Innovation Agenda, including in relation to complementarity with regional or national programmes, and take corrective measures where needed to ensure that the joint undertaking 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 membership in the joint undertaking with regard to any member that does not fulfil its obligations;
- adopt the financial rules of the joint undertaking;
- adopt the annual budget and the staff establishment plan;
- decide on the distribution of administrative costs among the members other than the Union;
- exercise in accordance with paragraph 4 and with regard to the staff of the joint undertaking, the powers conferred by the Staff Regulations of Officials of the European Union (the 'Staff Regulations');
- appoint, dismiss, extend the term of office, provide guidance and monitor the performance of the executive director;
- adopt the Strategic Research and Innovation Agenda at the beginning of the joint undertaking and update it throughout the duration of Horizon Europe, where necessary;
- adopt the work programme and corresponding expenditure estimates as proposed by the executive director, after taking into consideration the states' representative group's opinion, to implement the Strategic Research and Innovation Agenda, including the administrative activities, the content of the calls for proposals, adopt measures for attracting newcomers, in particularly SMEs, higher education

institutions and research organisations, into the activities and actions of the joint undertaking;
- 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 joint undertaking's final accounts;
- make arrangements, as appropriate, for the establishment of an internal audit capability of the joint undertaking;
- approve the organisational structure of the programme office upon recommendation of the executive director;
- approve the joint undertaking's communication policy;
- unless specified otherwise, approve the list of actions selected for funding;
- adopt implementing rules for giving effect to the Staff Regulations and the Conditions of Employment of Other Servants in accordance with Article 110(2) of the Staff Regulations;
- adopt rules on the secondment of national experts to the joint undertakings or the use of trainees;
- set up, as required, advisory or working groups, including in collaboration with other joint undertakings, in addition to the bodies of the joint undertaking referred to in Article 13;
- submit to the Commission, where appropriate, requests to amend this Regulation;
- request scientific advice or analysis on specific issues to the joint undertaking'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 joint undertaking from Horizon Europe funding upon recommendation of the executive director;
- ensure the performance of any task that is not specifically assigned to a particular body of a joint undertaking, subject to the possibility that the governing board may assign such task to another body of the joint undertaking concerned.

Articles 92, 93, and 94 of the Single Basic Act set out the EU-Rail specific composition, functioning, and additional tasks of the Governing Board.

To be noted that in accordance with Article 86(5) SBA, the Europe's 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].

### 4.3 The Executive Director (ED) & ED Decisions

The Executive Director (ED) is the chief executive responsible for the day-to-day management of the EU-RAIL JU in accordance with the decisions of the Governing Board. The ED is the legal representative of the EU-RAIL JU and has the role to take ED decisions which have the purpose to implement the strategic plan and budget of the Programme. The ED is accountable to the Governing Board and shall provide the GB with all information necessary for the performance of its functions.

In accordance with Article 4, the ED shall, among others:

- ensure sustainable and efficient management of the joint undertaking and efficient implementation of the work programme;
- prepare and submit for adoption to the governing board the draft annual budget and the staff establishment plan;
- prepare and, after having taken into account the opinion of the states' representative group or the Public Authorities Board as appropriate, submit for adoption to the governing board the work programme and the corresponding expenditure estimates for the joint undertaking, to implement the Strategic Research and Innovation Agenda;
- prepare and submit for assessment and approval to the governing board the consolidated annual activity report, including information on the corresponding expenditure and contributions from members other than the Union referred to in Article 11(1);
- monitor the contributions referred to in Article 11(1), report to the governing board 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 particularly 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 governing board;
- submit for approval to the governing board or to the Public Authorities Board as appropriate the list of actions to be selected for funding by the joint undertaking;

[4] https://shift2rail.org/wp-content/uploads/2022/01/GB-Decision-01-2021.pdf
[5] https://shift2rail.org/wp-content/uploads/2020/01/S2R-JU-Financial-Rules.pdf

- assess applications for associated members to the joint undertaking following an open call for expression of interest and submit proposals for associated members to the governing board;
- inform regularly the other bodies of the joint undertaking on all matters relevant to their role;
- sign individual grant agreements and decisions in his or her remit on behalf of the joint undertaking;
- sign procurement contracts on behalf of the joint undertaking;
- ensure the programme's monitoring and assessment of the progress compared to relevant impact indicators and the joint undertaking's specific objectives as defined in Part Two, under the supervision of the governing board and 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 change to it to the governing board;
- protect the financial interests of the Union and of other 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 joint undertaking;
- take any other measures necessary for assessing the progress of the joint undertaking towards achieving its objectives

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

#### *4.3.1.1 The System and Innovation Pillar Programme Board*

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

The Programme Board shall be responsible for providing advice to the Executive Director on:

- Resources, implementation and monitoring the progress of the Programme (System and Innovation Pillars),
- identify risks and opportunities and related mitigating actions,
- providing strategic guidance and making recommendations, with regard to the management of the Programme,

- advise the Executive Director in solving issues escalated to his attention (e.g. potential resourcing conflicts between the Innovation and System Pillars) in accordance with the EU-RAIL Regulation on Programme implementation and propose a way forward,
- advise the Executive Director on the need to complement the Programme with specific expertise to be contracted as needed,
- assist and advise the Executive Director in any matter of relevance

The composition of the System and Innovation Pillar Programme Board shall be:

- Chair: EU-RAIL ED
- Members:
  - (a) 1 representative of the EC,
  - (b) the Other Founding Members,
  - (c) 2 representatives of the System Pillar Core Group.
  - (d) Observers may be invited to attend the meetings on the basis of the agenda points.

The meetings of the Programme Board 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 Programme Board shall meet indicatively monthly.

The Executive Director shall established by an ED Decision the System and Innovation Programme Board after having consulted the Governing Board; s/he shall report at each GB meeting about the work performed by the Programme Board.

## 4.4 The System Pillar

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

The main governance bodies involved in the System Pillar are:

- The EU-Rail Governing Board
- The System Pillar 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 deliver it.
    - the System Pillar outputs
- The System Pillar 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 delivery of the new systems
(b) Manages the common business objectives and deliverables from the Tasks

- The System and Innovation Programme Board advises the Executive Director, specifically, on:
  (a) the coordination of resources, budgets and timescales of the System and Innovation Pillars
  (b) supported by the System Pillar Core Group, project and programme management of the JU including interaction between the two pillars as well as change management and conflicts.

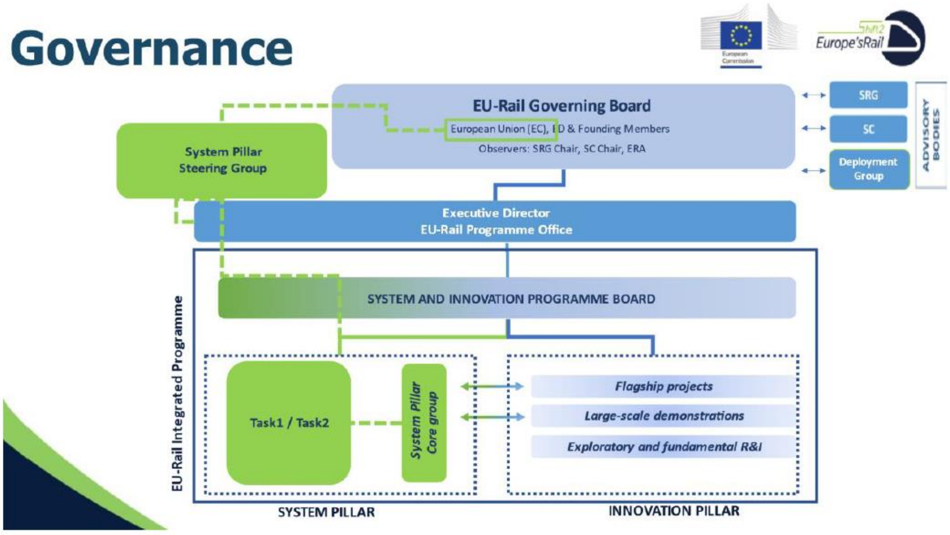



*Figure 1 - Governance of the JU*

#### *4.4.1.1 The Governing Board*

The Governing Board shall oversee activities performed under the System Pillar according to the arrangements set out in Article 93(4) of the Single Basic Act.

#### *4.4.1.2 The System Pillar Steering Group*

Article 96 of the Single Basic Act sets out the following in relation of the System Pillar Steering Group:

- The System Pillar steering group shall be an advisory body of the Europe's Rail Joint Undertaking in charge of providing advice on System Pillar issues.
- The System Pillar steering group shall be composed of representatives of the Commission, representatives of the rail and mobility sector and of relevant organisations, the Executive Director of the Europe's Rail Joint Undertaking, the chairperson of the states' representatives group and representatives of the European Union Agency for Railways and of the 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 System

Pillar steering group as observers. The System Pillar steering group shall regularly report to the states' representatives group on its activities.

- The System Pillar Steering group shall be chaired by the Commission.
- The recommendations of the System Pillar steering group shall be adopted by consensus. Where no consensus is reached, the Executive Director of the Europe's Rail Joint Undertaking shall prepare a report for the Governing Board, in consultation with the European Union Agency for Railways and the Commission, outlining the key common points and diverging views. In this case, the states' representatives group shall also prepare an opinion for the Governing Board.
- The System Pillar steering group shall adopt its own rules of procedure.
- The System Pillar steering group shall be responsible for providing advice to the Executive Director and Governing Board on any of the following:
    - The approach to operational harmonisation and the development of system architecture, including on the relevant part of the Master Plan;
    - delivering on the specific objective set out in point (c) of Article 85(2), namely:
        - develop through its System Pillar a unified operational concept and a functional, safe and secure system architecture, with due consideration of cyber-security aspects, focused on the European railway network to which Directive (EU) 2016/797 of the European Parliament and of the Council applies, for integrated European rail traffic management, command, control and signalling systems, including automated train operation which shall ensure that research and innovation is targeted on commonly agreed and shared customer requirements and operational needs and is open to evolution
    - carrying out the tasks set out in point (a) of Article 86(5), namely:
        - develop in its System Pillar a system view that reflects the needs of the rail manufacturing industry, the rail operating community, Member States and other rail private and public stakeholders, including bodies representing customers, such as passengers and freight and staff, as well as relevant actors outside the traditional rail sector. The 'system view' shall encompass:
            - the development of the operational concept and system architecture, including the definition of the services, functional blocks, and interfaces which form the basis of rail system operations;
            - the development of associated specifications including interfaces, functional requirement specifications and system requirement specifications to feed into Technical Specifications for Interoperability (TSI) established pursuant to Directive (EU) 2016/797 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

- the detailed annual implementation plan for the System Pillar in line with the work programmes adopted by the Governing Board in accordance with point (b) of Article 94.
- Monitoring the progress of the System Pillar.

In effect it is the decision-making body for the System Pillar, ratifying the deliverables of the System Pillar, and providing a mechanism to deliver consensus, or a decision/recommendation where this is not possible

The Composition of the System Pillar Steering Group will be:

- Chair: EC
- 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: ERTMS Coordinator, EUSPA, ESA, other representative bodies to be considered.

The composition of the System Pillar Steering Group may be changed by the Commission, in line with the requirements of Article 96 of the Single Basic Act.

Meeting inputs shall be provided primarily by the System Pillar Core Group, via the Executive Director of the JU.

##### *4.4.1.3 The System Pillar Core Group [to be updated]*

The System Pillar Core Group is necessary to lead the day-to-day work of the delivery of the System Pillar through the Tasks and supporting the System Pillar Steering Group in its decisions. This will include:

- Providing guidance on the work of the System Pillar
    - (a) Assessment of outputs
    - (b) Technical management supporting decision making within remit set by the System Pillar Steering Group
    - (c) Ensuring sector alignment
    - (d) Supporting Innovation Pillar and System Pillar coordination
- Programme Management of the System Pillar
    - (a) Day to day management and delivery of System Pillar objectives
    - (b) Liaising with the System and Innovation Programme Board on progress and resource allocation
    - (c) Continuous monitoring and management of progress
    - (d) Management of budget and administration
- Managing inputs
    - Integrating relevant inputs from Innovation Pillar and external to JU
- Managing outputs
    - Production and day to day management of the "Standardisation and TSI input plan" [for Task 2/CCS+ outputs]
    - monitoring that the relevant EU-RAIL outputs to the [Task 2/CCS+] TSI and standardisation process:

        - is in line with the overall Operational Concept and System Architecture and associated principles is being delivered on time and in scope
    - Reports to Programme Board and System Pillar Steering Group on system pillar outputs
    - Day to day liaison with ERA including handling of Change requests to TSIs; including EECT and working group representation
    - Handling of standardisation requests

The System Pillar Core Group will be resourced to be competent to lead the SP 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 harmonized standards.

The Core Group will work with the Innovation Pillar, subject to the final structure of the latter, to enable when relevant alignment and integration of the Flagship projects at a Railway System level and *vice versa*.

The Core Group will also need to manage the resources within the Contracts and Programmes associated with the System Pillar.

### 4.5 System Pillar and Innovation Pillar interaction

The System Pillar and Innovation Pillar of EU-RAIL will work together to deliver a coherent output from EU-RAIL.

The System Pillar 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 to the system architecture), and the Innovation Pillar will impact the scope of the System Pillar where new technologies or processes mean that innovations can drive a change in approach, as well as delivering detailed specifications and requirements.

The high-level principles of the working arrangements and the relationship between the pillars are set out in the following diagram:

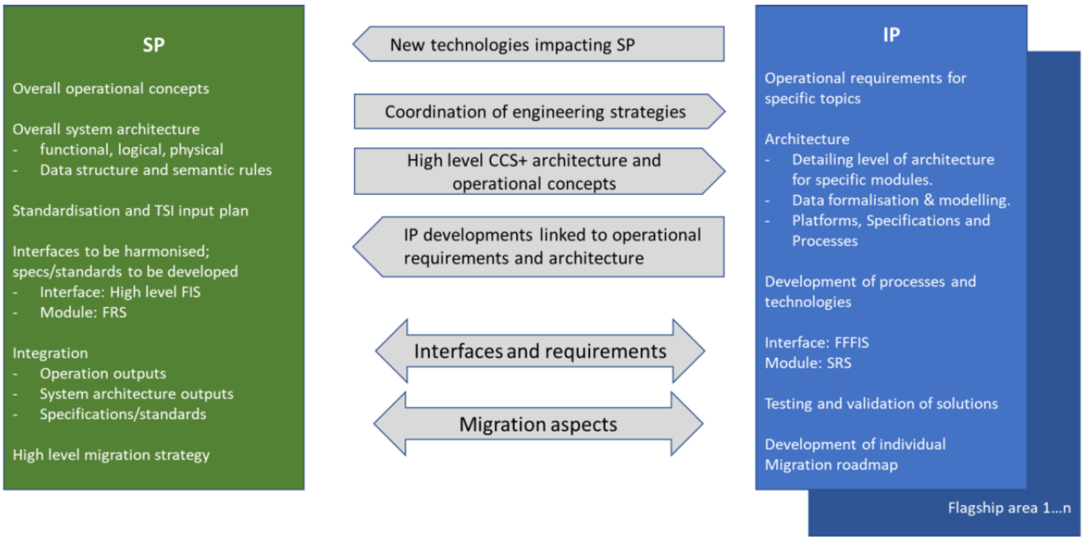



*Figure 2 - Relationship between the Innovation Pillar and the System Pillar*

The principle of interaction is that the System Pillar 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, the more detailed FFFIS&SRS of the specific systems. The detailed specifications will be verified by the System Pillar to ensure consistency with the overall architecture and operational concept. This will enable integration of the flagship projects both together 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 the ambition of EU-RAIL.

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

- The evolution of the EU-RAIL will produce innovation and new technologies that will require further development of the system architecture, proposals from the IP will need to be considered and included
- In case of misalignment between the 2 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).

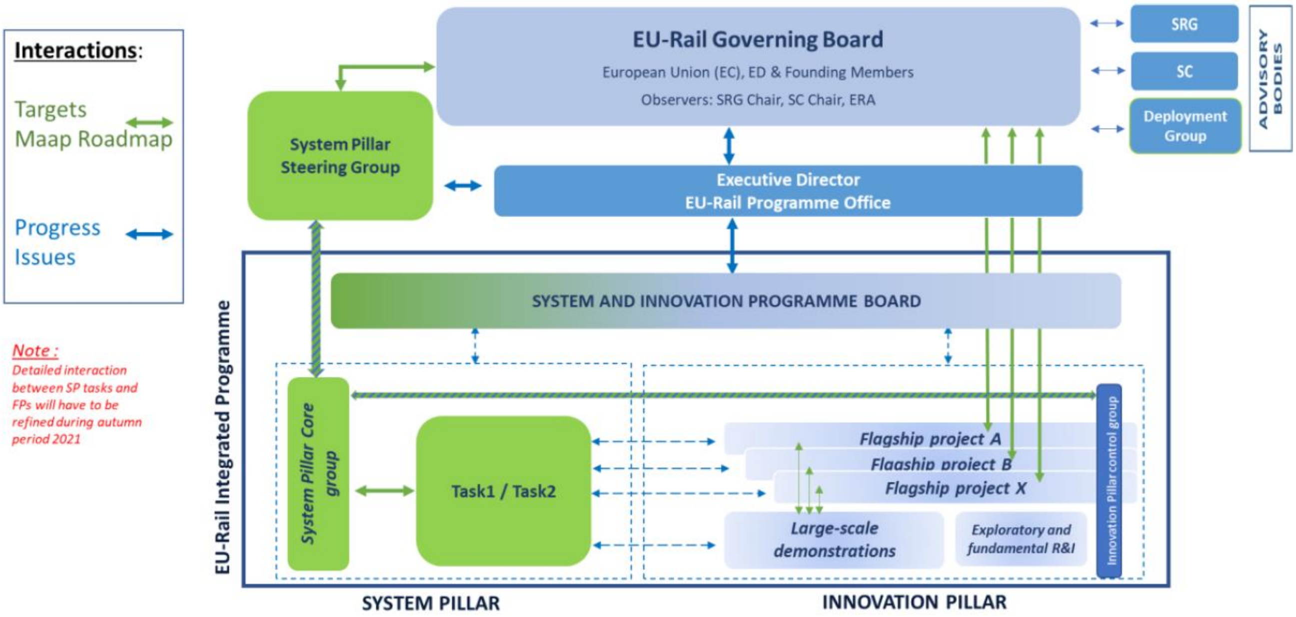



*Figure 3 - Interactions between Pillars*

## 4.6 Deployment Group

The Deployment Group is a stakeholders group, to be established in accordance with Article 22 of the SBA, which will advise the Governing Board on the market uptake of rail innovation developed in the Europe's Rail Joint Undertaking and to support deployment of the innovative solutions.

# 5 *The Europe's Rail Integrated Programme*

The Europe's Rail Joint Undertaking is entrusted to manage and deliver one integrated Rail Research and Innovation Programme, built around two main pillars interdependent to each other and the Deployment Group.

The System Pillar contributes defining the concept of Operations for Rail, through a System of Systems service-oriented approach, providing the overall framework for delivery of R&I, taking into account interfaces within different rail segments and other modes. These activities should ensure a common approach and efficient use of resources; EU-Rail is the platform for and provide the coordination and resources to enable sector convergence on common solutions at European level. EU-Rail shall therefore in particular coordinate and consolidate all relevant sector initiatives, noting the importance of unified requirements from the Railways. This is complementing and underpinning the focus on research and innovation towards impact-oriented solutions. Indeed, the work to define and then maintain the operational concept and functional system architecture will be the framework within which the 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 research and innovation, from exploratory research, via applied research to large scale demonstrations.

EU-Rail focus is on key priorities but 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, imaging, robotics, etc. but also addressing sub-components, e.g. mechanical, that otherwise would jeopardise the transformation to be delivered. In order to achieve such ambition, EU-Rail acts as "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 setting the right conditions towards modular (standard interfaces), scalable, plug & 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. It is not about coordinating the funding, it is about Integrated R&I Large Scale Demonstration activities, i.e. moving from small-scale demonstrators [prototypes] in one specific network or lab, to European wide live, operational network-scale demonstration of solutions in a different environment, reaching TRL 8/9[6] level, and to show the benefits from 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, under-represented in the current rail research and innovation activities. As they will be capable to contribute to the definition of specifications and demonstrate the benefits of the 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 changes or standards' changes needed to bring solutions to the market, closing the virtuous circle started in the definition of concepts within the System Pillar, before industrialisation and deployment.
The "Deployment Group" will tackle the transition from R&I to coordinated and consistent deployment at European level, to avoid creating new barriers to a one single European network.

[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 Technology Readiness Level 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 Technology Readiness Level 9 can be part of the In-Kind Contribution for Additional Activities (Article 2(10) SBA).

# 6 *The System Pillar activities*

## 6.1 Scope

### *6.1.1 Why a system architecture focus?*

Whilst many railways will have views of the future railway architecture, there is no common EU railway system view that is used today.

The railways have traditionally approached systems architecture following a national – even regional –technical approach, leading to a heterogeneous picture at European level. National markets for rail infrastructure and vehicles continue to exist in a way that has been overcome in other modes of transport or sectors. The problem with this is that innovations and changes to the system are very difficult and costly to achieve. Ultimately this undermines the performance and competitiveness of rail.

The purpose of the System Pillar is to improve the European railway system to offer better services for the European citizen, passengers and freight. For this, the key drivers are the following:

- Cost efficiency for integration,
- Migration and deployment,
- Cost efficiency for maintenance and evolution of the system
- Quicker roll-out of innovations
- Market accessibility (for equipment and service provision)
- Increase overall performance and agility of the railway including time, reliability and safety towards the customer through faster deployment of key new technologies
- Improved train service delivery across the European Union
- Facilitate rail as integral part of the mobility services across the European Union
- Manage diverse rail legacy, bringing interoperability and ease the migration
- Sound, qualified and reliable supply chain.

The System Pillar proposes to improve this approach by:

- defining a set of application profiles[7] based on harmonized objectives and requirements and deriving harmonized operational processes,
- using formal architecture approaches, such as the concept of layered functional architecture, , as deployed since several decades in many industries such as automotive, aviation, defence, energy, high tech, IT, software, telecoms, to frame the development of the rail system, and

[7] If the architecture shall endorse as a modular building block system a too high diversity of profiles or quality levels it would get complex in terms of standardisation and implementation. Therefore, a fixed set of standard applications for certain quality levels shall defined that are the basis for the architecting process (applications like for high density traffic, regional low cost solution, etc.

- harmonising this system architecture approach at European level, including operational rules, engineering rules and implementations.

It is worth noting that complex hardware devices such as modern computers or smart phones, complex enterprise information systems, or systems of systems and large-scale business infrastructures such as heterogeneous communication systems and electricity transportation infrastructures would not exist without an underlying standardised and modular architecture.

The opportunities that an evolution of the rail system based on common operational visions and a standardised modular architecture will enable are:

- Easier and quicker introduction of innovation into railway system, the System Pillar architecture will be designed to take full advantage of current innovations and technologies and allow easier evolution and modernisation at later stages
- Sustainability, including increased market penetration of rail services, both passenger and freight.
- Reduced costs and better amortisation of developments and innovations through economies of scale
- Reduced cost by reduction of solutions' variances
- Achievement of interoperability in space and time, with a removal of operational and administrative borders, and Real time Traffic Management across EU, where national and international services across EU are made easier
- More flexible trains and services, enabling dynamic and mixed train formations and more efficient operation and timetabling
- Enable full end-to-end services and intermodality, and freedom for passengers and freight to travel at international level, i.e. the Single European Railway Area with end-to-end journeys, with through-ticketing, more efficient connection of the railway with other transport modes
- Improve the competitiveness of the European railway sector.

This evolution of the rail system, and thus the System Pillar also operates within constraints, which are:

- To take care of investment protection or identify alternatives to address the phasing out of elements that would reduce the overall performance; therefore need for an executable transformation roadmap. This needs to be taken into account in migration schemes.
- Due to legacy systems, each MS could have different roadmap towards a European rail system though these should be coordinated as far as possible. Minimum requirements for these roadmaps should be defined.
- Migration plans will have to take into account the separation between the operator and the infrastructure manager business cases, as well as their possible evolution.
- The system should be robust and resilient.
- The system should be agile, available and simple to use and operate.

- The system should be structured and operated secure and protected against cyberattack and physical attacks, and take into account Artificial Intelligence and robotization developments.
- All aspects of the System Pillar and the architecture need to enable all rail stakeholders to deliver a safe and continuous railway, and take into account rail specificities, including technical and operational aspects.
- The continuity of railway services in transition phases has to be achieved

The work of the System Pillar is not a complete change for the railway system. Rather it consists in integrating new scientific knowledge and other industry best practices in order to accelerate and better organise its evolution.

The optimization task of the System Pillar is to design an architecture that on the one hand standardizes the interaction of new and advanced methods and technologies. On the other hand it shall improve several architecture qualities, of which examples are described below:

| | **Quality Attribute** | **Description** | **Scenario/ Measure** |
|---|---|---|---|
| Q1 | **Safety** | The functions for securing movements on the railway network must meet very high “functional safety” requirements. At the same time the safety assurance shall be possible at lower cost based on modern control algorithms. | Methods for safe control, development of modular safe components and their certification shall be supported by improved architecture support. |
| Q2 | **Availability** | Railway systems must be highly available, since in the event of a failure, rail traffic can be immediately restricted. This includes the RAM “Reliability”, “Availability” and “Maintainability” from EN 50126. | The cost of high availability shall be reduced by making use of modern IT strategies for redundancies and recovery. |
| Q3 | **Security** | Very high security requirements apply, since security indirectly affects availability and safety. | • “Security by design”<br>• Standards for security supervision functions in the products.<br>• Structural security support in the architecture<br>• Standardised requirements for component security and their life cycles |

| | | | |
|---|---|---|---|
| Q4 | **Performance and its scalability (latency and throughput)** | The system must be powerful enough to handle the growing rail traffic of the future and to be able to perform the computation within fractions of a second. | A high grade of automation and digitization increases the amount of network messages and computing cycles. Modern communication and computing structures shall support this increase. |
| Q5 | **Modifiability** | Digital systems change in the life cycle more often because additional information flows are needed that run through the overall system. So changes and updates need to be very efficient and need a support by the architectural functionalities. | • Allowing to update (release) components independently<br>• Replace components with different longevity independently with a product of a new generation. |
| Q6 | **Modularity / Extensibility** | It must be possible to select configurations within the modular framework to facilitate migration strategies, independent life cycles, and adaptations to specific business challenges. This includes that the products are exchangeable. | • Use only part of the components<br>• Replace some component with other implementation (e.g. GoA2 vs. GoA4)<br>• Extend the system with additional components to implement new functionalities not yet contained. |
| Q7 | **Scalability** | The overall quality of the CCS+ system landscape shall be measured in "cost/(Q1 to Q6)". For this lowest possible quotient, lower values should also be possible for the costs. | • "Low cost for low capacity" as well as "higher cost for high capacity"<br>• "Low cost for lower availability" as well as "higher cost for higher availability" |
| Q8 | **Cost** | The system should be designed taking into account the overall cost to deploy and update with a view to increasing the productivity of the system overall | • Overall cost of implementation<br>• Benefits associated with implementation/upgrade |

The approach to developing the structure of the architecture will be based on best practice, for example the development of a layered functional architecture approach relying on two main principles:

1. *Functional principle:* a functional architecture describes the input/output behaviours – or equivalently functions – of a system, independently of their technical implementation, which avoid imposing any technical solution within a functional vision. It is fully possible to specify a solution in terms of functional behaviours, which means that one only specifies what the system shall do and not how it shall be

constructed and implemented. Functions are usually robust over time, which means that, compared to a technical architecture, a functional architecture is much more stable in a time perspective, which makes it very good for establishing long lasting and robust standard and interfaces within an industry.

2. *Layer principle:* a functional architecture has to be organized in decoupled functional layers. This means that the functions of the system of interest shall be distributed in independent groups of functions, called functional layers, that can only exchange functional flows (data, matter, energy, etc.) through standard functional interfaces. In other words, a function within a given functional layer can only discuss with another functional layer through the functional interfaces that this other functional layer provides. Functions overlapping two layers are thus forbidden. This layer principle is crucial to allow the system to evolve since it allows to change a function in one layer without any impact on the others. It has therefore a fundamental impact in terms of ease of evolution and mastering of the associated costs.

A classic example of layered functional architecture is the OSI model used in communication which segregates a communication infrastructure architecture in seven decoupled functional layers, covering applications on one hand and physical transmission on the other hand (see Figure 1). Such an architectural organization allows the implementation of a new application without any impact on the network and physical layers or to change a signal processing protocol without any impact on the applications offered to the end-users. Such an architecture is critical to reduce complexity, speed innovation and reduce cost; all essential elements to ensure rail is competitive in the future.

<table>
<tr><th colspan="3">Layer</th><th>Protocol data unit (PDU)</th><th>Function</th></tr>
<tr><td rowspan="4">Host layers</td><td>7</td><td>Application</td><td rowspan="3">Data</td><td>High-level APIs, including resource sharing, remote file access</td></tr>
<tr><td>6</td><td>Presentation</td><td>Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption</td></tr>
<tr><td>5</td><td>Session</td><td>Managing communication sessions, i.e., continuous exchange of information in the form of multiple back-and-forth transmission between two nodes</td></tr>
<tr><td>4</td><td>Transport</td><td>Segment, Datagram</td><td>Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing</td></tr>
<tr><td rowspan="3">Media layers</td><td>3</td><td>Network</td><td>Packet</td><td>Structuring and managing a multi-node network, including addressing, routing and traffic control</td></tr>
<tr><td>2</td><td>Data link</td><td>Frame</td><td>Reliable transmission of data frames between two nodes connected by a physical layer</td></tr>
<tr><td>1</td><td>Physical</td><td>Bit, Symbol</td><td>Transmission and reception of raw bit streams over a physical medium</td></tr>
</table>

*Figure 1 – ISO OSI model for communication*

The layered functional architecture principle is illustrated in Figure 2. First, each function of a system that is organized according to this architectural principal shall belong to one layer only.

Cross-layer functions are therefore forbidden. This principle usually leads to the construction of a reference library of standard elementary functions allocated to the different functional layers. Secondly a function of one layer cannot have a direct access to the functions of the other layers. It can only access to the functional interfaces that the other layers are providing, that is to say to the methods and the data that are offering. Defining a functional layer within a layered functional architecture does therefore not only mean defining the functions which are in the considered functional layer, but also defining the methods and the data that a given functional layer offers to its environment. Industrial standards aligned with the layered functional architecture principle shall typically standardize such elements.

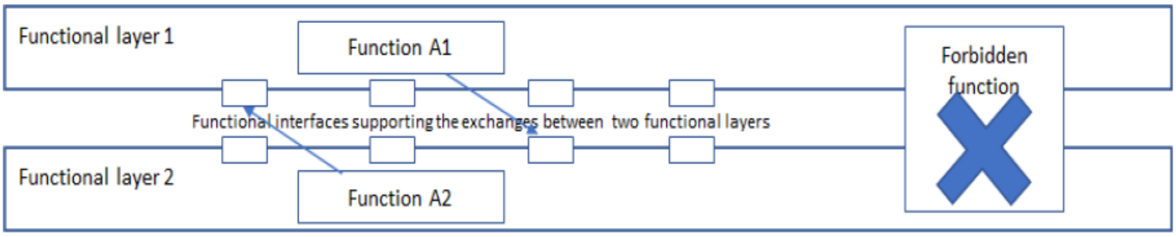
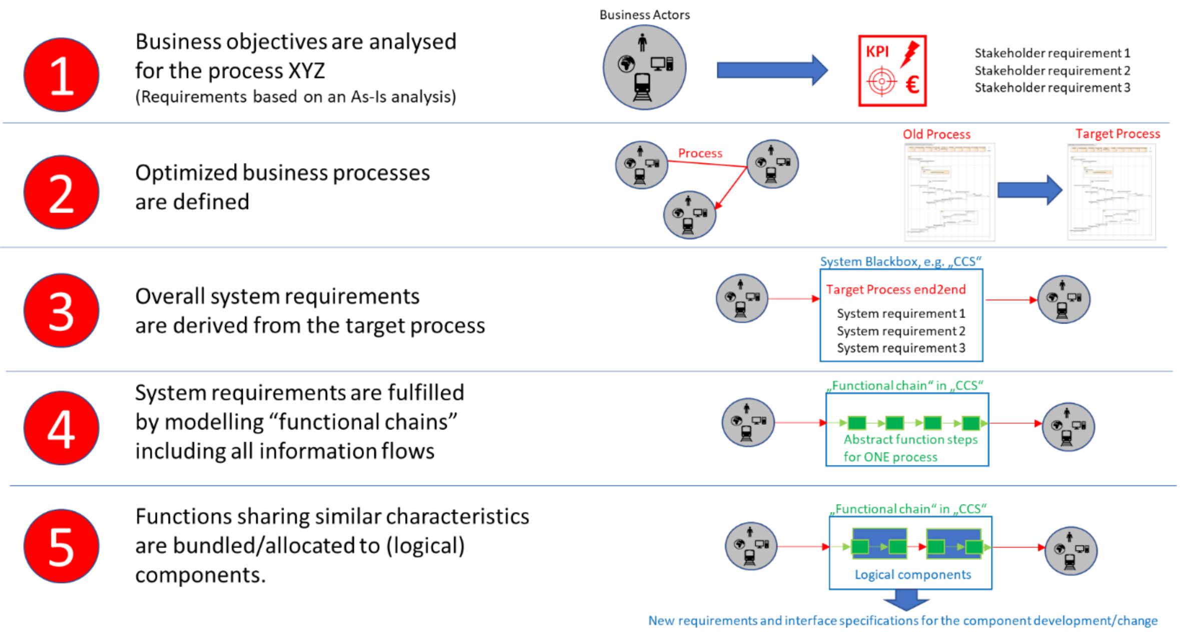



*Figure 2 – Core principle of a functional layered architecture*

### 6.1.2 *The tasks of the System Pillar: achieving a standardised architecture in rail*

To achieve an architecture that offers the demanded functional improvements concerning production performance, reliability, quality, and cost as well as the needed architecture quality the System Pillar shall analyse the business processes in scope. For the operational processes the following deduction steps shall be considered:




This is an iterative process where the results in step 5 will have to be verified against the business objectives in step 1, to ensure their coherence and feedback.

The proposals on architecture outlined here are early drafts that the System Pillar will have to develop also in collaboration with the Innovation Pillar, constituting the shared and ambitious vision of the sector on how to operate rail in the next decades. Thus the proposals shall be understood as draft preliminary versions. The purpose of their presentation here is not to define or propose the architecture of the SERA concept, but rather to develop sufficient understanding to develop the scope and tasks of the System Pillar.

The first step is to define the full perimeter of interest of the rail system, while being as independent as possible of specific technologies.

Using this point of view, the railway system can be indicatively broken down according to the following independent & complementary functional layers:

- **Manage customer services** which captures the business functions managed by the railway system that are visible from the end-users (either train passengers or freight customers);
- **Operate railway system** which covers authorisation, monitoring & control of the railways and operations of the railway network and its traffic, including the operational features and principles to operate the network and support operation of trains;
- **Control & command trains** which enables operating the railway system, including command control of the movements of trains authorised to travel on the network and all train control functions required to ensure safety or automation;
- **Manage energy** which deals with the basic functions dedicated to energy management, both off and on-board;
- **Manage communications & physical infrastructure** which contains the basic functions that are managed by the communication & physical infrastructure;
- **Manage railway crew, fleet & assets** which consolidates all the functions related to human or technical reliability, availability, maintainability, safety & security of the railway system.

These functional domains correspond with the sub-systems that are defined by the Interoperability Directive as one can see in Figure 63 that presents an indicative generic global high-level architecture for a railway system.

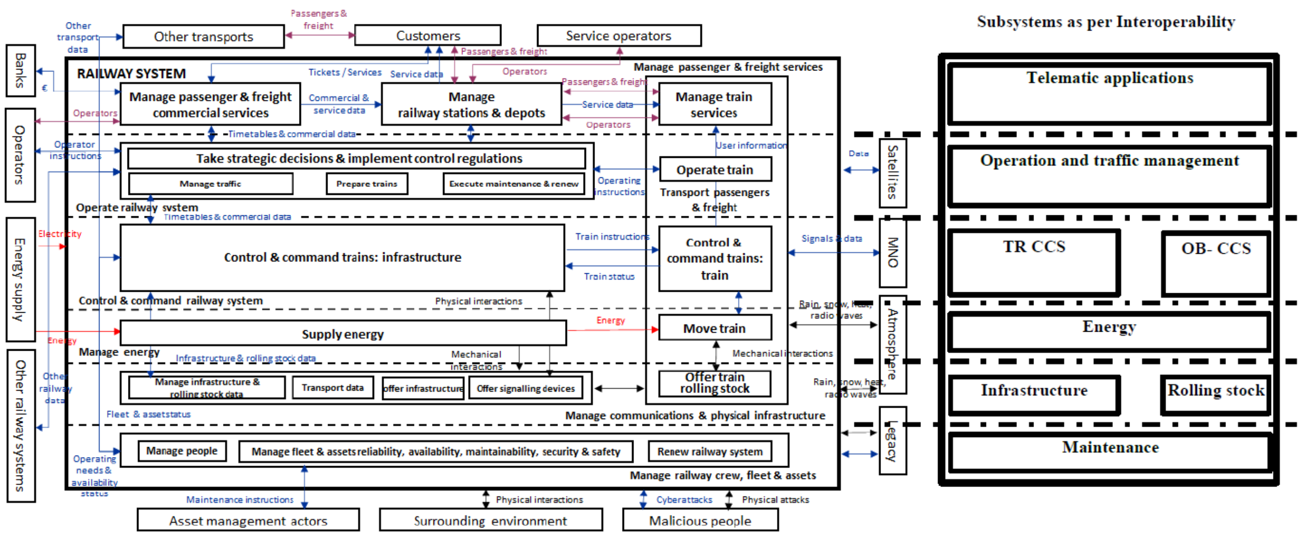



*Figure 3 –domains of the railway system and their alignment with sub systems as defined in the Interoperability Directive*

Note that the railway system functions that are described in the above architecture are split here according to their on-board or off-board nature, if needed. On-board functions are the railway system functions provided by a train, seen here as sub-functions of the global "transport passengers & freight" function which models functionally the train, where off-board functions refer to all the other railway system functions which are not provided by a train, but by the various elements of a railway system (trackside infrastructures, control & command information systems, operating centres, depots, railway stations, commercial departments, maintenance organizations).
Given that it is necessary to define the whole rail system in order to determine the areas of priority and focus, and in order to ensure consistency of approach, Task 1 of the System Pillar will define the high-level overall railway architecture and operational concept for the EU Rail System.

### *6.1.3 System Pillar Task 1: EU Rail System*

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

The System Pillar Task 1 will be focussed on the European railway network to which Directive 2016/797 applies.

The vision of the European railway system is:

- Open access to SERA, i.e. no technical and operational boundaries for trains, standardisation (economies of scale), safety (including learning from information sharing) and resilience;
- Performant and competitive;
- Synchronised deployment, and
- Full alignment with the future system

The system architecture used by the System Pillar needs to be structurally and logically consistent.

The system architecture needs to reflect the structural reality that, currently, there is no single European railway system. However, the objective of technical and service integration into a seamless European rail system needs to be maintained and interfaces need to be defined accordingly.

Consistency with the definitions in the Interoperability Directive, in particular the various Subsystems and Interoperability Constituents, needs to be considered. However, these definitions may evolve if necessary, based on the results delivered by EU-RAIL.

The target architecture(s) will consider the optimal level of technical and safety harmonisation building on cutting edge technologies, making it possible to facilitate, improve and develop railway services within the Union, and with third countries, and to contribute to the completion of the SERA and the progressive achievement of the internal market. Interoperability must be achieved and maintained.

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

To achieve the overall evolution and target architectures defined in Task 1 will be a complex challenge. 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.

Thus, the justification for Task 2 of the System Pillar in the area of Control Command and Signalling (CCS).

#### *6.1.4 System Pillar Task 2: CCS+*

##### *6.1.4.1 Why a CCS focus?*

The regulation and implementation of European rail control-command and signalling (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[8].

Historically it was simply the train driver's responsibility to follow signals, but with higher speeds (> 160 km/h), optical trackside signals were no longer sufficient and therefore supplemented by cab signalling. Over time automatic systems were developed to monitor drivers' operation (continuous speed monitoring and avoidance of signals passed at red). These systems have been developed to be different and they are still substantially different in each national railway network, and thus a major barrier to operate one European network.

A central focus at European level has been the implementation of ERTMS (European Railway Traffic Management System), a major industrial programme to harmonise the automatic train control and communication system and underpin interoperability throughout the rail system

[8] CCS+ is not only about the movement of trains. A large part of the control processes deal with the efficient access of construction and maintenance processes that occupy the track. Cost reductions can be achieved for those processes by integrating their planning, granting and supervision processes into the automated CCS+ landscape. At the same time the duration of occupation times can be reduced.

in Europe. Deployment of ERTMS provides the backbone for a digital, connected Single European Rail Area.

Significant steps have been taken to address core issues relating to the achievement of an interoperable rail system based on ERTMS. Despite a very slow start, there are now coherent and ambitious plans across the EU to deploy ERTMS in the coming years.

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

For trackside CCS beyond that specified in the CCS TSI, there is currently a network or deployment specific approach of trackside engineering, operational concept, signalling rules and their interfaces – for example route setting and protection, which are not harmonised in the TSI CCS and are implemented following national or company specific rules.

The current typical CCS on-board configuration includes multiple proprietary TCMS (train control management systems) 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.

Modern planning and control technologies can make use of the full potential of ERTMS to fine control a traffic flow in a much more performant, adaptive and robust way. They key is to simplify and empower the production automation architecture by eliminating hindering legacy technologies that were developed long before ERTMS. Additionally the connectivity shall be increase to integrate new or cross sector end-device technologies with higher cost-efficiency and performance.

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 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.

Hence the CCS+ task is to develop the operational concept(s) and functional system architecture for a genuine integrated European CCS system, supported by a model-based systems architecting & engineering approach, beyond the current specifications in the CCS TSI, with much greater standardisation and much less variation than at present. This integrated CCS system shall on the one hand deliver unrestricted movement of trains, on the other hand, it shall 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 investment made, the System pillar should not only create adequate interface but care about migration feasibility (i.e. clear and affordable transition steps) and find paths for moving beyond the current system with proprietary interfaces and allowing modularity of components.

The software and hardware installed on board or trackside should be operated and maintained following principles and standards as used in the IT or industrial automation domain: regular, scheduled updates with pre-tested configurations ensure errors and shortcomings are eliminated, maintaining all the products and system throughout EU in line with the interoperability specifications, with manageable upgrade mechanisms.

The need for the CCS+ task is because digitalisation technologies are ready for use in rail with huge potential to improve passenger and freight services. Digitalisation coupled with automation is the most effective way to increase performance and capacity with less new infrastructure investments. Without high quality architecture, adding such new technologies and maintaining compatibility will not be possible.

The purpose of the focus on CCS+ is therefore to take advantage that as networks and Member States migrate to CCS systems of ERTMS L2 or above – the opportunity is taken to do this in a harmonised manner following functional layered architecture principles: this will set a common baseline that will allow to evolve systems at the technological evolution pace. It will be a major change from “black boxes” to “software solutions” computing environments.

Operational interoperability is an equally important goal of the Single European Rail Area.

A properly designed radio-based ERTMS can significantly reduce the trackside cost, complexity, and network specificities of classic ERTMS Level 1 and class B lineside signalling and provides the opportunity to streamline the operational principles and technical specifications for ERTMS and wider CCS components and functions – improving interoperability and the overall performance of the system.

A further major opportunity is thus to create harmonized operational rules.

On this basis, a converging shared vision on future rail operations based on ERTMS-alone Level 2 and Level 3 networks will set up the baseline for the operational and technological solutions to ensure and continue evolutions of rail.

##### *6.1.4.2 CCS+ scope [to be updated through continuing scoping work through Jan 2022]*

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

The role of railways and infrastructure managers – is to define the services, performances and operational needs of the CCS+ system to meet passenger and freight requirements. The role of the supplier is to conceive, design and develop the technologically and operational solutions of the functional system architecture. The system pillar shall develop the definition of CCS+ architecture requirements and specifications in a joint approach involving the complete sector.

In the case of CCS system architecture, there is a significant overhauling of the existing architecture, which needs to be developed consistent with the defined operational principles, and bearing in mind the deployment and migration challenges, with the goal of a general harmonisation at EU level, towards integrated European traffic and capacity management.

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

The following diagrams set out some initial high-level system architecture diagrams that suggests the direction of the scope of the CCS+ architecture, and hence the CCS+ scope. These diagrams highlight in solid yellow those functional blocks that should be part of the scope of the CCS+. The light shaded yellow boxes indicate related systems where data and interfaces will need to be described. These diagrams are initial proposals and will need further development in the next stages of the development of the system.

The control & command trains activities can however only be understood within the global control & command process which can roughly decomposed into four successive types of activities:

- strategic activities, resulting in strategic decisions & regulatory controls, based on operational information, which intend to anticipate the future behaviour of the railway system,
- operational activities which lead to operational decisions implementing the strategic decisions, based on control & command information,
- control & command activities that lead to control & command decisions answering to the operational decisions while taking into account train level information,
- local train level activities, initiated by control & command decisions, that result in local train level decisions, integrating local observations and having an impact on the field.

The System Pillar shall therefore also integrate all the upstream anticipating and operating activities which are driving the control & command trains actions at global control & command and train levels. This explains why the CCS+ scope to be considered is bigger than only the control & command system, as captured by the corresponding functional layer.

As a consequence, the technical scope proposed for the System Pillar shall cover the two following interconnected functional domains, which are both including off-board[9] and on-board functions:

- Control & command trains (both infrastructure and trains),
- Operate railway system.

According to the end-to-end philosophy, the System Pillar scope shall however also include the sub-functions to interface to the of the management of railways stations & depots function, within the management of passengers & freight services, as soon as they are impacting the operate railway system functions. In this last matter, a typical example may be for instance the function dedicated to the management of the railway depots which can clearly impact the railway timetables, in case for instance of the unavailability of a train due to an incident within a railway depot. The same applies for construction sites and foreseeable degraded situations.

The resulting indicative functional scope of the System Pillar Task 2 is presented in Figure 7.

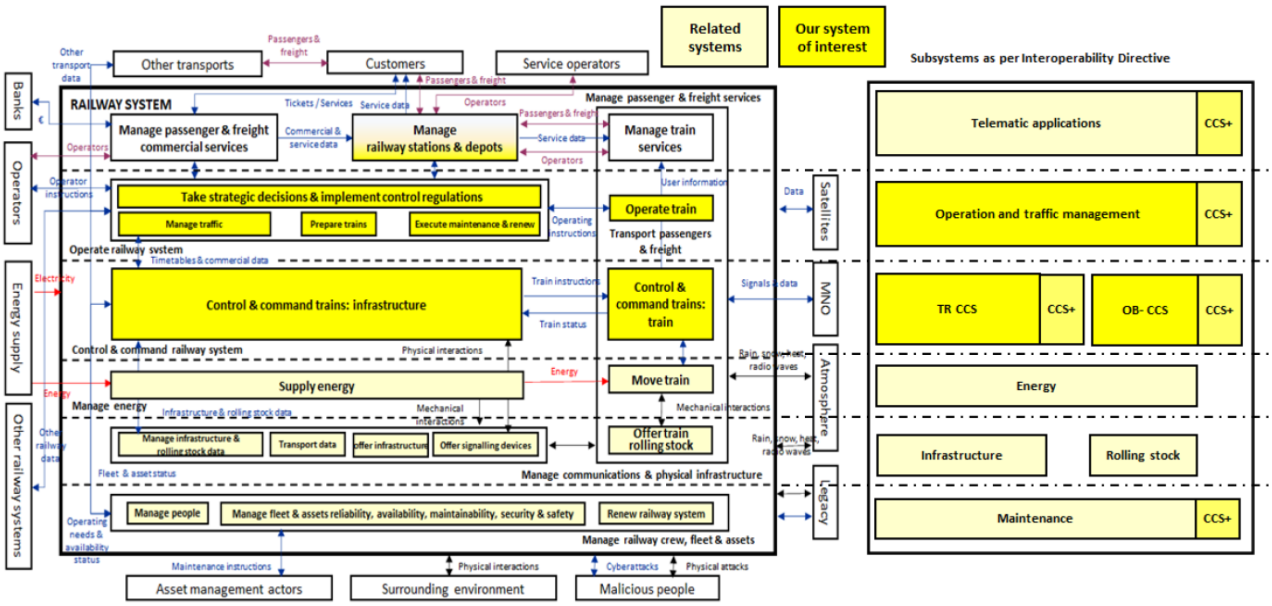



*Figure 4 - Functional scope of the System Pillar (level 1 functions)*

In order to understand better the resulting technical scope for the CCS+ scope, Figure 8 sets out the level 2 details.

[9] Off-board functions refer to all control & command functions that are not embarked in a train. They group the functions that are allocated to signalling devices distributed along the trackside and the centralized control & command functions delivered by central control & command centres.

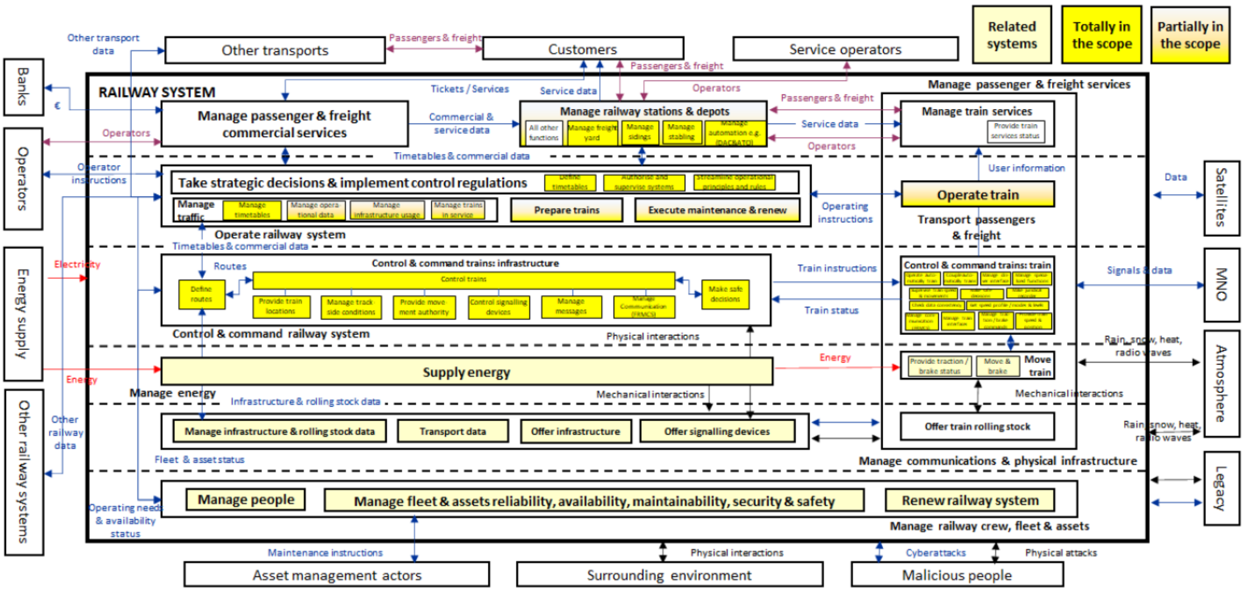



*Figure 5 - Functional scope of the System Pillar (level 2 functions)*

The railway system architecture will need to be detailed in the System Pillar and include the complete operational & functional vision, completed by the logical & technical architecture vision, when necessary.

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 decomposed in a harmonized way according to a unified European architecture into a series of modules with standard functions and standard interfaces. This is key for ensuring interoperability, system integration ability and mastering evolvability of the railway control & command system.

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

## 6.2 Deliverables

The System Pillar will be the 'generic system integrator' for the EU-RAIL and perform the role of architect of the future railway system. This means that the System Pillar would prepare and propose the concept of operations, the system architecture, the associated standards and specifications, and migration strategies.

The EU-RAIL through the system pillar preparatory work will agree with the partners a set of principles for the use of IP (intellectual property) recognising the need to provide outputs that support the system pillar objectives, including the conditions under which the outputs will be made available.

### 6.2.1 Task 1: Railway System

The Task 1 deliverables areas found in Figure 9.

**Deliverables**

1. As-is analysis of the Railways system
   a. Operational assets & pain points (including safety considerations)
   b. Functional, logical & physical assts & pain points
2. To-be concept of operations of the Railways system
   a. Stakeholders and stakeholder needs
   b. Nominal [& degraded] business processes, rules & objects (including safety considerations)
3. To-be system architecture of the Railway system
   a. Functional, logical, physical architecture
   b. Railway data structure and semantic rules
4. Railway system architecture migration roadmap
   a. Impact & gap analyses
   b. Proposed stable operation & architecture states
5. Methods & tools for Railway system processes & architectures

**Form**

1. Concepts
   a. Business concept papers
   b. Architectural concepts
2. Descriptions and requirements
   a. Operational scenario & business process descriptions
   b. Architecture, data and dysfunctional models
   c. High level traced/assessed needs & requirements
3. Assessments & tests
   a. Economic assessments
   b. Global simulation results

For those outputs marked in red the System Pillar outputs are based also on contributions from the Innovation Pillar or external to the JU

Services are within the direct supervision of the JU

**Services**

1. Communication / online forum
2. Publication / knowledge & documentation management
3. Support to TSI change management process
4. Support harmonization of operational concept of the Railways system

*Figure 6- Deliverables for Task 1*

*<u>Note:</u> The outputs marked in red are under the responsibility of the System Pillar but could have been built upon inputs coming from the Innovation Pillar or external initiatives to the JU*

#### 6.2.1.1 As-is analysis of the railway system

The analysis of the current railway system architecture will be to identify the pain points, including safety considerations, of the system with respect to the existing operational, functional, logical & physical assets deployed in Europe and the work force associated to deliver it; a prioritization exercise will be required.

#### 6.2.1.2 Concept of operations of the railway system

Overall operational interoperability, beyond technical interoperability, is an important goal of the Single European Rail Area. The harmonisation of operational concepts will strongly contribute to this objective.

The operation of the European railway system (the operational concept) is determined by the operational needs (operational use cases), the support achievable from the technical systems and the consequent human interaction necessary to complement the technical systems.

By means of the work in the System Pillar there is the demand to develop the future rail target system(s) on the basis of an overall functional layered Rail System Architecture.

The outcome of this subtask aims also for future concepts for the operation of Europe’s railways that in parallel with Rail System Architectures will guide technological solutions needs as well as the development of specifications and standards.

Business concept papers and business process descriptions which are important for achieving operation interoperability and the System Pillar objectives will be delivered within task 1 to describe the nominal and degraded business processes, rules, actors and objects.

A key part of these deliverables will be the identification of the relevant stakeholders with their specific needs and use cases. They should also include high level business needs & requirements necessary to achieve operational interoperability and the System Pillar objectives that will be traced and assessed throughout the work of the System Pillar.

#### 6.2.1.3 To-be system architecture of the railway system

The development of the target rail System Architectures will be the main objective of this subtask. The architecture developed within this subtask will include the mapping with the regulatory basis and subsystems, modularity and interface specifications.

The target architecture will consider the optimal level of technical and safety harmonisation building on cutting edge technologies, making it possible to facilitate, improve and develop railway services within the Union, and with third countries, and to contribute to the completion of the SERA and the progressive achievement of the internal market.

The rail system functional architecture will support the overall coherence and the coherent evolution of the EU Rail Target System[s], including:

- Common Business Objectives, deployment, economic assessment, KPI’s,
- Deployment and migratory strategies
- Compatibility, modularity, system integration ability
- Conformity Assessment Strategies supported by strategic partnership across EU industrial sectors and sector strategies towards the acceptance of global standards

The functional, logical and physical railway architectures will be developed within Task 1.

They will be delivered as concept papers and models and will be complemented by the railway data structure and semantic rules. Special focus will be put on functional and sub-system interfaces.

The deliverables for architecture and data will be completed with the relevant dysfunctional models. They should also include architecture needs & requirements that will be created or taken up, traced and assessed throughout the work of the System Pillar

In addition, an economic assessment is foreseen as necessary to assess the costs and benefits of the proposed target system, this is expected to be developed together with the Innovation Pillar. It will also address issues where in spite of an overall positive business case, the incentives for individual actors are not aligned.

To achieve cohesive work forward, this subtask will also be responsible for the methodological support to develop the system architecture (meta model, modelling rules, architecture framework glossaries, etc). This will also include tools and models for the integrated simulation of the results for the different deliverables within the System Pillar. The global and integrated simulation is expected to be developed together with the Innovation Pillar.

#### *6.2.1.4* Railway system architecture migration roadmap

With the target system defined and taking into consideration the as-is analysis of the railway system, a high-level -migration roadmap will be delivered within Task 1. The starting point of this deliverable will be the impact and gap analysis between the as-is and target system. These analyses will allow task 1 to deliver a roadmap including proposed stable operation & architecture states.

This may lead to additional specific tasks being defined in the System Pillar remit beyond the two currently defined (e.g. task 3 related to energy systems)

Economic assessment will also be expected for the migration roadmap delivered and is expected to be developed together with the Innovation Pillar.

### *6.2.2 Task 2: CCS+*

Task 2 will focus on the next iteration of the railway system evolution that is focused on the CCS+ scope.

The summary of these deliverables can be found in the following Figure 10.

**Deliverables**

1. As-is CCS+ analysis
   a. Operational assets & pain points (including safety considerations)
   b. Functional, logical & physical assets & pain points
2. Target CCS+ concept of operations
   a. Stakeholders and stakeholder needs

**Services**

1. Communication / online forum
2. Publication / knowledge & documentation management
3. Support to certification / authorisation
4. Support to TSI CCS/OPE change management process

b. Nominal & degraded use cases & operational scenarios (including safety considerations)
c. Nominal & degraded business processes, rules & objects (including safety considerations)
3. Target CCS+ system architecture
   a. Functional, logical, physical architecture
      a. System requirements
      b. Interface specifications (FiS/FFFiS)
   b. Dysfunctional architecture (key FMECA & FTA)
      a. System requirements
      b. Interface specifications (FiS/FFFiS)
   c. CCS+ data structure and semantic rules
      a. System requirements
      b. Interface specifications (FiS/FFFiS)
4. **Standardisation and TSI input plan**
5. CSS+ architecture migration roadmap
   a. Impact & gap analyses
   b. Proposed stable operation & architecture states
   c. Proposed migration routs
6. Methods & tools for CCS+ system processes & architectures (to be consistent with task 1)

**Form**

1. Concepts
   a. Business concept papers
   b. Architectural concepts
2. Descriptions and requirements
   a. Operational scenario & business process descriptions
   b. Architecture, data and dysfunctional models
   c. Traced/assessed needs & requirements
   d. Release and change descriptions (CCM=
3. Assessments & tests
   a. Cost/benefit analysis
   b. Test cases and means
   c. Maturity records (pilot projects)
4. Specification & standard
   a. TSI impact analysis, TSI CR specification, TSI update proposal (incl. T&M)
   b. Draft standard descriptions (FRS & SRS)
   c. Interface specifications (FiS / FFFiS)

For those outputs marked in red the System Pillar outputs are based also on contributions from the Innovation Pillar or external to the JU

Services are within the direct supervision of the JU

*Figure 7 - Deliverables for Task 2*

*<u>Note:</u> The outputs marked in red are under the responsibility of the System Pillar but could have been built upon inputs coming from the Innovation Pillar or external initiatives to the JU*

The process and architecture development are a learning process encompassing an increasingly complex interaction between end-to-end processes, interfaces, and component requirements. Because of this, managing the architecture process involves the establishment of a matrix of workstreams which needs an agile management methodology to handle a continuously growing amount of requirements (e.g. for components).

One among other reasons for the slow progress of European innovation projects is to elaborate stakeholder involvement and management processes, combined with a persistent shortage of qualified resources. On top of that, it is absolutely crucial that completeness is ensured from the beginning not to repeat ERTMS deployment problems. CCS+ scope is much larger than the ERTMS scope, but the speed of development of the System Pillar should fulfil the high ambition of the stakeholders. Working methods and associated tooling should therefore correspondingly support the speedy progress within both Pillars while at the same time safeguarding quality requirements. Rules and procedures and a code of behaviour shall define, amongst others, an efficient decision and working methodology.

#### *6.2.2.1 As-is CCS+ analysis*

As a subset of the Task 1 as-is architecture analysis, the description of the current developments for the different systems included within the scope of CCS+ will allow to build the necessary migration paths towards the future CCS+ system. For this, within task 2, existing operational, functional, logical & physical assets for CCS+ deployed in Europe will be analysed from a pain point perspective, including safety, security, robustness and HOF considerations; a prioritization exercise will be required.

#### *6.2.2.2 CCS+ concept of operations*

As mentioned under task 1, the operation of a railway system (the operational concept) is determined by the operational needs (operational use cases), non-functional requirements (RAMSS), the support achievable from the technical systems, and the consequent human interaction necessary to complement the technical systems.

In particular for the CCS+, this operational concept is necessary for nominal scenarios but key also when they operate in degraded conditions, and so come to perform the desired operation. System requirements based on an agreed operational concept should be put in place. The set of operational procedures should allow a harmonised set of engineering rules and implementations (single CCS+-market) and avoid that the CCS+-toolbox becomes complex due to national/specific operational procedures.

The focus shall be on the development of the operational concept based on cab signalling and radio-based ERTMS-only networks with broad harmonization of safety, security and operational principles, which is key to achieve generic subsystems and phase out national requirements. This aspect also considers human factors of railway staff (drivers) operating across borders allowing common training and licensing requirements for future cross-border operations.

An integrated planning and traffic flow system (traffic management system) shall interface to the radio-based ERTMS to allow for optimized real-time operations. Maintenance and construction sites shall be integrated seamlessly into the production control process based on automated permission and supervision systems. Assets shall be changed or replaced under protection with a minimum of configuration effort or production disturbance.

The ambition is high in order to reach harmonisation of operations based on the simplification provided by radio-based ERTMS. Hence, processes, security and safety considerations both for nominal but also degraded operation will be unified, allowing that unique operational and engineering requirements are set to CCS+ systems and products. For example, harmonisation of basic safety, signalling and production rules or traffic management.

The specifications for product independent operational processes shall be in scope, wherever possible and reasonable.

These goals and unified processes shall grow stepwise, according to the migration strategy outcome of the System Pillar.

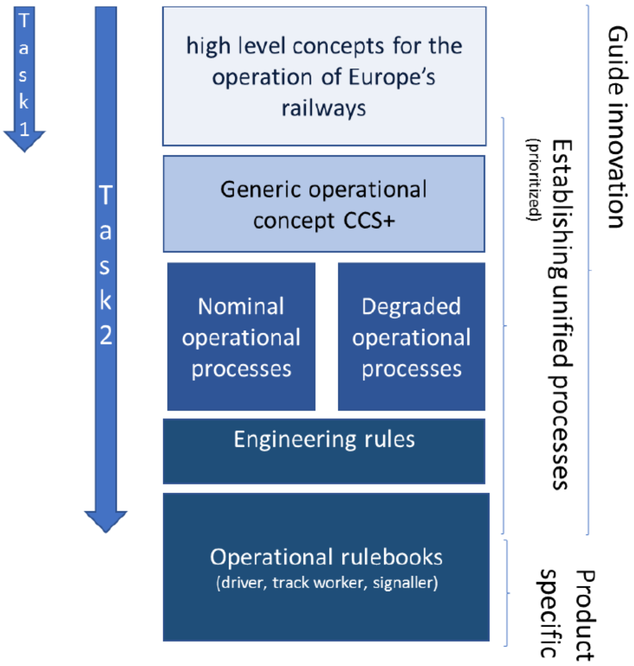



*Figure 8 - Migration Strategy Outcome Of The System Pillar*

Business concept papers, feasibility and business process descriptions will be delivered within task 2 to describe the nominal and degraded business processes, rules and objects also including safety and security considerations for CCS+. Key part of these deliverables will be the identification of the relevant stakeholders and their specific needs.

#### 6.2.2.2.1 Relevance to the OPE TSI

The scope of the TSI OPE addresses operational principles and rules.

In the TSI OPE, the scope may be broadened to include:

- Harmonised operational rules, including infrastructure rules, linked to ETCS level 2 and 3 radio-based operation without overlay of Class B
- Harmonised operational rules, including infrastructure rules, linked to wider CCS technical standardisation– in particular for automatic train operations, traffic management and freight operations (shunting, use of digital automated coupling etc)

#### 6.2.2.2.2 Operational concept for asset management, deployment and maintenance

The digitisation and higher automation of the CCS+ architecture shall be supported by introducing modern and efficient asset management processes as known from the IT sector.

This includes

- the continuous development and deployment of software updates to all components supported by simplified validation and certification and automated configuration systems,

- automation and reduction of data engineering, setup and configuration effort based on runtime intelligence and automated configuration detection and management.

#### *6.2.2.3 Target CCS+ system architecture*

The functional, logical and physical architecture for CCS+ will be developed within task 2. Initial deliverables will include concept papers and models and will be complemented by the railway data structure and semantic rules.

The deliverables for architecture and data will be completed with the relevant dysfunctional models. These models are expected to include the necessary requirements related to degraded situations that will need to be incorporated to the system requirements and interface specifications mentioned before.

Complementing the system requirements and interface specifications, System Pillar and Innovation Pillar are expected to work together to build the necessary test cases and means for validation including maturity records achieved in the framework of pilot projects realised in the Innovation Pillar.

They should also include detailed CCS+ architecture needs & requirements that will be traced and assessed throughout the work of the System Pillar.

In addition, an economic assessment is foreseen as necessary to assess the convenience of the proposed CCS+ target system, this is expected to be developed together with the Innovation Pillar.

In line with the standardisation and TSI input plan, the necessary system requirements and interface specifications (functional interface specifications FIS, Form-Fit Functional Interface Specification FFFIS depending on the level of detail deemed necessary) will be delivered together with the Innovation Pillar (see further detail below).

Distinct sub tasks will include:

On-board CCS+

This subtask develops the “Control & command train: train” functional domain including assessment and potential incorporation of deliverables of the ongoing LinX4Rail projects outputs, OCORA relevant initiative outputs and Connecta works, also projects outputs and relevant elements of the DAC initiative. These will be aligned with the operational concept. The development of this subtask includes for the relevant scope the proposal of the detailed system architecture, the data and sub-system modelling and interface specifications. There will be a consolidation of the CCS+ functional & data architecture, specification and interfaces.

Trackside CCS+

This subtask develops the “Control & command trains: infrastructure” functional domain including assessment and potential incorporation of deliverables of the ongoing LinX4Rail projects outputs, RCA, EULYNX relevant outputs, ETCS Level 3, ATO, DAC developments. These will be aligned with the operational concept. The development of this subtask includes for the relevant scope the proposal of the detailed system architecture, the data and sub-system modelling and interface specifications. There will be a consolidation of the CCS+ functional & Data architecture, specification and interfaces.

It is clear that the overall vision is towards a rail system without trackside signalling related infrastructure, subject to the specific situational environment and supporting business models, i.e. from Eurobalises to radio/satellite/inertial/optical fibre measurement unit/sensors based positioning depending on the location.

Manage rail terminals

This subtask develops the “Manage Terminals” functional domain including incorporation of ongoing DAC, S2R L3 work, and relevant national initiatives. These will be aligned with the operational concept. The development of this subtask includes for the relevant scope the proposal of the detailed system architecture, the data and sub-system modelling and interface specifications. There will be a consolidation of the CCS+ functional & Data architecture, specification and interfaces.

#### *6.2.2.4 TSI and Standards*

##### 6.2.2.4.1 Standardisation and TSI input plan

A central task of the System Pillar is not only to define target system architectures and operational concepts, but also coordinate and deliver the means for implementation through inputs to Technical Specifications for Interoperability and harmonised standards.

In order to achieve this, the System Pillar, as part of Task 2, will develop a strategic Standardisation and TSI Input Plan of the main changes to be introduced within TSIs (mainly CCS and OPE TSIs) and Commission standardisation request. This will include, *inter alia*, new functionalities and rules. This plan will also be made on the basis of migration considerations and alignment with Innovation Pillar flagship projects.

This will enable:

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

Through the Standardisation and TSI Input Plan, the System Pillar will define a clear and agreed plan for the evolution of the CCS+ system, the TSI enhancements, and standards, which will support interoperability, modular interchange ability, system integration ability, robustness, harmonisation and implementation of the SERA, and the role of EU-RAIL (both System Pillar and Innovation Pillar) in delivery.

Through the defined processes, the System Pillar will be the focus for coordination, specification and sector agreement of any enhancement change linked to CCS+ scope in TSIs and standards which will support interoperability, harmonisation and implementation of the Single European Rail Area.

This will ensure:

- consistency with the target operational concept, and system architecture
- coherence of approach
- decisions driven by business objectives
- clarity of planning
- quality of output

###### 6.2.2.4.2 TSI inputs and standards

The Standardisation and TSI Input Plan will define the needed enhancements to the TSIs (e.g. specifications, operational rules; mainly for CCS and OPE TSIs) and harmonised standards and the expected timeline for delivery.

The Standardisation and TSI Input Plan will:

- define the expected standards which will support interoperability, harmonisation and implementation of the SERA to be delivered by the JU and the expected timeline.
- inform the development of the EC Standardisation Request, for those standards to be harmonised

TSI inputs and harmonised standards will be developed by both the Innovation and System Pillar.

##### *6.2.2.5 CCS+ architecture migration roadmap*

The System Pillar shall also define, assess and deliver possible migration paths between the various current railway control & command architectures existing among Europe and a harmonized future European railway control & command architecture, building upon input at national level.

Understanding how to define, organize and manage such a migration towards better standardization & interoperability is a crucial topic for the European railway industry.

In this migration matter, the key point is to describe precisely how the current architectures may be step-by-step modified in order to be progressively harmonized over time.

In other words, an architectural migration roadmap shall explicitly elicit the succession of stable intermediate states that are allowing to pass from the existing architectures to a unified target architecture[s] for the railway control & command system at European level. This architectural migration roadmap shall then be completed by a project-oriented migration roadmap, describing the main activities that are to be done in order to implement the architectural migration roadmap and highlighting the underlying financial dimension.

The impact on migration is an essential component in the development of other subtasks such that the railway system can successfully evolve from current systems and states of deployment towards the determined target system[s] architecture. This subtask will consider economic and technical approaches to achieve this. The output will be a migration roadmap describing the deployment states among time. This task will work closely with the regulatory authorities (i.e. EC and ERA) to propose the strategic development steps for the TSI and standards.

With the target CCS+ system defined and taking into consideration the as-is analysis of the CCS+ existing related systems already deployed, a complete migration roadmap will be delivered within Task 2. The starting point of this deliverable will be the impact and gap analysis between the as-is and target CCS+ systems.

It is also expected as a deliverable to achieve the migration considerations that will be necessary to input into the Standardisation and TSI input plan.

This analysis will allow task 2 to deliver a roadmap including proposed stable operation & architecture states, as well as the clear migration routes that will allow to reach the target CCS+ system within SERA

Economic assessment will also be expected for the migration roadmap delivered and is expected to be developed together with the Innovation Pillar. It will include analysis of how to ensure that all relevant actors have a clear incentive to migrate.

# 7 The Innovation Pillar activities

## 7.1 Flagship Area 1: Network management planning and control & Mobility Management in a multimodal environment

### *7.1.1 Objective and level of ambition*

The main objective of the flagship area on "Network management, planning, and control & 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 a Single European Rail Area.

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.

In order to achieve an acceleration in the European approach, research and innovation 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 European scale, built upon a harmonised functional system architecture to ensure agile, borderless and mixed-traffic operations is the target solution that the various legacy TMS should be migrate towards.

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

#### *7.1.1.1 Targeted objective, opportunities opened and associated risks*

To achieve the overall objective of a dynamic European traffic management, several 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 opportunity to move towards a more unified European network, contributing to deliver a Single European Rail Area. Better

connection of the rail networks will allow to extend capacity planning and operation at European level, enabling capacity optimization and automatic management of cross-border traffic by predicting and controlling routes of cross-border trains in European networks and corridors.

The interconnection of rail networks, long-distance corridors (e.g. freight corridors), and the integration of station and yards, will make it possible to optimize capacity, enhance dynamic scheduling and also 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 interactions between the various actors, an organizational framework and deployment strategy not well defined or not implemented, and potentially the lack of European regulations to enforce it.

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

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

| 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 | Assets management, external resources (crew, rolling stock). X2R4, S2R Integrated Mobility Management (I2M), Optima using 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 plan |
| Target scope for Planning and Operation | National | European |
| Traffic management | Partial automatic algorithms on national level<br>X2R4-WP8 enhanced TMS concepts | Train prediction, smart conflict resolution, decision support |
| Planning versus Operation | Iterations at local/national level, not real-time | Real-time feedback loop between Planning and operation |
| 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 Human Machine Interface (TD5.2) | 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 complete transport chain |
| Overall mobility approach | End-user perspective (IP4) | Offer perspective with rail integration in door–to-door, end-user benefit at connections (information, PRM) |
| Mobility orchestration with adapted rail as backbone for the mobility demand | None | Develop orchestration between rail sub-networks, in order to move to a more unified European network. Also 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 SP that allows to |

| Topic | State of the art including S2R | EU-RAIL JU innovation |
|---|---|---|
| | | use the same system architecture for simple regional TMS applications with low effort as well as more sophisticated solutions for higher traffic densities and complex network topologies. |

*Table 1 - Ongoing Shift2Rail Activities and EU-RAIL Innovations*

Interoperability framework from S2R I2M activities will be used as a baseline for all developments.

#### *7.1.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

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, also across borders. This will be developed in close co-operation with sector organisations like UNIFE, UIC, RNE and, European Rail Freight Corridors.

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

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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'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 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

The following interactions with the other Flagship Areas (FAs) were identified:

- Collaboration with FA2 will be focused on achieving an overarching system solution by joint design of interfaces with SP involvement. 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, 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 extent (e.g., short- or long-distance) with FA2. FA2 will provide parameters for planning and simulation tools to calculate the capacity benefits of applied 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 System (IAMS) enabling the sharing of data such as maintenance plans, predicted disturbances, asset status following, topics that were started already in Shift2Rail I2M. Both FAs will be aligned to feed cooperative planning tools in FA3 with train planning and operation information to balance impact on train service and assets management, including possession planning and possession management tools.

- FA4 (Energy) will interact with the TMS to optimize the timetables and reduce the fleet energy consumption. It will be considered how to exploit slacks in the real-time timetable to send targets to the trains in order to allow energy-saving and sending back information about the confidence of the on-board system to respect the punctuality target.

- FA5 (Freight) will benefit from cross-border planning and the connection of TMS with automated yards and ports, and 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 with various resource management systems. Cooperation will also exist in the area of DAC, with real-time data exchanges such as Train composition information, Train integrity, and others.

- TMS will support the **regional rail services (FA6)** by considering FA6 requirements for TMS to provide a simplified TMS and on-demand passengers 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 foreseen.

*Details of the exchange between the Flagship Areas can be found in Annex B*

Regarding the TT (Transversal Topics), the asset models behind traffic management and planning will need to be linked to Digital Twins of the future rail network and related operations, but other aspects will also benefit of Digital Twins, such as demand forecast, capacity optimization, impact analysis in real-time of a disruption.

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.

Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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 Who does what by stakeholder group*

- Infrastructure Managers and Railway Undertakings define the main challenges, use cases and functional needs. Together with system suppliers and Academia, they specify, prioritize and cluster demonstrators to ensure that a wide range of improved processes and state-of-the-art technological developments are covered. IM's and RU's are hosting the demonstrations and providing test facilities.
- Suppliers and Technology Providers propose solutions for identified use cases and functional needs. They define the technical requirements and interface specifications, aligned with the System Pillar architecture, develop the solutions, and contribute to design adequate demonstrations. They deliver products and systems, and support the integration within the demonstrations.
- Research Institutes and Academia plan, develop, study and evaluate demonstrators together with IM´s, RUs and System suppliers, and are coordinating dissemination activities. They contribute to the process of innovation, as well as to the procedural aspects for validation, certification, and homologation.
- System Pillar: the SP will have a close connection with FA1, as TMS is interacting with many sub-systems within CCS+ or at Rail System level. To achieve a dynamic traffic management, new operational concepts will have to be developed, and many specifications and processes will be defined or modified.

*7.1.1.5 Interaction with other Programmes, European and/or National*

The flagship area on „Network management planning and control & 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. Other related programmes should align their work to the overall future approach.

The Rail Freight Corridors (RFC), as well as others, such as PTOs (Public Transport Operators), should be considered for a role in the demonstration activities.

Additionally, there are some national R&D programs 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, handling a cross border train as two or more trains rather than one) and to ensure an enhanced, interoperable planning and management of European-wide railway timetables, hence an improved quality of planning which is the systemic fulfilment and balance of all related requirements inter alia, efficiency, robustness, efficient reserves, fair trade-offs.

The improved functionalities and performances of planning & simulation software are enabling the automation in decision support systems (e.g. for supporting the management of short term path requests), enhancing conflict resolution, optimizing 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 foreseen in future planning processes, i.e. the coherence with external services and operational technologies will be ensured by taking into account already at the planning stage the related driving modes and onboard technologies. This specifically addresses the areas of cross-border planning, yard and station processes, traffic management and ETCS or ATO modelling.

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, as well as reduced energy consumption and CO2 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 to provide a more agile, optimized 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 being capable to support interoperable traffic management on a European dimension, 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-3) 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 European-wide traffic management approach, it is essential to address the customer requirements concerning a simplified, efficient and performant cross-border traffic. This includes requirements like the optimisation of the quality of cross-border train paths in the scheduling process (e.g. resource negotiation with subsystems), as well as the corresponding real-time deviation management. An optimized overall system architecture and operational workflows have to be developed together with the System Pillar.

The mentioned activities allow a more accurate modelling of operations and train behaviour and thus, a more effective operational use of network capacity (incl. resources, yards, terminals, etc.) leading to reduction of delays and a higher level of comfort as a result of international and national train flow optimisation in combination with better information.
Standardization of interfaces and processes will facilitate this objective and will also reduce the expenditures and the operational costs of the resulting technology supporting the future EU traffic management approach.

**Integrated rail traffic within door-to-door mobility**
To achieve the target that rail can be the backbone of door-to-door mobility it is essential that the offer is attractive and reliable, and therefore competitive with private cars and pure 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 step by step the service offer.

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, systems for dynamic best offers (incl. real-time availability of resources and network constraints ). Additional enablers are improved accessibility and attractiveness at the interconnection, specifically for Persons with Reduced Mobility (PRM).

This operational enhancement towards 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 of $CO_2$ emissions. Furthermore, it will support the public transport market and ensure that rail remains the central component of a sustainable mobility.

### *7.1.2.2 Technical enablers: 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, some functions must be delivered with enough maturity, indicatively above TRL7. An estimation of the technical readiness level of the capabilities in 2025, 2027 and 2031 is provided in the table below.

| **Capabilities (made of functions/services) enabling Operational objectives** | **Up to TRL** | | |
|---|---|---|---|
| | **until 2025** | **until 2027** | **until 2031** |
| Improve strategic and tactical planning | ***D1*** | ***D4*** | ***D7*** |
| 1. Cross-border Planning: | | | |
| European cross-border scheduling | ***7*** | 8 | 8/9 |
| Improved capacity allocation using rolling planning and TTR | 7 | 8 | ***8/9*** |
| 2. Decision support and optimization: | | | |
| Decision support for short term planning | ***6*** | 7 | 8/9 |
| Optimization methods for capacity efficiency and energy saving | 6 | 7 | ***8*** |
| 3. Simulation: | | | |
| 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 vs. ATO over ETCS …) | 7 | 7 | ***8*** |
| 4. Improved integration: | | | |
| Integration with yard capacity planning | ***6*** | 7 | 8/9 |
| Integration of station capacity planning | ***6*** | 7 | 8/9 |
| 5. Operational feedback for planning: | | | |
| Planning using feedback loops from operations | 6 | ***7*** | |
| Integration of feedback loop with ATO/TMS for higher capacity | 6 | ***7*** | |
| Using ATO journey profiles for timetabling | 6 | ***7*** | |
| | | | |
| Develop resilience for a connected real-time rail network | ***D2*** | ***D5*** | ***D8*** |
| 6. Cross-border operation: | | | |
| Real-time connection of the networks as managed by TMSs and involved actors | 7 | ***8*** | 8/9 |
| Modelling and decision support for cross-border traffic management | 6 | ***7*** | 8/9 |
| 7. Improved integration: | | | |
| Connection TMS & CTC and automated yards | 7 | 8 | ***8/9*** |
| Integration with yard management | 7 | 8 | ***8/9*** |
| Integration of station management | 7 | 8 | ***8/9*** |
| Integration of energy management (Electric Traction System) | 7 | ***8*** | 8/9 |
| Real-time crew / rolling stock dispatching | 7 | ***8*** | |
| 8. Improved resilience and efficiency: | | | |
| HMI for TMS based on User Experience (UX) Design and user input | ***8*** | | |
| Real-time convergence between planning & & feedback loop from operations | 5 | 6 | ***8*** |
| Cooperative planning multi-actors within rail | 5 | ***7*** | |
| Dispatching, incident management and customer information | 5 | ***7*** | 8 |
| Disruption management | 5 | ***7*** | |

| Capabilities (made of functions/services) enabling Operational objectives | Up to TRL | | |
|---|---|---|---|
| | until 2025 | until 2027 | until 2031 |
| TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables | 5 | 7 | ***8*** |
| 9. Decision support and optimization: | | | |
| Automation of very short term train control decisions | 5 | ***7*** | 8 |
| Real-time conflict detection & resolution for main line and optimisation | 5 | ***7*** | 8 |
| | | | |
| Integrate rail traffic within door-to-door mobility | ***D3*** | ***D6*** | ***D9*** |
| 10. Integrate rail with other transport modes: | | | |
| Improve rail integration using B2B intermodal services | ***7*** | ***8*** | ***8*** |
| Develop standardized interfaces | ***8*** | | |
| 11. Services for inclusive rail-based mobility, including PRM needs: | | | |
| Travel assistance across modes (esp. PRM) | 7 | ***8*** | |
| Hands-free solutions & smart information in public transport | ***8*** | | |
| Innovative platform-based passenger guidance solution, measurement and guidance of customer flows to and on the platform | 5 | ***7*** | ***8*** |
| 12. Anticipate demand leading to improved resource utilisation: | | | |
| Short term demand forecast calculation | ***7*** | ***8*** | |
| Long term demand forecast calculation | 5 | ***7*** | 8 |
| Integrate demand forecast in Digital Twin to optimize offer | 5 | ***7*** | ***8*** |
| Manage/inform disruptions across modes | ***7*** | ***8*** | |
| Optimize rail capacity to better match the demand | 5 | 7 | ***8*** |
| | | | |
| Other enablers supporting the above capabilities | | | |
| By System Pillar interaction: Define overall system architecture, processes and interfaces for European TM functions | | | |
| By FA TT interaction: Digital Twin(s) adapted to various FA1 Use Cases | | | |
| Cyber protection of systems and data | | | |

*Table 2 - Technical readiness of the capabilities in FA1.*

#### *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 stepwise setup integrated/joined multi-national demonstrators. FA1 strategy is to jointly use available state-of-the-art and R&I solutions to compose demonstrators with needed capabilities. A harmonised interoperability for planning, methods and system specifications will be the starting point for all common activities.

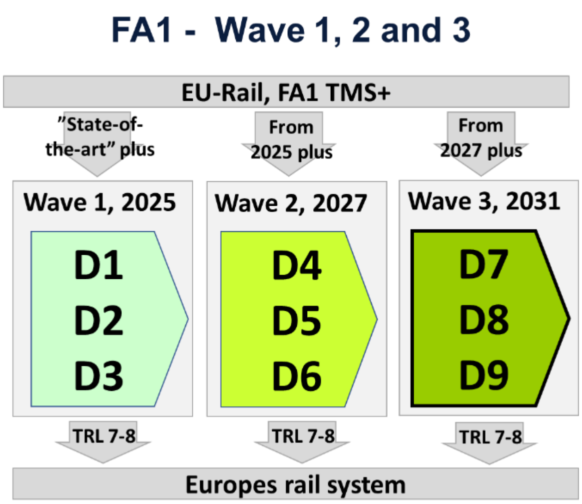


*Figure 9 - Schematic of planned FA1 Demonstrators (D1-D9) in 2025, 2027 and 2031*

The activities of FA1 are organised around three streams, improving the planning, operations and integration of European rail traffic. The demonstrations use the same decomposition, with (D1, D4, D7) for planning, (D2, D5, D8) for operations, and (D3, D6, D9) for integration.

**Wave 1 2025:** The first wave of demonstrators is based on regional and local activities, integrating available state-of-the-art solutions and functions, as well as results from R&I. There will be three demonstrators (D1-D3), one for each stream, performed in 2025.
From the first wave, some results will be deployed with TRL 7-8, other results will function as input for the second wave in 2027. The composition of each demonstrator is crucial and requires well-structured cooperative planning and preparation to reach harmonised interoperability.

**Wave 2 2027**: 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 be already delivered according to TRL 7-8, other results will function as input to the third wave in 2031. Three demonstrators are planned for the second wave (D4-D6). It has to be decided within the preparation of the second wave proposal if it is possible to merge, at least partially D4 and D5.

**Wave 3 2031**: The third wave of demonstrators will be used to validate results and finalize reaming technical enablers, which will reach up to TRL8. The outputs will be consolidated and validated in combination with the results of previous demonstrators, e.g. by including them in larger systems. 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, aiming at one demonstrator in 2031.

**Improving strategic and tactical planning of the rail network:**

- **D1- 2025**

  In this demonstrator, activities will focus on tactical and short-term timetable planning, including cross-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 in this demonstrator:

  - The activity **"Tactical and short term time table"** will focus on tactical and short term timetable planning including cross-borders with improved models and functions.
  - The activity **"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 demonstrators will focus on showcasing the following capabilities (see table 2):

  - Towards European cross-border scheduling

- Decision support for short term planning
- Integration with yard and station capacity planning

- **D4- 2027**

  This demonstrator will cover activities related to the support of strategic and short-term planning considering ERTMS and ATO evolvement and their effects on capacity. In addition, integration with the ATS will be considered.

  The following activity will be included in this demonstrator:

  - The activity **“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 evolvement 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

- **D7- 2029/31**

  In this demonstrator, automated solutions for improved strategic and tactical planning will support cross-border scheduling and TTR planning process, based on harmonised methods for capacity planning with intelligent functions with optimization and simulation support. The following activity will be included in this demonstrator:

  - **“Capacity planning methods incl. cross-border operations”** for demonstrating automated solutions for improved strategic and tactical planning.

  The demonstrators will focus on showcasing the following capabilities:

- Improved capacity allocation using Rolling planning and TTR
- Optimization methods for capacity efficiency and energy saving
- Improvement of rail simulation models for selected Use Cases

**Increasing the resilience of a connected real-time rail network:**

- **D2- 2025**

  The following activity will be included in this demonstrator:

  - The activity **’’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. A special focus will be human factors, automation and visualization. This activity will provide the input needed for the continuation of activities below.

  The demonstrators will focus on showcasing the following capabilities:

- TMS and human factors

- **D5- 2027**

For the second wave of demonstrations, all topics covered by the first wave will be brought further to the second wave, some of them will be concluded and demonstrated in 2027. The focus of this demonstrator is the traffic management system at the regional and global levels. The regional demonstrator will cover decision support and interaction between actors, 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 plan will cover several EU countries, nodes and networks, with feedback loops from planning to operation.

- The activity **''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 furthering the Wave 3 demonstration activities.
- The activity **''Decision support and automation for national and international rail network''** will focus on global area TMS (mixed traffic). This activity will be concluded in 2027 providing input for furthering the Wave 3 demonstration activities.

The demonstrators will focus on showcasing the following capabilities:

- Real-time connection of the networks
- Improved modelling for cross-border
- Integration of energy management (Electric Traction System)
- Real-time crew / rolling stock dispatching
- Cooperative planning multi-actors
- Dispatching, incident management and customer information
- Disruption management
- Increased automation in decision support
- Conflict detection & resolution

- **D8- 2031**

For this large-scale demonstration planned for 2031, TMS will include real-time effect of ATO and the resulting service quality, as well as feedback loops with planning process effects 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 improved control of nodes, yards and stations, and improved connection to industry sidings and ports, as well as interaction with other rail networks are demonstrated.

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

The demonstrators will focus on showcasing the following capabilities:

- Real-time convergence between planning & operations

- Connection TMS & 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**

- **D3 – 2025**

  This demonstrator will cover demand-driven predictions to improve 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 travels in combination with demand forecast 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 demonstrators will focus on showcasing the following capabilities:

  - Short term demand forecast based on various data sources (e.g., real-time, CRM).
  - Manage / Inform disruption across different mobility modes with real-time data.
  - B2B service platform ensuring cross-operator information transfer.
  - Cross regional multimodal travels, incl. first & last mile and Demand Responsive Transport (DRT).
  - Hands free travel experience and smooth transfers between transportation modes.
  - Walk-in/out including barrier free access, access gate interaction, automatic payment.
  - Standardized Interfaces and data formats.

- **D6- 2027**

  Within this demonstration, more challenging long term demand driven predictions will be used, taking into account the results from short term demand forecast 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 to have an inclusive mobility network are also tackled here, with a focus on PRM guidance based on real-time data.

  The demonstrators will focus on showcasing the following capabilities:

  - Combination of Short and Long Term Demand Forecast with Disruption data.
  - Integration of Demand Forecast into Digital Twins.
  - Cross-border multimodal travels, incl. first & last mile.
  - PRM automatic guidance and incident management based on real-time data.

- **D9 – 2031**

This demonstration 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 on a pan-European level to move towards an inclusive mobility network.

The demonstrators will focus on showcasing the following capabilities:

- AI-based optimization of rail capacity.
- Pan European B2B service platform.
- General approach to platform based guidance.
- Digital Twin usage for predictive support of operators (incl. short & long term demand).

### *7.1.3 Impacts*

#### *7.1.3.1 Description of the impacts against existing rail services*

| | |
|---|---|
| | Meeting evolving customer requirements<br>FA1 will support the delivery of much more flexible approaches to 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 a cohesive overall 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 actors. |
| | More sustainable and resilient transport<br>FA1 will provide more robust traffic management processes through integrating dynamic forecast asset status in the decision process and improved efficiency of maintenance operations due to better scheduling following more precise traffic forecast information that will result increased operational reliability (fewer service disruptions). Optimisation of the TMS and fewer disruptions of the train services will enable better utilisation of available resources and energy consumption. |
| | Harmonized approach to evolution and greater adaptability<br>FA1 will contribute to the common evolution of the system and greater harmonisation of the traffic management, in order to facilitate the delivery of the Single European Rail Area and improve the rate of deployment of new technologies. By developing a new approach for a European Traffic management with the System Pillar, including operational and functional requirements that allows to use the same system architecture for simple regional TMS applications with low effort as well as 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 cross-border traffic as well as mainlines and regional lines. |
| | Reinforced role for rail in European transport and mobility<br>FA1 is supporting a better integration of the rail in a more sustainable Mobility system, in order to deliver better services for passengers and freight, and to bring higher usage and larger passenger volumes. Connecting transportation modes and breaking the silos between public and private transportation industry actors will enable door-to-door mobility. Developing the matching solutions for the special demands will allow |

| | |
|---|---|
| | incentivizing people in their choice of mobility and hence support the promotion of rail, the optimization of investments, and the contribution to health and wellbeing. |
| | Improved EU rail supply industry competitiveness<br>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 integrate better the rail mode, and to preserve its role as the backbone of the mobility system.<br>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 in order 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. |

*Table 3 Descriptions of this FA1 impacts related to the intended impacts in the Master Plan*

### *7.1.3.2 Quantitative KPI demonstrated in this FA*

**Improved planning and operational evaluation: D1, D4, D7**

- Increased number of possible trains on a given infrastructure on a reference day using improved processes and methods:
    - Baseline 2022, expected increase 5% to 20%, depending on the line or area.
- Reduction of answering time between the short term request of a cross-border train path and the answer with a firm offer:
    - Down to 5 minutes.
- Improved robustness of timetables and hence, reduced impact of disturbances and disruptions
    - Baseline 2022, expected decrease 5% to 15% of delay minutes in a reference week depending on the line or area

**Develop resilience for a connected real-time network: D2, D5, D8**

- Prediction Quality: less than 5 percent of trains more than 5 minutes mean deviation in a typical scenario of at least 100 trains running in a 2h interval ahead of actual time
- Prediction performance (incl. dynamic infrastructure restriction handling, train regulation and automated conflict resolution): less than 120 secs in a typical scenario of at least 100 trains running in a 2h interval ahead of actual time
- ATO Journey Profile / Segment Profile provision cycle time down to 30 secs

**Integrate rail traffic within door to door mobility: D3, D6, D9**

- Demand forecast for improved service planning :
    - Achieve 65% precision in the average forecast 1 week in advance
    - Achieve 80% precision in the forecast at 1 hour
- Improved matching between demand and supply :
    - Achieve 75% reaching planned travel time of passengers

#### *7.1.3.3 Exploitation, deployment and migration considerations*

Within Flagship Area 1 it is expected to deliver solutions for the improvement of methods and processes that supports an extended network management planning and control framework, while ensuring safety, availability, and environmental sustainability demands.

The overall goal to improve the global performances 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 forecast for improved service planning, and improved matching between demand and supply global networks, EU freight corridors, national-, regional- and Urban/commuter-networks.

These developments in technology, methods and processes imply very important investments from the organizations involved in the Europe's Rail Joint Undertaking 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. Although the involvement of a large community from both the user side as well as the supplier side is a good start for a wide deployment. A set of measures was established to ensure future exploitation. These measures are listed below:

- 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 used products and processes in the design, manufacturing, operation, maintenance and also 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 System Pillar to draft a set of standards for information exchange at different levels, e.g., data from inspection results to holistic approach to strategic decisions. Functions, system and interfaces requirements
- Propositions of specific European regulation to be adopted by the member states for enforcing or enabling the adoption of new technologies, methods and processes.
- Plug & Play industry standards and open-source architecture to allow 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 research and development of human factors strategy, training and deployment planning to ensure a successful migration of the nearly developed systems.

## 7.2 Flagship Area 2: Digital & 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 the factors: Control, Command and Signalling (CCS) asset density, CCS asset performance, and asset life cycle cost.

Option one, building new infrastructure/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, the major opportunity is offered by digitalization and automation of rail operation, where DATO (Digital "Automated" Train Operations) represents the most visible result of a major transformation of rail operations. DATO builds upon the next generation of Automatic Train Control (ATC), in addition to enhancements on the Train Control and Monitoring System (TCMS) allowing for integration at the on-board level. ATC[10] is the combination of Automatic Train Protection (ATP) systems, Automatic Train Supervision (ATS), and Automated Train Operation (ATO) – together representing an evolution of the current Control, Command and Signalling (CCS) subsystem –termed CCS+. Such targets build upon the specific set up of the Europe's Rail Joint Undertaking (JU), where the System Pillar (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, as well as proof of concepts. It is a joint commitment to deliver it and without such commitment an unrealizable ambition.

#### *7.2.1.1 Targeted objective, opportunities opened and associated risks*

The targeted objective of FA2 is to take the major opportunity offered by digitalization and automation of rail operation and to develop the respective systems. This means:

- Next-generation ATC, including ATO Grade of Automation (GoA) 4, based on a European approach agreed in the System Pillar under the leadership and commitment of the Commission services, building on harmonised, adaptable and scalable trackside and onboard CCS+ system architecture. This will be building upon radio-based ERTMS or above, representing the next evolution of the system, incorporating the latest technological advances, and with functionalities enabling full optimisation of

[10] 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, intended to keep a safe distance between trains and to 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 the train operation part, so the traction and braking controls, but also creating the trains speed profile, the communication with the wayside equipment, the opening and closing of the train doors, and automatic train reversal.

performance in line with the Traffic Management improvements developed in Flagship Area 1. This will be a major transformation of rail operations, and also a stepping stone setting the basis for the future evolution of the system, while making use of existing assets and investment done in e.g., Shift2Rail innovations or in solutions compliant with the Technical Specifications for Interoperability (TSI), where applicable.
- Delivering scalable automation in train operations, up to GoA 4, meaning that the rail system is ready for fully unattended train operations including setting a train in motion, driving and stopping the train, opening and closing the doors, remote train 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 improved punctuality, reliability, flexibility (by real-time adaptation to the demand), productivity as well as reduced operating costs, recovery time 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.
- Allow precise traffic flow management, supporting punctuality, reliability, and productivity improvements.
- Allow the control of much higher train densities with a significantly reduced Life Cycle Cost (LCC) of CCS components compared to today.
- Deliver scalable solutions fitting for high- and low-density lines, supporting the generation of large-scale component markets and standardisable industrial asset management processes as well as to speed up the deployment and ensure 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 Traffic Management Systems (TMS) and the future TMS developed in FA1. Development should be up to the level that ERA authorisations are achieved that allow it to place it in service.

The current CCS TSI allows for onboard configurations with multiple proprietary TCMS and legacy (i.e., non-ETCS) interfaces between the main onboard building blocks across Europe. As regards ERTMS trackside configurations, the current CCS TSI does not include the definition of the interfaces with 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 shall start from seeking the necessary convergence of the relevant actors within the System Pillar 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.

Flagship area (FA) 2 “Digital & Automated up to Autonomous Train Operations” will develop a next-generation ATC system, with the following objectives:

- Lowering expenses of railway undertakings and infrastructure managers,
- Decreasing travelling times for passengers and freight,
- Increasing the overall capacity of the rail operation,
- Increasing the punctuality,
- Improving the quality of operation,
- Increasing 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. Next to that, further adopting/optimizing 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, as well as 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 to explore the use of new technologies and gain experience from early partial implementation, and on the other hand to integrate a full system capitalising convergence achieved in the System Pillar. A well-structured and committed collaboration process is the success condition for delivering it.

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 consideration of 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 soft- 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 reducing the cost and by agreeing on an effective EU deployment process, while research and innovation advances. 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 (Infrastructure Managers (IMs), Railway Undertakings (RUs), and industry), and therefore governments could postpone, minimise, or even avoid future investments. The role of the System Pillar to anticipate such risks and to deliver the necessary input to FA1 is important. To avoid the risk of slow innovations on the one hand and the risk of a vendor lock-in on the other hand, an adequate degree of decomposition of hardware and software elements must be found. For such a decomposition the economic, legal, regulatory and organizational implications need to be assessed and jointly agreed upon in the rail sector, which goes beyond the technical scope of FA2. Furthermore, freight automation is an important challenge within FA 2, due to the complexity for loco-hauled freight application being higher than for Electrical Multiple Units (EMU), and there is not too much experience as compared to e.g., for passenger trains in mass-transit. Therefore, freight automation needs to be considered a very sensitive and important challenge within FA 2. Finally, the human factor consideration on the impact of new technology on staff for e.g., remote management or human-machine interface (HMI) for highly automated systems needs to be taken into consideration.

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

Shift2Rail (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 Train Control and Management System (TCMS) technologies, with the new generation of onboard 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 localization, (passenger) train integrity functions, obstacle detection, 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 mainline 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 (of e.g. perception systems, 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 can be helpful for a next-generation ATC development in this FA. As an example, in the Netherlands NS 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 and several Italian universities to design ATO over ETCS for autonomous railway infrastructure maintenance and surveillance vehicles. SNCF is also investigating GoA4 for freight and passenger train over ETCS and over line side signalling over ETCS L1. Remote-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 3 gives an overview of the innovation 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.

| 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. | Mixed operation for radio-based ERTMS on lines with/without (mixed situation trackside) Trackside Train Detection (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. |
| 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, e.g., for changes). |
| 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 onboard 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 cyber security: the Adaptable Communication System (ACS) – integrated in the Future Railway Mobile Communication System (FRMCS) developed outside S2R - and protection against any significant threat in the most economical way. | Enhanced communication systems allowing for adequate latency, handling the data volumes, safe computing (platforms), AI functions, and a digital map infrastructure for the integration with the TMS and ATP system. |
| Studies on ATO over ETCS for main-line and regional passengers. | Automatic Train Operation (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 application and segments as e.g., improved interface to the traction system or new braking systems. |

| State-of-the-art: | Shift2Rail: | Further innovation needed and covered by FA2: |
|---|---|---|
| Studies on ATO over ETCS for freight. | Freight Train Operation (ATO): ATO demonstrator GoA2. | Freight specific application e.g., brake blending, mass-damper system, physical and dynamic model, continuously changing train configuration and freight driving rules need be further development and demonstrators. |
| 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 safe train positioning, highly accurate and safe, incorporating new sensors. |
| Electro-Mechanic Brake for Railway Applications, high Safety Level electronic Solutions for Brake Control and new generation of disk and friction materials. | New braking systems: with higher brake rates and lower noise emissions to have 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 reducing braking distances. |
| New generation of TCMS and 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 as e.g., incident handling, self-healing. |
| All-weather obstacle detection (OD) and track intrusion detection (TID) system 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 obstacle detection and track intrusion detection (TID) system and remote control for distributed power. | Safe environment perception, including signal reading and obstacle detection, supported by virtual certification. Remote driving and command, for depots, for lines with low traffic, and for fallback operations as well as for shunting. |
| Overall feasibility analysis that goes across 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: | Shift2Rail: | Further innovation needed and covered by FA2: |
|---|---|---|
| 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 ease verification and authorisation processes. | Modelling techniques to support the development, verification, and validation solutions. |

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

#### 7.2.1.3 System integration, interactions with System Pillar and with other Flagship Areas

The Commission leadership in the System Pillar will be a key condition to set the basis for a concept of operations and system architecture, which shall underpin innovation related to digitalization 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 GoA 4 and a next-generation ATC architecture as a critical core part to pave the way to fully automated and, in selected specific cases, up to autonomous operation and to a well-performing, cost-efficient and easy to migrate ATC system.

Flagship Area (FA) 2 has several links to other work-streams of Europe's Rail, which are listed below. An overview of the relations with other FAs, Transversal topics (TTs) and the System Pillar (SP) is given in Figure 13.

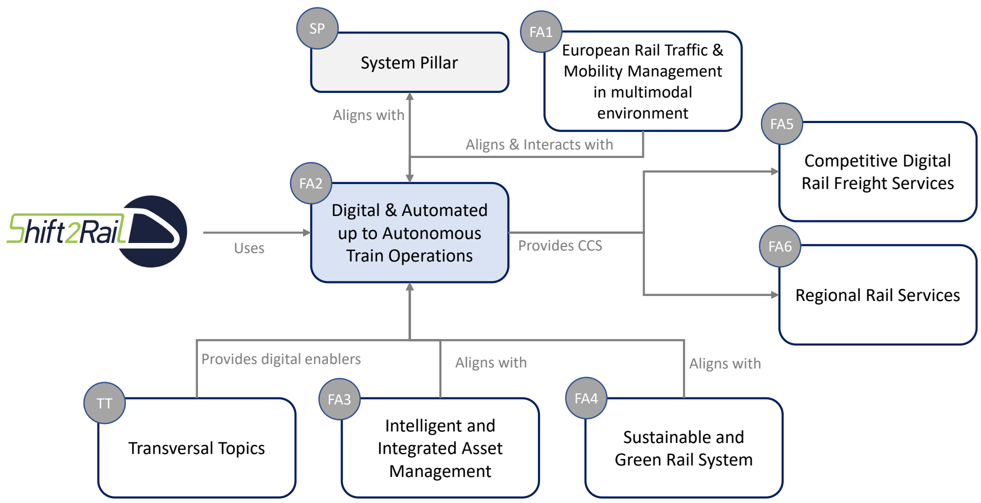



*Figure 10 - Overview of the relations within Europe's Rail*

SP – The System Pillar (SP). FA2 will interact closely with the SP to ensure a smooth takeover of the definitions delivered by the SP as e.g., 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 initially 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 System Pillar, FA2 shall be able to execute its programme and deliver the missing details or maturity in a closely synchronized 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 detail on the interaction between the System Pillar and Innovation Pillar is outlined in Annex A to the present MAWP, as a proposal from the System Pillar based on the initially identified needs.

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

FA1 – European Rail Traffic & 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 extent (e.g., short- or long distance). FA2 ATO onboard (OB), trackside (TS) and TCMS 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 now available train position and speed information in the Safe Train Positioning (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 by the provision of an interface to an operational Traffic Management System (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 & Integrated asset management. Specific trains or rail vehicles for diagnostic or inspection purposes as well as 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 next-generation ATC system is to contribute to increasing the sustainability of the railway system. It must manage energy consumption and hence interaction with both onboard and trackside energy management systems is required. FA2 delivers, in close cooperation with FA1 a methodology and model to quantify ATO's benefits on energy reduction.

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 the digital automatic coupler (DAC). FA2 will develop ATO to automatically operate trains during commercial runs (i.e., on the track e.g., with a train ID) and will provide technologies within an ATC architecture, in 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 relating 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 automatic and autonomous shunting operation 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 mainline and stabling operation. 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.

FA6 – Regional rail services / Innovative rail services to revitalise lower usage lines. Next-generation ATC solutions for functions such as safe train positioning and safe environment perception, will serve as a backbone for DATO rail services on lines with low numbers of passengers. FA2 will provide technologies to, among others, 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 with the TMS for energy network management. Also, a digital register, acting as a data source for e.g., safe train positioning or planning and engineering will be discussed between FA6 and FA2.

*Details of the exchange between the Flagship Areas can be found in Annex B*

Transversal topics (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 Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.
Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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*

The infrastructure managers (IMs) and railway undertakings (RUs) are responsible and accountable for the output of the railway system as a whole. They have a deep knowledge of the requirements for operation, maintenance, and system evolution. As future users of the next-generation ATC technologies, they need to provide functional as well as non-functional requirements for further solutions. They are in the lead for the demonstrations to check the feasibility and impact of (the cluster of) next-generation ATC technology components. They can offer a train set, test sites, and regular lines for tests, as well as 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.

The suppliers are experienced in the development, implementation, maintenance, and certification of rail systems and their components and will thus be the main stakeholders to provide 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 to ensure 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.

The 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, as well as to the procedural aspects for validation, certification, and homologation.

The related specification for the next-generation ATC systems will be developed by all stakeholders together 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, SESAR, 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 System Pillar. Specifically, with respect to satellite technologies to be used in FA2, an exchange with ESA, EUSPA and ENISA is required.

### *7.2.2 Results/Outcomes*

#### *7.2.2.1 Operational solutions outcome*

To fully achieve the objectives of section 7.2.1.1, operational solutions will cover a wide range of applications for next-generation ATC technologies. Next to the application on main lines, 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 in operation, due to their difficult-to-estimate dynamic behaviour. Furthermore, specific solutions for next-generation ATC on light rail urban transport, regional lines in remote areas or with low-density traffic will be provided, as the system needs to be adapted here 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.

The implementation of these operational solutions will take place through demonstrators at TRL7+ of the technical enablers. For next-generation ATC developments, principles of ATO over ETCS from S2R and TSI CCS 2022 will be used and, where needed, further developed.

To secure investments and ensure an economic upgrade path, the evolution of DATO and next-generation ATC shall support backward compatibility of all automation levels. Furthermore, the overarching automation process (from TMS to next-generation ATC - ETCS and non-ETCS) shall also support end-to-end customer solutions independent from the existing infrastructure, to guarantee the automation of the operation over the entire value chain. 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, as well as architectural software design patterns and methods enabling evolution. Here, conceptually separating functional views from the deployment, as well as service-oriented designing will be applied.

The use of formal modelling techniques will ensure the quality, application and completeness of the specification and planning, while allowing evolution and controlling the interoperability and interchangeability, as well as help to reduce field testing. The following additional operational scenarios are considered to define the required technical enablers, services and functions below: Mixed operation for radio-based ERTMS on lines with/without (mixed situation) Trackside Train Detection (TTD) and with L2 or L3 - capable vehicles of different system versions, Train Integrity Monitoring System (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 onboard + 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, e.g., 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, as well as in marshalling yards, depots or terminals in connection with their specialized technologies for passenger and freight trains.

The outputs from an operational perspective are listed in Table 4 below. **An estimation of the technical readiness level of the capabilities in 2025, 2027 and 2031 is provided in Table below.**

| Activity | | | TRL 2025 | TRL 2027 | TRL 2031 |
|---|---|---|---|---|---|
| ATP/ATS | Target ERTMS application with simplified migration, mainline | 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. | | 6/7 (L2, HL3)<br>5/6 (L3) | 8 (L2, HL3)<br>7 (L3) |
| | Target ERTMS Application, scaled to minimal cost | Simplified sensor mixes, reduced radio coverage, etc. | | 6/7 (L2, HL3)<br>5/6 (L3) | 8 (L2, HL3)<br>7 (L3) |
| | 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, e.g., for changes) including integration with the modular ATC systems and the TMS | | 6/7 (L2, HL3)<br>5/6 (L3) | 8 (L2, HL3)<br>7 (L3) |
| | Fully mature ERTMS | Full supervision (cab signalling) continuously in all normal modes, also for shunting, or for yellow fleet movements. | | 6/7 (L2, HL3)<br>5/6 (L3) | 8 (L2, HL3)<br>7 (L3) |
| ATO | Application main lines | GoA3/4 | 7 | 8 | 8/9 |
| | | Application in mixed traffic | | 7 | 8 |
| | | Power Supply transitions | | 7 | 8 |

| Activity | | | TRL 2025 | TRL 2027 | TRL 2031 |
|---|---|---|---|---|---|
| | | GoA2-4 on ATP transitions | | 7 | 8 |
| | | Application on freight trains | 7 | 8 | 8/9 |
| | Automatic Processes | Automated train formation & preparation (including coupling and uncoupling) | | 7 | 8 |
| | | Automatic stabling | | 7 | 8 |
| | | Automated maintenance and inspection | | 7 | 8 |
| | | Remote control | | 7 | 8 |
| | Regional lines | GoA3/4 | | 7 | 8 |
| | Application light rail | GoA2/3 | 7 | 8 | 8/9 |
| | | Mixed road traffic | | 7 | 8 |
| Migration Strategies | Fast and simple vehicle upgrades, in particular existing fleet | Adequate degree of decomposition of hardware- and software elements, agreed upon in the rail sector, to avoid the risk of slow innovations on the one hand and the risk of a vendor lock-in on the other hand, facilitating migration. For such decomposition, the economical, legal, regulatory, and organizational 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 onboard components allow the combination of different releases of onboard units (ATO, ETCS) or track-side protection systems on runtime. | | 6/7 | 8 |
| Rail optimisation techniques | Depending on TMS (FA1) and progress related to activities | | | | |

Table 5 - Overview over the operational outcome

#### *7.2.2.2 Technical enablers: capabilities to achieve the targeted operational outcomes*

Technical enablers are key for successful implementation of the identified capabilities: improved operation performance, higher capacity, and cost-effective deployment. Although these technical enablers are included as parts of the ultimate ATO GoA 4 goal, their intermediate results and developments do not need to be used only in combination with DATO. The technical enablers for the capabilities are described below.

<u>Capability for improving operation performance</u>

Automating functions, such as the wake-up and train preparation capability is needed to start operation, causing the need for remote control, auto-diagnostics, and operational tests.

Automated self-repairing/reset capability of DATO and next-generation ATC operated trains shall also be available.

Trains must be continuously traceable for traffic control and train operators in automated operation. 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.

A safe unattended operation must be ensured by comprehensive, modular, and scalable perception systems (onboard 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 the monitoring and diagnosis of assets, beyond the incident prevention functionalities.

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 towards GoA4 for fully automatic vehicles and powerful environment perception. Suitable interfaces for the remote operating person must be also developed (e.g., remote driving desk), considering human factors and the required training.

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

<u>Capability for offering more capacity to customers</u>
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 innovation on trackside and onboard ATP, for instance in the direction of novel CCS architectures enabling ETCS L3 moving block with minimum infrastructure elements and based on a digital topology, as 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 to achieve a much shorter headway and flexibility, supported by enhanced connectivity and localisation, will be based on System Pillar 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 as well as suitable testing facilities, need to be developed to ensure fast and safe deployment.

From a procedural perspective, the aspects of operational harmonization, 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 as well as automated planning and engineering, a neutral and sufficiently formal reference model is required as an enabler, as well as the digital twin. A specific aspect is the development of advanced HMI to enable the operators to interact safely and reliable with fully automatic systems.

To ensure the safety, quality, and applicability of specifications, based on harmonized and unequivocal European rules, using formal methods can provide significant benefits. Therefore, formal methods will be used for specification and demonstration; based on 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 RAMSS life cycle phases, with demonstration of the realized safety levels and to build 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 deployment - 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 integration effort, needs to be targeted. Specifically adapted processes for specification, development, certification and safety cases need to be put into operation in order to reduce the integration effort substantially. This will pave the way for modular computing platforms, which give the opportunity for application consolidation. For the software part, railway adequate 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 as well as investigating service-oriented design need to be applied. As the management of interfaces' specification and their underlying functionality are crucial parts for allowing evolution while controlling the interoperability, the use of formal modelling techniques to ensure quality, applicability and completeness need to be further elaborated here. To make those improvements effective, an adapted development cycle including an adapted safety cases procedure and modularized certification is required for the reduction of integration efforts.

Table 5 presents an overview of the capabilities that enable the operational objectives. It also includes the technology readiness levels (TRLs) for demonstrators in 2025, 2027 and 2031.

| Capabilities enabling operational objectives | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| **Capability for improving operation performance** | | | |

| Capabilities enabling operational objectives | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| *Functions/services/technical enablers for automated operation:* | | | |
| **Connectivity**, including FRMCS, V2X, 5G | 7 | 8 | 8/9 |
| 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 | 5/6 | 7 | 8 |
| **Absolute safe train positioning**, highly accurate and safe, incorporating new sensors | 5/6 | 7 | 8 |
| **Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO | 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 | 8 |
| **Safe environment perception**, including signal reading and obstacle detection, supporting cooperative awareness, supported by virtual certification | 5/6 | 6/7 | 7/8 |
| **Remote driving and command**, for depots, for lines with low traffic, and for fall-back operations as well as for shunting | 6 | 7 | 8 |
| **Autonomous route setting,** on low traffic/regional networks, in terminals, in depots and in urban environment. | 5 | 6 | 7 |
| **Capability for offering more capacity to customers** | | | |
| *Functions/services/technical enablers for reduced headway:* | | | |
| **Mixed Level 2, Hybrid L3, moving block** and relative braking distance | 5/6 | 7 | 8/9 |
| **Virtual coupling incl. self-driving freight wagons,** supporting cooperative awareness | 4/5 | 5/6 | 6/7 |
| **Next generation of braking subsystems**, to safely detect and manage low adhesion and reducing braking distances | 5 | 6 | 7 |
| **Capability for supporting cost-effective deployment** | | | |
| *Functions/services/technical enablers for cost-effective deployment:* | | | |
| **Testing, validation and (virtual) certification** platforms and facilities | 5/6 | 7 | 8 |
| **Modelling techniques** to support the development, engineering and planning, verification and validation solutions | n/a | n/a | n/a |
| **Architectural software design patterns** and **methods** enabling evolution | n/a | n/a | n/a |
| Development of **railway-industrial DevOps** | 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 | 8 |
| Evolved **onboard communication networks** | 6 | 7 | 8 |
| Functional Open Coupling covering all required subsystems in an operational environment | 7 | 8 | 9 |
| **Deployment and migration strategic plans**, including training and human factors | n/a | n/a | n/a |

*Table 6 - Overview of capabilities enabling operational objectives*

For services in the third block TRL are not applicable (n/a)

#### *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 L3 moving block, hybrid level 3 and FRMCS, showing increased system capacity,
- Next-generation ATC, both for trackside and onboard, 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, resilience and the reduced operating costs and energy consumption in at least four use cases:
    - High density mainlines,
    - Regional low-traffic services in strong link with FA6,
    - Freight services, also considering self-driving freight wagons,
    - 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 the urban environment.
- Test validation platform, to enable the next-generation ATC technologies in an efficient cost-effective way.

Demonstration will include interoperability aspects, challenging topology, and climate situations across Europe to show and assess the full impact of next-generation ATC and will be clustered in three phases (2025, 2027 and 2031), with increasing complexity and maturity levels for the aforementioned scenarios:

- Demonstration cluster 1 (2025) consists of bringing S2R results and further rail sector innovations to a higher TRL, such as GoA3/4 over mixed radio-based ETCS levels (TRL7), and the remote driving and command in depots and yards (TRL6) including perception systems, as well as first demonstrators on next-generation ATC), and modular onboard and trackside ATC architectures. First steps in the development of the new functions and technical enablers will also be completed, leading to proof-of-concepts and/or validation in laboratory and field (i.e., up to TRL5 in Lab and TRL6 on site). The Modularisation of the ATC system is developed in steps in close collaboration with the SP in the first cluster PoCs review.
- Demonstration cluster 2 (2027) integrates technical enablers and functions to enhance the performance and capabilities of next-generation ATC, also supporting migration and enlarging the deployment scope of automation. This will allow to demonstrate ATO GoA3/4 in depots, yards and specific lines without train protection, shunting and stabling operations, and under ETCS L1 and non-supervised modes (TRL7). This cluster includes validation of next-generation ATC tailored to regional low-density traffic lines and first steps in highly automated urban light-rail operations (TRL6). Modularisation is developed in close collaboration with the SP towards functional demos.
- Demonstration cluster 3 (2031) goal is twofold. First, it will focus on certified solutions (TRL8/9) 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 towards prototypes.

It is expected that all three demonstration clusters take maximum orientation in the system architecture, including modular trackside and onboard architecture concepts, as defined in the System Pillar. However, it is understood that especially in demonstration cluster 1, to not hamper the development, some trade-off may have to be taken between the pace of demonstrator development and full architectural compliance.

### *7.2.3 Impacts*

#### *7.2.3.1 Description of the impacts against existing rail services*

From an operational standpoint, the impact of the next-generation ATC innovation consists in reference to EU-RAIL JU's Master Plan of an increased punctuality, an increased railway capacity, a reduction of energy consumption, an increased flexibility in (re)planning, and an increased cost efficiency.

| | |
|---|---|
|  | Meeting evolving customer requirements<br>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, setting up the 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 towards more demand-oriented services. |
|  | Improved performance and capacity<br>As a result of the more precise operation, the buffer time between trains can be reduced, allowing more trains on the network and thus an increased railway capacity. This is also the case due to an improved reaction time through the optimal complementary working of man and machine, and shortened process times for turning trains, starting up trains, maintenance, and cleaning activities. Also, realising the incorporation of timing points on critical infrastructure can optimise the usage of the network even more. |
|  | Reduced costs<br>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 for 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 less maintenance cost and less failure cost. The modular and when possible reduced amount of needed ATC system components and the support of higher train densities reduces the infrastructure cost per train run and allows the offer of cheaper capacity.<br>A reduction of energy consumption 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. As a consequence, this will lead to fewer emissions, too. |

| | |
|---|---|
| | Reinforced role for rail in European transport and mobility<br>For the 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, a higher 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, higher sustainability, and solutions for socio/cultural developments. Simpler demonstration and better supervision of safety level are expected using supportive technology and by achieving a better collaboration between man and machine, reducing accidents and personal injuries. The higher capacity and punctuality will lead to a decrease in travelling times for both passengers and freight. This, together with a higher riding comfort by better adherence to the optimal speed profile, will create a higher customer satisfaction. For employees of the RUs and IMs their jobs could change. Train drivers will need to do less driving, possibly from a remote operation centre, but could get more of a monitoring role. Planners will get more support from the system itself, and disruptions can be managed more flexibly. For society as a whole, a modal shift towards trains from air/car transport is foreseen, 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 a higher sustainability. All these operational and especially societal benefits of next-generation ATC will provide solutions for future socio/cultural developments: urbanization, 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<br>Digital and autonomous train operation will provide a step change for modernizing the rail system by increasing the capacity and optimizing rail operations. Development of a modular architecture based on new innovative solutions which can provide a better performance of the system. |

*Table 7 - Descriptions of FA2 impacts related to the intended impacts in the Master Plan*

### *7.2.3.2 Quantitative KPI demonstrated in this FA*

To identify the contribution of FA2 to the impacts mentioned above as well as defined in the MP the following detailed KPI can be used as described in table 7.

| **Type of impact** | **KPI** | **Expected Improvements** |
|---|---|---|
| **A first technical KPI which can show the improved flexibility in the responsiveness is the system response time which could be given based on the reaction requested from FA1.** | Responsiveness is understood as the time to react to a request from FA1 in a shorter time than today. Responsiveness provided by FA2 is the enabler for improved flexibility and can be measured as time. | Reduction from 2h to 2Min. |
| **The accidentology indicator will show the improvement of the operational safety for mixed traffic in urban environment with trams while reducing the human factor in the normal operation.** | No. of collisions with third-parties per 10.000 km travelled | Decrease by 50% (ca. from 0.2 to 0.1) |
| **As operational KPI the improvement of the capacity can be used, as the increase as well indirectly improves travelling times, punctuality, quality of operation and reliability.** | No. of trains on line per hour and direction | Increase of 10% |
| **The cost-related operational KPI is the reduction of the Life-Cycle Cost (LCC)** | | |

| Type of impact | KPI | Expected Improvements |
|---|---|---|
| **where especially the cost of operation includes energy consumption and productivity. CAPEX are assumed to be kept at today's level but with additional functionality. OPEX-relevant factors reduced by different measures as e.g. Staff productivity increased by higher automation in train driving and shunting, Energy consumption reduction and improved punctuality by automation.** | Energy consumption in kWh reduction measured as energy per passenger-km | Reduction by 10% compared to driver's average, |
| | Increased Staff productivity is understood as raising the productive hours, which are understood as worked hours from staff minus waiting times, commuting/shuttling times, etc. | Increase by 30% |
| | Punctuality is understood here as reduction in cumulated delay time and measured as delay/service in time | Reduction by 20% |

*Table 8 - FA2 quantified KPI*

### *7.2.3.3 Exploitation, deployment and migration considerations*

A key aspect of this FA will be the way to deploy and to migrate from the current railway system to the future more automated and digitalized railway 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 less investment in new infrastructure or reduced 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 deploying next-generation ATC solutions on the other hand, meaning a better spread of their activities. Research centres will develop and deploy innovative technologies. This migration strategy would speed up the roll-out of next-generation ATC within the European Union.

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. That way, a generic next-generation ATC migration path could be provided. This migration path would likely need to coordinate with some other programs (e.g., FRMCS, ETCS, ERTMS) as well as intensively with the System Pillar. This way the roll-out of the technologies will experience a pull from the market. Overall, the business case on a 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 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. The migration path towards full deployment of next-generation ATC will be aligned and complemented to the migration path of the broader CCS+ architecture proposed by the SP including innovations for other trackside and onboard innovations in an adaptable stepwise approach. So e.g. technical enablers developed and demonstrated here should be used in and benefit from GoA1/2 and C-DAS implementations.

### 7.3 Flagship Area 3: Intelligent & Integrated asset management

#### *7.3.1 Objective and level of ambition*

##### *7.3.1.1 Targeted objective, opportunities opened 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 research and innovation, especially as more rail services will be needed to solve existing challenges and meet societal demands, following EU guidelines such as the Green Deal.

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

This Flagship Area has the goal to provide 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 life-cycle costs or extend life cycles while meeting the safety and improving the reliability and 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 three interrelated areas of application to enhance European rail industry competitiveness:

- Cost-effective asset management addresses short, mid 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 health conditions for workers[11] involved and increasing quality and consistency of the results.
- Environmentally-friendly production of resilient assets, supported by new design principles, solutions and fabrication techniques.

[11] Work in the rail infrastructure is physically demanding and requires much stooping and standing. Both fleet and infrastructure maintenance face similar problems: increase demand due to fleets grow and infrastructure being more used, an aging workforce that needs influx of new staff while the work is not attractive requires an increase of productivity. Robotics is the solution to these issues by bringing automation to the most frequent, difficult, dirty and hazardous tasks. This is also in line with the occupational safety and health (OSH) "Framework Directive of the EU

Addressing this broad scope as one Flagship Area, 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 lowering costs and environmental footprint. A joint effort increases the impact and creates a 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 scalable and deployable at EU level. Moreover, the solutions will support EU-wide standardization processes and TSI drafting, which will benefit the overall railway sector.

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

- No appropriate business cases for some technical evolution of different activities, driving to excessive cost of final solutions for a real market uptake.
- No sufficient consideration of human factors nor appropriate human-machine interfaces in the design and use phases of innovation (e.g. potential reluctance to use augmented reality or localisation systems by maintenance staff), even not fulfilling suitable levels of explanation and dissemination of their benefits.
- Unfit or underdeveloped reference system architecture framework and Conceptual Data Model (CDM) to correctly integrate innovations and make changes in the holistic systemic view.
- Lack of information exchange or unavailability of data due to proprietary and/or heterogeneous systems and/or lack of willingness and/or legal framework for data exchange impacting on developments and interfaces.
- Siloed proposals for technologies, not considering overall value chain demonstration cases and/or without integrated approach may suppose lacking real impact in their evolution.
- Lack of accuracy in the predictions damages the quality of the prescriptions provided by applications in decision-making processes resulting in not meeting the requirements for the railway sector.
- Unaccustomed certification processes for new assets, systems, or processes, especially when not considering CSM (Common Safety Method) and strong technical background since its inception.

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

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

a) **Cost-efficient and reliable trains** with Health Monitoring Systems and Condition Based Maintenance possibilities.
b) **Advanced Traffic Management & Control Systems** defining communication protocols.
c) **Cost Efficient and Reliable High Capacity** Infrastructure benefitted from innovative and optimised frameworks, processes and strategies.

d) **Technologies for Sustainable and Attractive European Rail Freight** (addressing both rolling stock and infrastructure) looked into asset management from a maintenance perspective.
e) **The Cross Cutting Activities** with a common smart maintenance concept; and
f) **Rail Functional System Architecture & Conceptual Data Model (CDM)** developed a conceptual data model to facilitate data exchange.

In the current context, FA3 will introduce innovative and state-of-the-art technologies in the following fields.

| State of the Art including Shift2Rail results | Progress Beyond, 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 standardize static railway system configuration with digital twins to enable a dynamic view of the railway system considering commonly agreed data structures to make sure data can be shared between various applications, stakeholders and disciplines such as traffic management, Autonomous Train Operation (ATO), etc. |
| 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 |
| Connection of RAMS (Reliability, Availability, Maintainability and Safety) information to Life Cycle Cost (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 (Artificial Intelligence) assessing the effects of costs and environmental footprint on different scenarios (e.g. new type of vehicles, climate change, new maintenance strategies, new materials, etc) |
| Vehicle-track interaction research studies with low TRL level development | Implementation of innovative vehicle-track interaction solutions for better infra and rolling stock design and behaviour to integrate 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 testing on-site of new production processes, innovative technologies in maintenance impacting operations |
| Parallel approaches to reduce material use and waste, and to extend service lifetime | New design techniques for vehicles and infrastructure components to reduce the use of materials while maintaining and prolonging the time in service effectively contributing also to rail resilience and environment 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 paradigm with the objective of enhancing operational performance |
| **Maintenance procedures and methods** | |
| Isolated but promising developments on asset monitoring and inspection which may not be connected to post-analytics workflows | Use of diagnostic vehicles, in-service trains, check points, way side systems, on-board sensing and other methods feeding smart identification and definition of root failure causes, degradation models and |

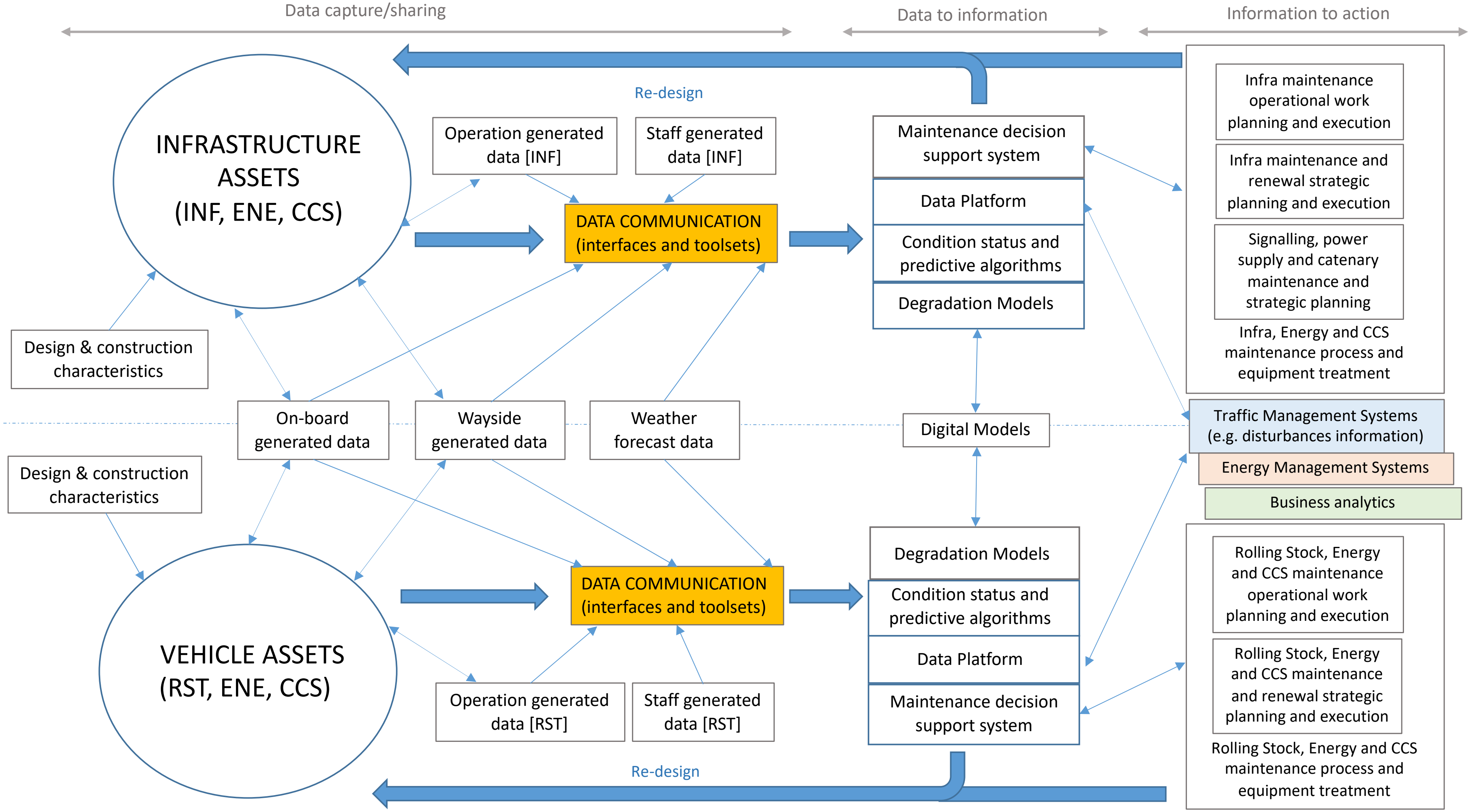
| State of the Art including Shift2Rail results | Progress Beyond, Innovation and New Products |
|---|---|
| | maintenance thresholds for subsystems applying, among others, AI techniques |
| Breakthrough technology developments for non-invasive inspection within Shift2Rail | Enhancements of non-invasive solutions to increase automated inspection (1) using IoT, sensors, satellites, or service trains or way side systems to capture data, and (2) exoskeletons, robots, biomimicry and drones, for construction and/or maintenance interventions |
| Atomised use of data in area-specific applications such as infrastructure maintenance decision-making | End-to-end integration of asset generated and operational data into operational and maintenance dispatch in automated workflows |
| Heavy dependency of decision-making on human experts. Arising problem of aging railway personnel | Transfer of maintenance human expert knowledge into AI (Artificial Intelligence) systems by codifying expertise, thereby providing AI based assistance to human decision makers. The objective will be 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 level demonstration of algorithms for prescriptive maintenance of subsystems |
| **Supporting technologies and innovative materials** | |
| Low TRL developments on the coordination between the train operation and maintenance | Cooperative planning tools to balance impact on train service and assets management (connection to TMS and FA1), including possession planning and possession management tools<br>Integration of predictive maintenance impact on maintenance schedule |
| Area-specific perception developments within Shift2Rail projects such as TAURO | Sensor technologies for passenger and freight vehicles enabling automated detection, analysis, visualisation, and geo-localisation of anomalies of assets as well as external conditions |
| TRL 3-4 developments for asset inspection in various areas such as UAVs or perception with few high TRL demonstrations | Automation of asset inspections via high TRL applications of enabling technologies such as UAVs. Increase of asset digitalization enhancing the data provided to prognosis and health assessment models |
| Taylor-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 railway 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 |

| State of the Art including Shift2Rail results | Progress Beyond, Innovation and New Products |
|---|---|
| | mobile operational assets, addressing both onboard and wayside systems, and developing a modular homogeneous system for railway check points & route inspection reports |
| Application specific interfaces to enable the use of predictive maintenance developments in projects such as In2Track (1, 2 &3) | Development of HMIs (Human Machine Interfaces), integrating Augmented Reality 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 to extend the useful life of assets from a construction and maintenance point of view contributing also to rail resilience and environment friendliness. |

*Table 9 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail*

#### *7.3.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

In this context, FA3 will leverage the integrated R&I (Research & Innovation) Programme of the Partnership, contributing to a high 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 a better overview of the whole railway system from the maintenance point of view.


Data capture/sharing
Data to information
Information to action
Re-design
INFRASTRUCTURE ASSETS (INF, ENE, CCS)
Operation generated data [INF]
Staff generated data [INF]
DATA COMMUNICATION (interfaces and toolsets)
Maintenance decision support system
Data Platform
Condition status and predictive algorithms
Degradation Models
Infra maintenance operational work planning and execution
Infra maintenance and renewal strategic planning and execution
Signalling, power supply and catenary maintenance and strategic planning
Infra, Energy and CCS maintenance process and equipment treatment
Design & construction characteristics
On-board generated data
Wayside generated data
Weather forecast data
Digital Models
Traffic Management Systems (e.g. disturbances information)
Energy Management Systems
Business analytics
Design & construction characteristics
Degradation Models
Condition status and predictive algorithms
Data Platform
Maintenance decision support system
VEHICLE ASSETS (RST, ENE, CCS)
DATA COMMUNICATION (interfaces and toolsets)
Operation generated data [RST]
Staff generated data [RST]
Rolling Stock, Energy and CCS maintenance operational work planning and execution
Rolling Stock, Energy and CCS maintenance and renewal strategic planning and execution
Rolling Stock, Energy and CCS maintenance process and equipment treatment
Re-design

In general terms, asset management is a 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, etc. together with this systematic approach to the governance for maintenance, over whole assets life cycle, will suppose a part of the smart maintenance development.

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

Following the framework defined by the System Pillar, FA3 will push the boundaries of smart and prescriptive asset management addressing, among others, the following topics:

- The link to the Transversal Topics, using existing tools (e.g. BIM) and developing data models (e.g. CDM) and Digital Twins as a basis for advanced visualization, 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 as well as migration strategies for the incremental adoption of the new asset management paradigm and transformation requirements.
- A tight coupling with Traffic Management Systems (TMS) fostering the exchange of information.

*Details of the exchange between the Flagship Areas can be found in Annex B*

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.
Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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 Transversal Topics, while benefiting from an enhanced traffic management system within Flagship Area 1. Within FA3 it is foreseen the development of digital twins which, for example, will specifically tackle the vehicle to infrastructure interaction to aid the prediction of the degradation of components. These digital twins, specific for FA3, will be connected and fed by other ones specific for other FAs. For example, to predict the degradation of the rails there could be a FA3 specific digital twin which uses information about the number of vehicles, its type, speed and 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 Flagship Area 4 towards a sustainable and green rail system meaning that FA3 solutions will also help reduce the environmental footprint of the railway system. In this respect, FA3 will focus especially on the reducing the environmental footprint of rail infrastructure (except stations), while FA4 will focus on rolling stock and stations.

Finally, Flagship Area 3 will provide innovative technologies for maintenance automation to the freight services in Flagship Area 5 and the regional rail services in low density areas in Flagship Area 6, to enable a sustainable and competitive digital freight system and to trigger the revitalisation of non-main 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: easy to install without many adjustments, meaning self-supporting, including power supply (energy harvesting) and wireless communication protocols.

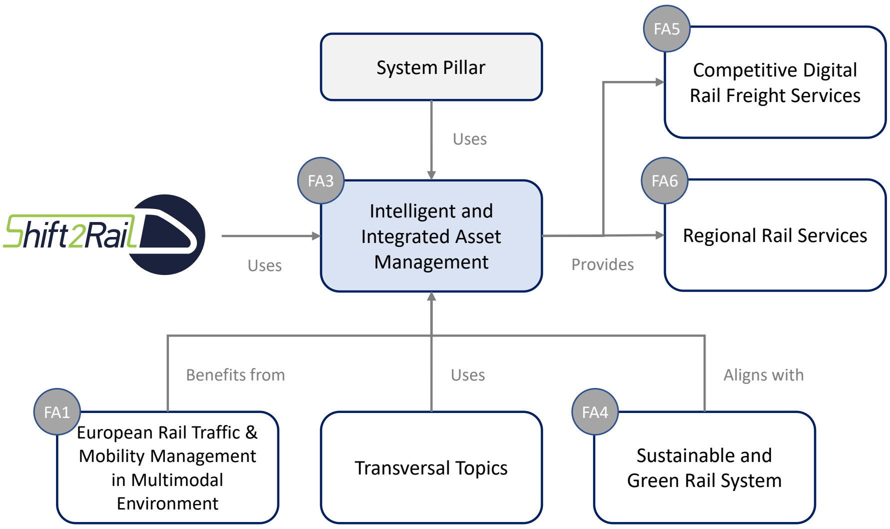



*Figure 11 - Overview of the relations within Europe's Rail*

The activities that will be developed within the FA3 will be tightly coordinated with the System Pillar and it is also foreseen a very important degree of collaboration, for example, for the definition and standardization of information exchange among on-board or wayside measurement systems and software platforms to display information, standardization of the validation procedures of additive manufacturing based repaired components, etc.

### *7.3.1.4 Who does what by stakeholder group*

Flagship Area 3 will align stakeholders across the railway supply chain to trigger the market uptake of technology developments to assist asset management.

**Infrastructure Managers and Railway Undertakings.**

The vast group of Infrastructure Managers (IMs) and Railway Undertakings (RUs) represent the core of Europe's operative rail network. IMs and RUs will provide a precise understanding of the rail system and the relations between solutions and performed operations on asset behaviour. As a group, they will ensure the right priorities are taken. Furthermore, they will support the testing of developments and host the required demonstrators.

**Suppliers**.

Suppliers (including manufacturers, integrators and service and technology providers) will (1) develop solutions to be integrated in the existing assets and (2) develop a new generation of assets to assist both rolling stock and infrastructure. The group of suppliers represents the core of the supply industry enabling the shortening of the development phase, easily adopting new technologies and integrating and migrating these into mainstream products.

**Research Centres.**

Research institutes and universities will support the generation of new technologies which will be matured into market-ready solutions together 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 research and innovation activities considered within FA3 are expected to interact with other programs and initiatives at European and national levels. It is worth mentioning the following European programs:

- The European Partnerships of AI-Data-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 within Pillar III (Innovative Europe) of Horizon Europe has two specific knowledge and innovation communities such as EIT manufacturing for new fabrication techniques and EIT Digital for the digitalization of assets information and processes.
- Connecting Europe Facility, Life and Digital Europe where large-scale demonstration can also be funded.
- European Recovery Plan or European Structural and Investment Funds.

Finally, it is also foreseen the interaction with other EU national programs as well as from other non-EU countries such as UK, Switzerland or other third countries, if relevant and added value, which also have smart and integrated asset management as a priority.

### *7.3.2 Results/Outcomes*

FA3 final operational solution and outcomes have been categorized in five high level capabilities that represent the core of the innovative work foreseen in the next years.

#### *7.3.2.1 Operational solutions outcome*

To achieve the overall goal of this Flagship Area, five high-level capabilities have been identified, addressing data and information sharing, monitoring and inspections, decision-making, design, and interventions. The FA3 capabilities are presented as follows:

1. **<u>Information sharing across the supply chain and TMS</u>**

The focus is on the ability to capture and share information securely across the entire rail system lifecycle, including operation, of rail assets. Furthermore, this area of action includes the secure exchange of information between the existing TMS and the Intelligent Asset Management System (IAMS). This requires the ability to tailor solutions to the needs of migration, evolution, and competition over subsystem lifecycle, enhancing the modularity of the system. Developing technical solutions jointly, with all stakeholders, also gives the opportunity to challenge the legal constraints leading towards an appropriate legal framework.

2. **Unmanned and non-invasive monitoring and inspections**

The objective 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, monitoring by satellite, and their connection to decision-making tools.

3. **Advanced and holistic asset decisions**

The focus is on the capability of making decisions in an advanced, automated, centralised, and holistic manner, considering the different assets, actors, standards, and regulations, especially 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), so as 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 lifecycle and maintenance, following the design-to-maintain for better operations' 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, as well as 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). This capability will particularly contribute to the reduction of the environmental footprint of railway assets and the increase of their resilience.

5. **Remotely controlled and unmanned interventions**

The objective 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 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 Technical enablers: capabilities to achieve the targeted operational outcomes*

The achievement of the objectives of Flagship Area 3 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:

1. **Cost-effective asset management:** applying remote (e.g., satellite, drone, etc.), wayside and on-board monitoring technologies or data analytics.
2. **Advanced and high-tech automated execution of construction and interventions:** such as robotics, exoskeletons or other supporting technologies for execution of work.
3. **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 that have been called "technical enablers". Such enablers are either commercial products already available (COTS solutions) or functionalities to be implemented within FA3, as they have been classified in the table below.

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| **Information sharing across the supply chain and TMS** | | | |
| Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation, etc.) and to enable high performance computing with the data | 6 | 7 | 8 |
| Secure standardised interfaces, methods and processes for different data exchange (e.g. inspection devices to Asset Management Platform, etc.) | 6 | 7 | 8 |
| High-performance, secure, wired and wireless communication networks and edge computing solutions specific for information sharing across the supply chain and TMS | COTS | COTS | COTS |
| **Unmanned and non-invasive monitoring and inspections** | | | |
| Improvement in terms of cost reduction and/or better accuracy and implementation of inspection systems (e.g. microwaves, magnetic fields, GeoRadar, Lidar, accelerometers, optical fibres, etc.) enabling asset diagnostic | 6 | 7 | 8 |
| Advanced unmanned automated solutions (e.g. robotic vehicles) with AI and ML algorithms for automated (robotic) monitoring and inspections including proof of safety for AI-based solution (trustworthy, robustness, interpretability) | 6 | 7 | 8 |
| Data fusion algorithms to combine information provided by different inspection techniques to better determine the health status of the assets | 6 | 7 | 8 |

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| Development of context awareness techniques for unmanned interventions (e.g. accurate positioning, computer based vision, laser scanning, GeoRadar, etc.) | 6 | 7 | 8 |
| Energy efficient solutions and energy harvesting techniques for high autonomy and reduced CO2 footprint of inspection systems and vehicles. | 5 | 6 | 7 |
| Development of synchronization algorithms for inspection data stamping in terms of accurate position and time | 6 | 7 | 8 |
| High performance wired and wireless communication network and edge computing solutions specific for unmanned and non-invasive monitoring and inspections | COTS | COTS | COTS |
| **Advanced and holistic asset decisions** | | | |
| Standardisation of railway asset LCC determination which accounts also for cost of potential hazard risks and cost of potential unavailability based on probabilistic models | 7 | 8 | 8/9 |
| Component failure probabilistic models to integrate cost of potential hazard risks and cost of potential unavailability in 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 diagnostic between assets. | 8/9 | - | - |
| Predictive and prescriptive data analytics and Machine Learning algorithms for anomaly detection and failure prediction | 6 | 7 | 8 |
| Digital Twins integrated with BIM, GIS tools, and Virtual and Augmented Reality to enable agile visualization for different stakeholders of asset health status (historical, current and forecasted) | 7 | 8 | 8 |
| Trustworthy, 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** | | | |
| Use cases for an accurate digital twin of railway components, processes and systems to virtually test the performance in different virtual scenarios (to compare performance, cost, $CO_2$ footprint with different process variables) | 7 | 8 | 8 |
| New ethical-by-design materials with advanced LCC characteristics | 5 | 6 | 7 |
| Advanced automated certification techniques | 5 | 6 | 7 |

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| Advanced embedded sensors for self-diagnostic materials for multiple use cases | 7 | 8 | 8 |
| 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) | 5 | 6 | 7 |
| Development of additive manufacturing techniques and validation standards for manufacturing and repairing assets | 6 | 7 | 8 |
| Development of wearables to support interventions (e.g. augmented reality, staff accurate positions for context awareness, etc.) | 6 | 7 | 8 |
| Advanced unmanned robotic vehicles with AI and ML algorithms for automated robotic interventions, which may include construction related aspects, for new lines as well as renewals | 6 | 7 | 8 |

*Table 10 - Overview of capabilities enabling operational objectives*

#### *7.3.2.3 Demonstration implementations*

The demonstration of the solutions in Flagship Area 3 will encompass the five outcomes presented in section **Error! Reference source not found.**, 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:

a. The integration of the complete value chain, from TIER 2 to the top management of systems.
b. The exploitation of synergies between stakeholders at different levels, for instance, with respect to crossed monitoring.
c. The prioritisation of activities to achieve 2030 European objectives in rail mobility, exploiting Shift2Rail results.

The demonstrators will have several **operational differences** to be covered, including:

- **Climate.** The proposed solutions will have to be able to take into account the wide variety of European climate types.
- **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 considering all assets, including track, civil structures, earthworks, signalling, vehicles, track side, stations or power infrastructures.
- **Planning level.** Following the ISO 55000 standard, demonstrators will cover the Strategic Asset Management Plan level (SAMP), the Asset Management Plan level (AMP) and the Implementation of the Asset Management Plan level (IAMP).

In the context presented in this section, Flagship Area 3 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 certification and validation of the new technologies and processes as part of those demonstrators. They will be implemented in an agile manner, not repeating three times seven identical demonstrators, but implementing for each demonstrators new capabilities at high TRL, taking stock of the development previously demonstrated within FA3 or done in S2R.

1. **Asset Management & TMS.** The main aim of the demonstrator will be to show the integration between the Intelligent Asset Management System (IAMS) and the Traffic Management System (TMS) enabling the share of data and optimising decisions using common metrics.
2. **Asset Management & 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 and planning of interventions, and redirecting rolling stock to workshops to execute the (re)scheduled work both manually as well as by new technologies and solutions to conduct inspection tasks automatically.
3. **Long Term Asset Management.** Development of Life Cycle Cost (LCC) models for infrastructure and rolling stock. This demonstrator will include cross-border infrastructure remaining useful-life analysis and space-time cross-analysis and visualisation.
4. **Asset Management & Infrastructure.** The objective will be to integrate on field and on board systems with central platforms capable of managing Big Data to enable prescriptive interventions, minimising dangerous situations and service disruptions during operation.
5. **Asset Management & 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 involved logistics. This will enforce the use of BIM to standardise system configuration and AI tools to execute simulations and predictions. The Digital Twin demonstrator will include visualisation, prediction and simulation.
6. **Design & Manufacturing.** This demonstrator will be the showcase of eco-friendly production of resilient assets supported by new fabrication techniques such as additive manufacturing (focussed on infrastructure assets).
7. **Robotics & Interventions.** The focus of this demonstrator will be the showcase of 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 a project level, these high-level demonstrators need to be further detailed and filled with specific, tangible and suitable use cases illustrating the impact of the technologies of FA3 in concrete solutions. The choice of these use cases will be based on sound business cases supported by a wide range of stakeholders possibly covering a wide range of assets proofing the versatility of the technologies, such as:

- Physical infrastructure: track, civil structures, earthworks, signalling, track side, 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 reliability of the system or work conditions.

Where an opportunity would materialize to achieve more aggregated demonstrators, especially linking demonstrators in the area of asset management, in business cases that will link digital twins, TMS and asset management for rolling stock and/or infrastructure, this will be pursued.

| # | 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 & Interurban | Suburban | Regional & Community | Freight | Passengers | Freight | Mixed | Tracks & S&C | Civil Structures & EWs | Signalling | Vehicles | Trackside monitoring | Stations | Power/Energy | SAMP | AMP | IAMP |
| 1 | Asset Management & TMS | Integration of Intelligent Asset Management System (IAMS) & TMS | Capabilities 1 and 3 | FA1 | x | X | x | x | x | x | X | x | | | x | x | | x | | | x | x |
| 2 | Asset Management & Rolling Stock | Asset Management of Rolling Stock Operation, including specific solutions for freight | Capabilities 1, 2 and 3 | FA5<br>TT | x | X | x | x | x | x | X | x | | | | x | | | | | | x |
| 3 | Long Term Asset Management | Infrastructure & Rolling Stock long-term Asset Management | Capabilities 2 and 3 | TT | x | X | x | x | x | x | X | x | x | x | x | x | x | x | x | x | | |
| 4 | Asset Management & Infrastructure | Asset Management of Infrastructure Operation | Capabilities 2 and 3 | FA1<br>TT | x | X | x | x | x | x | X | x | x | x | | x | x | | | | | x |
| 5 | Asset Management & Digital Twins | Digital Twin Asset Management, addressing both Rolling Stock & Infrastructure | Capabilities 3 and 4 | TT | x | X | x | x | x | x | X | x | x | x | | x | | x | x | x | x | |
| 6 | Design & Manufacturing | Advanced and Holistic Design | Capability 4 | FA4 | | | x | | | | X | | x | | | x | | | x | x | | |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Robotics & Interventions | Remotely controlled and unmanned interventions | Capability 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 against existing rail services*

This Flagship Area will provide prescriptive capabilities into 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 will be to produce significant value to the wider economy and the environment thanks to a variety of innovative technical and operational solutions that will be delivered by joint research and innovation activities.

The expected outcomes of FA3 as a whole are (1) a strengthened European rail industry competitiveness with more qualified products; (2) higher volumes and more cost-effective rail transportation on existing lines; (3) a reduction of $CO_2$ emissions from the maintenance of existing lines and the construction of new assets; and (4) the increase in durability and reliability of assets while optimising life-cycle costs, among other positive direct effects generated due to the synergies with other Flagship Areas.

In this context, following Europe's Rail JU Master Plan, FA3 will address the impacts presented below.

| | |
|---|---|
| | Meeting evolving customer requirements<br><br>Future rail asset management will improve the overall performance of the railway system and will reduce the unavailability. It will increase in operational reliability by fewer service disruptions and decrease incidents through continuous and precise condition monitoring of key components predicting failures in advance and scheduling preventive maintenance actions. |
| | Improved performance and capacity<br><br>Development of maintenance needs prediction capabilities towards optimisation of the maintenance procedures and to reduce the required asset down-time for maintenance activities. |
| | Reduced costs<br><br>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 cost. With the technologies developed in this FA, the maintenance time and frequencies will be reduced thanks to the introduction of digital and IA solutions and reducing the need for human interventions. |
| | More sustainable and resilient transport<br><br>FA3 solutions will increase the availability of the rail network and provide a more robust railway system based on less physical components, smart and more accurate monitoring and assets management. Benefit will be materialised from the perspective of human factor by providing better working conditions and less on site works for the railway staff. |
| | Improved EU rail supply industry competitiveness<br><br>Global technological leadership supported by a combination of innovation and technical standards, defining innovative maintenance decision-making concepts. This FA will enhance the industry competitiveness related to the design and maintenance optimisation of the rail systems taking into account current trends. The harmonisation and |

| | |
|---|---|
| | simplification of maintenance by applying and integrating advanced monitoring approaches, data analytics methodologies and decision support solutions. |

*Table 11 - Descriptions of FA3 impacts related to the intended impacts in the Master Plan*

The enhancements triggered by FA3 into the European rail asset management capabilities will finally be closely aligned with the overall strategic objectives set in the Single Basic Act (SBA) governing the European Joint Undertakings and in close connection to them, as presented in the following table.

### *7.3.3.2 Quantitative KPI demonstrated in this FA*

To ensure the delivery of the aforementioned impact points, a close monitoring scheme will be implemented using key performance indicators (KPIs). 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 within Flagship Area 3, targeting the main impacts foreseen in the programme, as shown in the following table.

| # | Demonstrator Name | High level theme and result | KPI's |
|---|---|---|---|
| 1 | Asset Management & TMS | Integration of Intelligent Asset Management System (IAMS) & TMS | I. Qualitative and prompt integration of information, including reducing time to transfer asset condition status to TMS by 50 %, in specific use cases |
| 2 | Asset Management & Rolling Stock | Asset Management of Rolling Stock Operation, including specific solutions for freight | II. reduction of maintenance costs up to 10% in specific use case and/or<br>III. 25% reduction of in service failures<br>IV. increasing rolling stock availability respective reducing workshop downtime targeting 10% in specific use cases |
| 3 | Long Term Asset Management | Infrastructure & Rolling Stock long-term Asset Management | V. Tools which provide at least 3 possible strategies of long term management with an accuracy (as defined by ISO) improvement of 33% |
| 4 | Asset Management & Infrastructure | Asset Management of Infrastructure Operation | VI. reduction of maintenance costs targeting10% in specific use case, and/or<br>VII. 25% reduction of in service failures |
| 5 | Asset Management & Digital Twins | Digital Twin Asset Management, addressing both Rolling Stock & Infrastructure | VIII. The number of assets managed and monitored by Digital Twins is increased by 50 % |
| 6 | Design & Manufacturing | Advanced and Holistic Design | IX. For repair: Extension of remaining life 25%<br>X. 20% time reduction (from design to manufacturing) |

| # | Demonstrator Name | High level theme and result | KPI's |
|---|---|---|---|
| | | | XI. 20% cost reduction |
| 7 | Robotics & Interventions | Remotely controlled and unmanned interventions | XII. Increased accuracy of inspections of 25% with respect to conventional interventions and/or<br>XIII. Reproducibility of inspections of 25% with respect to conventional interventions<br>XIV. Cost reduction of the interventions by at least 10% |

Table 12 - This FA quantified KPI

#### *7.3.3.3 Exploitation, deployment and migration considerations*

The developments in this Flagship Area, as outlined in the previous paragraphs, imply significant investments from the organisations involved in the Europe's Rail Joint Undertaking and from the European Union. The participation and commitment of a large community from both the user side as well as 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, a 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 Infrastructure Managers and Railway Undertakings as well as 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**, so that solutions are closer to commercial exploitation, making them more attractive for suppliers and supporting the last stage investment needed, based on the success of the demonstrator and the visible demand from the market. This will include consideration on certification and validation processes and will involve the relevant authorities as soon as this is reasonably possible.

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

- **Coordination with the System Pillar** to define a set of standards for information exchange at different levels, for instance, data from inspection results to holistic approach to strategic decisions.

- **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, opportunities opened and associated risks*

This Flagship area has the goal of providing new innovative products and services based on leading edge technologies to minimize the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier, 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 technical enablers have been identified, which are outlined in the following points:

- Innovative solutions to minimize energy consumption and associated environmental footprint of the overall rail system, considering assets i.e. rolling stock, linear infrastructure and railway real estate (including stations, hub's and other railway buildings) and operating materials (fuel, coolants, oils, etc.).
- Holistic approach towards generation, storage and optimal use of energy in the infrastructure, more globally the railway system, connected to the European energy network.
- New tools and new designs of different subsystems and associated manufacturing processes based on circular economy in the 6R model - re-invent, reduce, reuse, recycle, repurpose & realise - for more efficient use of resources throughout their life cycle and reduction of their footprint.
- Innovative approaches to design and use (processes and standards) focused on increased capacity and modularity of solution.
- Systems improvement including electro-mechanical components for low consumption, low emissions, low noise and low vibration levels.
- Healthier and safer subsystems such as air-filtration and disinfection systems, eco-friendly HVAC with natural, halogen-free and low or even zero GWP refrigerants and technologies.
- New designs of rolling-stock especially modular interiors for a more adaptive, attractive and economically sustainable railway transport for passengers, supported by industrial standards.

The work within this Flagship Area will enable a faster route to commercialize the new developed solutions making the European rail service more attractive, healthier and reducing the environmental footprint.

Given the level of investments needed towards decarbonation of the overall rail system, for the assets and the associated operations, those R&I activities will accelerate the provision to the markets by decarbonized products towards the objective of a Climate Neutral Europe for 2050.

The following gaps and corresponding risks to minimize the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier, more attractive and to provide resiliency against climate change will be taken into account:

- Development of technologies relevant for some of the FA4 activities are led meanly by other industries (e.g. hydrogen solutions within the JUs Clean Hydrogen, batteries within the partnership BATT4EU, sustainable construction in the Bulid4People partnership), which might be difficult to be directly transferred to railways for different reasons, e.g. cost of technologies, standards incompatibilities, technical constraints.
- Siloed proposals for technologies, not considering the entire value chain, missing some use cases and/or without integrated approach may suppose lacking real impact in their evolution.
- Not enough technological performance or development from one entity in actions affecting dramatically an overall demonstration progress.
- No appropriate business cases for some technical evolution of different activities, driving to excessive cost of final product or service for a real market uptake (e.g. Hydrogen production and storage cost).
- Longer and more costly than expected certification processes for new assets, systems or processes.

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

The current Shift2Rail projects achieved several goals in the specific Innovation Programmes. Starting from those results while proposing new field of activities, this Flagship Area 4 will further increase the TRL levels of the relevant solutions leading to new solutions in the following areas:

| State of the art especially from Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|
| S2R IP1: Traction has undertaken development of the new generation of traction drives using silicon carbide technology which will achieve TRL 7 in 2022. A carbon free mobility road map from 2022 to 2030 detailing the work required to develop a credible alternative for diesel traction, meeting 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 will be undertaken before EU-RAIL JU<br><br>IP5 studied last mile propulsion and next generation energy efficient propulsion systems for freight vehicles. | • To complete full Diesel suppression in Europe (and support exportation outside), further zero local $CO2_e$ trains and refuel /recharge infrastructures must be developed with the suitable technical, environmental and economical performances, aiming at multi-modal H2 HRS wherever applicable, for example. Moreover, additional harmonisation and standardisation work, including simplification of certification, has to be done to simplify European solutions allowing interoperable trains and lower costs for a quicker deployment of solutions. Batteries (BEMU long range autonomy) and H2 hybrid trains with low LCC are needed as well as |

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| WA 5.1 Energy studied standardised methodology for estimation of energy consumption by simulation and measurement enabling the standardised specification of energy efficient railway systems and generic energy labelling for rolling stock.<br><br>Other State of the art: in 2021 different low carbon train experimentation are carried out all over Europe. But the technical performances are lower than needs and/or the LCC is higher than expected, explaining the relative low deployment of such new traction solutions to replace the 9 000 Diesel regional trains in Europe.<br><br>Regarding Hydrogen, a "Study on the use of fuel cells and hydrogen in the railway environment" commissioned by Shift2Rail JU and the Fuel-Cell Hydrogen JU was produced in 2019, delivering a roadmap for the R&I activities. | new remunerative energy services (peak power shaving, load shedding capacity). Alternative fuelling solutions for regional railways such as hydrogen, e-fuels, battery fuelling are part of the overall investigation need.<br>• New environmental aspect, circular economy, recyclability must be taken into account, in these new solutions, from design stage to final demonstrations.<br>• Sub-urban catenary trains with on board ESS (Energy Storage System) are also needed to increase the transport service robustness in large urban areas, specifically the mass transit system where a single power supply weakness or even failure has today an unacceptable impact on trains punctuality: energy autonomy is needed for the comfort & safety of passengers or for traction to a nearby station. A powerful ESS on board is likely also to avoid the use of mechanical braking (energy losses, particulate matter emissions, maintenance costs). It is also a cost-efficient solution when place is missing in cities to strengthen substations to feed more trains. Moreover it allows infrastructure power peak shaving reducing the energy bill. |

*Table 13 - Alternative energy solutions for the rolling stock*

| State of the art especially from Shift2Rail results | 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 AC power supply, and energy management on the catenary for 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 theoretical and ideal operation of the system and its components. The legal aspect of the AC parallel operation of the sub-station, the impact, performance and theoretical added value of the solutions have been considered. A first set of specifications of the components needed, | It is needed to go further in the development of a solution for AC sub-station operation in parallel to reach an industrial maturity and prepare an on-site demonstration. Improvement of the specifications of the equipment are also needed to reach a maturity level enabling their development/production by a manufacturer. It is also needed to investigate the solutions to manage the charging (including fast charging) and the energy peaks consumption on the railway electric grid, i.e. the "local energy balance/management".<br>Management of energy storage system (on track, or management of the onboard |

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| the feasibility for industrial development have been carried out.<br>Concerning energy storage, the state of the art is limited to the development of the storage technologies and their implementation into the railway system for the specific applications of energy recovering (for on track storage) and traction power (for on board systems). | storage) are also solutions to investigate. Investigating those solutions will lead to manage storage systems for multi-services with an overall railway system approach. |
| **Stations as relevant energy hubs.**<br>Railways stations, as harbours or airports, in modern cities, have complex energy systems (variety of energy loads, sources and storages) and, as such, are relevant energy hubs integrated in 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 allow to link together the Smart (City) Grid with the Smart Rail Grid.<br>Extensive research regarding energy management for smart grids and under electrical market rules are mentioned in the H2020 bridge initiative https://www.h2020-bridge.eu/ which compiles most of H2020 projects on this topic.<br>Regarding the Railway power system, S2R TD3.9 and TD3.10 are aligned with this. | Models and AI solutions for the optimal energy management, considering the interaction of the infrastructure with the train, the station as a building and the local area around, will make the **stations**, **Energy Hubs** integrated in a more global **Smart Grid**, aligned with electricity market (VPP for balancing markets, local flexibility markets, ancillary services…) and energy communities' trends. This encompasses the forecasting of energy needs as well as the optimization of energy costs and CO2 emissions |
| **Hydrogen trains use**<br>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 their maturity has to be increased, many implementation projects and purchase of niche vehicles fleets being developed all over Europe.<br>Hydrogen can be implemented in retrofitting as well as new builds.<br>Growing hydrogen use will need a storing and refuelling system adapted to the railway need while at the same time being integrated in local hydrogen system easing scale effect integration, especially with the other transport modes.<br>Currently storing solutions for railways are 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 build algorithms to support the refuelling process and ensure its optimal conditions.<br>• Preparing and testing a model of a scalable hydrogen refuelling station that will enable the use a RES for its production and will guarantee its flexible extension with new modules. Because of the possible large increase of demand for hydrogen fuel in future, it will be necessary to estimate the maximum efficiency of electrolysers for producing |

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| | hydrogen from RES and develop plans for supplying the refuelling station with external sources.<br>• Preparation of safety standards related to the storage and transport of hydrogen by rail and ensuring appropriate safety standards for the refuelling station environment.<br>• Inclusion of rail applications within a wider ecosystem approach, namely H2 Valley, in collaboration with Clean Hydrogen JU. |

*Table 14 - A holistic approach to energy in rail infrastructure (design, production, use and intelligent management)*

| State of the art especially from Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|
| **Adaptation to climate change**<br>No work has been achieved on adaptation to climate change in Shift2Rail.<br>The life duration of railways assets (from 40 years for a rolling stock to 100 years for a railway track) shows that long term effects must be taken into account in their conception and maintenance.<br>A working group has been launched in July 2020 to consider climate change in the norm EN50125 'Railway applications - Environmental conditions for equipment, without any help from climate experts or climate data provided. This work is limited to technical aspects, the impact on organisations being out of scope.<br>Though the Copernicus Climate Change Service (www.copernicus.eu) supports society by providing information about the past, present and future climate in Europe, climate experts with specific software are not available in the railway sector to analyse the available data.<br>European Commission adopted its new EU strategy on adaptation to climate change on 24 February 2021 with 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 to the railway sector to make it resilient to climate change:<br>• Smarter adaptation: develop robust data (analyses of past, present and future climate parameters applicable to the European railway activities) and provide risk assessment (Common Safety Methods and Life Cycle Costs) for rolling stock, stations, workshops, infrastructures, operations and staff organisation.<br>• Faster adaptation: identify existing solutions and develop new ones for existing railway assets and future ones to reduce climate-related risks including SSBD.<br>• Systemic adaptation: develop and implement adaptation strategies: preventive and corrective actions (technical or organisational), constraints applied on conception, maintenance or operations<br>• Harmonisation and standardisation: develop and implement standards for green and eco-friendly materials |

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| **Smart and sustainable stations**<br>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 solutions oriented towards improving the design of selected station modules/components, as well as improving attractiveness (accessibility, customer experience, usability) and safety, including crowd management.<br>The achieved preliminary research within S2R provides the basis for the development of innovative solutions and their dissemination, which is the foundation for the railway sector's transition of railway stations to a circular economy model to a significant extent of the full life cycle of stations by 2030.<br>The current approach to Transit Oriented Development (TOD) is only focused on the architecture and urban planning around the transport nodes. | • New layout concepts for the design of stations favouring modular and natural-based solutions, supported by BIM methodologies. Design for more resilient infrastructures, more robust to extreme hazards (including climate change ones).<br>• Multi-modality aspects for H2, where applicable.<br>• Design of the energy systems of the station, supported by BIM-based BEMS.<br>• 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 in order to design more resilient infrastructures and to be better prepared for contingencies management.<br>• The innovative Smart TOD models will exploit the coexistence and synergies between the rail infrastructure and the urban environment (integration levels: environmental, social, economic and sustainable mobility). Improved Smart TOD models supported by analytics toolset and processes will be developed. This will enable a holistic development of rail assets and transport services integrating the local level (stations with urban surroundings) and the network level (coherency at the district and/or regional grid level). |
| **A sustainable rail system / Circular economy**<br>Starting of working group inside CEN (CEN/TC 256/SC 2/WG 54) for the acceptance of New Materials. | Development of environmentally friendly materials (recyclable, reusable, reparable, etc.) mainly composites based. These materials should be adapted for manufacturing process valid for market railway solution and should also help to increase 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 are participating stakeholder from whole railway industry. |
| **Noise and vibrations**<br>Before **S2R,** rail noise and vibrations were the focus of several FP7 projects, Acoutrain | Further simulation methods & tools for train, infrastructure noise & vibration and traction noise are needed to better predict, |

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| (noise) and RIVAS (vibration), Roll2rail in H2020.<br>**S2R** developed many activities in various projects FINE1 (Noise) and FINE-2 (Noise & 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 on system level including rolling stock infrastructure and its environment, ranking and characterization of each contributing source to optimize cost benefit scenarios and comfort. Several IP3 and IP5 projects raised noise mitigation measures. | design and develop the needed technical solutions.<br><br>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 15 - Sustainability and resilience of the rail system in a holistic approach to asset management, delivering more value*

| State of the art especially from Shift2Rail results | Further innovation needed and covered by this FA |
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| As state of the art, today's trains base the implementation of key functions on **compressed air** (brake, suspension, pantograph, MTB, sanding). The AGTU systems (air generation and treatment unit), used to provide compressed air, have a **poor energy efficiency (≈20%)**, a consistent **weight** (800-900 Kg per train), generate **high noise & vibration** and require significant **maintenance activities and costs**.<br>The major trend in other transport modes (road, aviation) has been to remove actuators powered by fluids and replace them by electric actuators. The same major trend appears in railways and the ultimate step will be to completely remove air compressors and related pipes on "airless" trains. | The first major step to be done is an airless bogie to be completed by an airless pantograph.<br>This will bring savings on energy & maintenance, noise reduction, improve reliability and give some weight saving usable for other train performances improvement (BEMU autonomy for ex if compressor & piping weight is replaced by batteries). This will also simplify the architecture of the train and its manufacturing and will need to ensure increase resilience to climate change and natural and man-made hazards while not increasing noise emissions.<br>The needed new components are:<br>• Electro-mechanical braking system. Their development started under S2R but the final demonstration has to be done<br>• An electro-mechanical pantograph (not available on the market yet) has to be developed and demonstrated<br>• Airless suspensions have to be developed<br>• Industrial standards, traditionally conceived for pneumatic, must be |

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| | revisited from electro-mechanical perspective ensuring functional interoperability with the existing systems by complying with the applicable TSI and EN standards and ensuring equal or better safety and availability |
| Electro-mechanical braking system requirements, prototyping and testing in S2R up to TRL 6<br>The work on electro-mechanical braking system have been done within IP1. By the end of 2020, functional and performance requirements was collected, evaluated and agreed. The main standards and norms 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, description of the functionality on braking system level including interface to the vehicle, signalling, wiring on a functional level will be delivered and technology feasibility tested. | On Electro-mechanical braking system (EMB), the next step to accomplish the TRL8 is the integration of this novel braking system into the train originally designed to integrate pneumatic/hydraulic braking system. This comprises interfaces for command and diagnostics, energy storage and power supply concepts, RAMS considerations and vehicle authorization. The most crucial task is the field test to solve all questions for vehicle integration and move operational experience and market acceptance to maturity level. This braking system will also need to improve their resilience to various unexpected natural or man-made hazards while mitigating noise emissions from parked trains. |
| **Eco-friendly HVAC** units with CO2 as 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 within first prototypes. But these solutions are less energy efficient, less performant to resilience and expected higher ambient operation temperature than those proposed in EU-RAIL JU new R&D. | The activities will bring further HVAC reduction of energy consumption (-30% compared to existing one and -24% compared to CO2 technology) by keeping the environmental impact of the used materials / refrigerants at a minimum. The reduction of energy consumption is especially very important for battery trains, since HVAC requires up to 30% of the total energy used by the train.<br>The improvements of HVAC will need to ensure:<br>• improved resilience to climate change and various unexpected natural or man-made hazards.<br>• improved weight performance besides energy consumption.<br>The improvements will be mainly achieved by implementing technologies with a higher COP (Coefficient of Performance) in cooling and heating mode.<br>A technology with a usable COP > 4 in cooling mode will be considered, e.g. by: |

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| | • Application of magnetocaloric effect for cooling / heating.<br>• Natural refrigerants (e.g. water) for COP up to 5<br>• Optimisation of the design of concepts, units and components<br>• Implementing the work at 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. |
| **Train weight reduction**<br>Composite carbody to reduce weight up to TRL 6/7 has been done in S2R IP1.<br>Running gear steering systems (especially in bogies), active suspension, new materials and new strategies developed to reduce **weight** and **noise** and **vibration**.<br>No relevant research activities beyond TRL 4 have been carried out at European level to introduce Permanent Magnet Surface Mounted (PMSM) in traction vehicles with **recycled magnets** to improve sustainability, valorisation of waste and reduced number of parts. | Train weight reduction still needs to be improved as any component or sub-system have been optimised in the S2R projects.<br>That will boost energy efficiency, support passenger capacity increase, allow to embark more batteries on BEMU for longer autonomy, reduce noise, train cost maintenance costs.<br>To simplify the train architecture, save weight, innovations at integrated component and sub-systems levels are proposed.<br>Three main axes will be used for weight savings on Bogie, drives and gearbox:<br>• Use of **new materials in structural and non-structural parts** (**composite**, etc…). Has been *partially* done in S2R<br>• Use totally new **3D impression (and related powders**) for bogie parts<br>• **Change bogie architecture** with frameless architecture<br>All of this 3 new ways of designing/manufacturing Bogie will need **new standards** especially on validation/certification **& TSI** for new concepts, materials and processes<br><br>The new bogie should bring up to 25% weight saving (up to 12 tons on a regional 4 |

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| | cars train). This and new running motors and running gear will improve technical & environmental performances, and support increasing resilience, capacity, accessibility, waste valorisation, as well as reducing track damage. |
| **Aerodynamic improvement**<br>This field is almost mature in VHSDT but still need a lot of improvement in Regional and intercity trains. The roof of the train is usually hosting the traction, HVAC equipment but due to cultural habit, the aerodynamic (air drag) is not optimised because maintenance teams wish a direct access to roof components | Entering into a new period where energy and CO2 emissions are key needs to bring new aerodynamic parts (hoods) to be implemented on the roof of such trains. It's not only a technical problem but a cultural and normative debate. Indeed, bringing this hoods on the train need the Operator/maintenance team approval and the safety aspect (elimination of the risk of a hood flying off while driving) must be agreed at European level and international norms. |

*Table 16 - Systems improvement including electro-mechanical components for low consumption, low emissions, low noise, low vibrations levels*

| State of the art especially from Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|
| **Air quality on board trains**<br>Since the beginning of the Covid19 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 RS applications or operating constraints.<br>Measurements of air quality on board trains, in tunnels and underground or covered stations have been developed last years over the world, related the to the growing concern of the population to live in healthy environment. They show that efficient solutions, technically and economically, have to be found to improve the air quality. All that was not addressed in Shift2Rail. | • Technologies and methodologies ensuring a reduced health risk for rail passengers and staff<br>• Air-distribution and air-flow management concepts for a more effective removal of contaminants from the passenger compartment while maintaining the thermal comfort<br>• Air-filtration and disinfection systems for an enhanced air cleaning in the HVAC system<br>• Enhanced surface materials for reduced virus/bacteria lifetime<br>• Passenger flow management to reduce contaminations' risks<br>• Standardized measurement protocol to assess the efficiency of technologies to improve air quality on board, in stations and tunnels<br>• Measurement and live visualization of air quality parameters to enhance passenger trust |

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| | • Technologies for both, new train generations and improvement of existing rolling stocks<br>• All aspects to be considered with respect to rail-specific requirements: LCC, safety, reliability, endurance…<br>• Development of standard for demonstration of effectiveness under train conditions |
| **Non-exhaust emissions**<br>No work has been achieved in S2R on the topic of non-exhaust emissions, as particulate matters emitted from the wear of mechanical braking systems, wheel-rail and pantograph-catenary line contacts.<br>The EU Clean Air policy aims to reduce air pollution as close as possible to WHO recommendation thus minimizing harmful effects on human health and on the environment. The railway sector needs to ensure all customers and inhabitants that public transportation is harmless and the best answer 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, ...) carried out campaigns of measurements, analysis, and tested various solutions to improve air quality. However few works have been published and no solution are available on the market for railways and subways.<br>Development of electrical braking may be a solution but with an unknown effect at the moment.<br>Vacuum cleaning trains are existing, but their operational speed of 5km/h doesn't comply with infrastructure maintenance constraints and their efficiency to improve air quality have never been measured.<br>The UIC Air quality sector has been launched end of 2020 to share knowledge, select and | The aims are to build a better understanding of the issue of non-exhaust emissions emitted by wear particles from brakes, wheels-rail contact, pantograph-catenary line contact, assess the risks and to elaborate a well sound action plan.<br>The works will anticipate coming regulations on air quality and ensure that railway is the best answer. The scope is ambient air with a focus on underground railway rights-of-way.<br>Actions needed are:<br>• <u>Analysis of air quality</u> on-board trains, in underground station and tunnels.<br>• Assessment of <u>rail emission factors</u>: characterize the non-exhaust emissions emitted by rolling stocks, railway stations and railway infrastructures (ballast abrasion, pollution during work, aging of the underground infrastructures) and determine the influence factors (link between air quality, emissions and assets characteristics). Assessment of polluting factors: characterize emissions caused by use of operating materials, e.g. on-board and way side lubricants, and determine the influencing factors (improvements of eco-friendly solutions over conventional products regarding emission to air, ground and water).<br>• Understand the <u>effect on health</u> of the specific composition of air quality in underground stations and tunnels to help the selection of efficient solutions.<br>• <u>Air quality mapping</u>: define a method to evaluate and report the non-exhaust emissions emitted by the railway activities (European Pollutant Release and Transfer Register (E-PRTR) - UIC |

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| share actions, perform collaborative expertise sharing, cross analyses on results.<br>The working group ISO / TC269 / SC2 / AHG04 has been launched in 2021 to standardise the "Methods for characterizing and measuring particulate emissions from friction materials".<br>The next Euro 7 standard for the road sector is planning to tackle emissions from tyres and brakes to ensure that particle pollution from all sources is reduced to the lowest levels possible. | reporting on Sustainable Mobility and Transport).<br>• Develop and assess <u>solutions to reduce</u> non-exhaust emissions at source: ex. low emission braking pads, operating materials.<br>• Develop and assess <u>solutions to collect</u> historic non-exhaust emissions: ex. vacuum cleaning train, collector/filtering/treatment on-board trains and in underground railway stations.<br>• Define a <u>method to evaluate and report the efficiency</u> of air pollutants reduction solutions in operational conditions. |

*Table 17 - Healthier and safer rail system*

| State of the art especially from Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|
| The current trains, including new generation, are not designed for modernization, 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, which limit the range of solutions for reuse and increase purchase and replacement costs, thus despite the requirements of operators over the 10 last years.<br>The driver's cabin is a bulky, expensive and not very scalable space. Only 1 on 2 is active during operations.<br><br>**Shift2Rail TD1.7 Modularity in Use** considered the reduction of the global refurbishment costs for Interiors. But budget and scope were limited to the “technical tube”: face and roof. Impact for carbodyshell, floor, plug&play fixation systems were not considered. A final demonstrator is planned for 2022 (TRL5).<br>The concept of a single driver’s cabin emerges reducing CAPEX and OPEX costs. Two forward-looking concepts will be proposed in 2022 (TRL 4-5). Due to limited | Further collaboration with operators, car-manufacturers and suppliers is of utmost importance to define new industrial standards and/or European standards, taking in account accessibility, modularity and circular design, easing the specific services, the increase of 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.<br>The target is TRL 8 for the following activities:.<br>• To develop and test common plug&play fixation systems for hard fixation point both for new train generation and improvement of existing ones.<br>• To find the better compromise between standards and the best customization.<br>• To integrate new sustainable materials.<br>• To integrate the circular design in standards.<br>• Specific activities could be for instance, quick mechanical and electric fixation systems, new driver’s desk (design, |

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| budget the scope is focused on use-cases without any hard technical considerations.<br>**S2R projects** showed that the European marketing services of operators and manufacturers haven't got any visibility on passengers needs beyond 5 years. The capacity to refurbish quickly is by such of crucial importance, especially for the mid-life maintenance's milestone. | integration of new technologies and human machine interfaces). |

*Table 18 - Attractiveness*

#### *7.4.1.1 System integration, interactions with System Pillar and with other Flagship Areas*

Regarding the existing development of the functional system architecture (LinX4Rail projects), the proposals of the European Commission, both proposing an energy layer in the description, it is of importance that the energy management has to be considered in a system view, moreover in the electrified network.

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

Some links with the other Flagship Areas of Europe's Rail will have to be taken in consideration:

- DAS/C-DAS and energy management linked with FA1 (in terms of TMS (Traffic Management Systems)), with FA2 (in terms of ATO (Automatic Train Operation)) and with FA5 for specific freight purposes.
- There will be an alignment with the green solutions developed in Flagship Area 3 towards a sustainable and green rail system. FA3 will focus especially on the 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 vehicles components (boogies, 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 multi-modal links and refuelling technologies will be also relevant to share for regional lines. It should be noted that it will have probably limited impact as the FA6 Regional train is only on revitalising of secondary lines and will develop specific low cost & agile vehicles having not many synergies with classical 4 to 6 cars regional trains studied in FA4.
- Digital Twin TT, link on FA4 virtual validation and certification as digital models of on-board sub-systems are needed on both FA4 and Digital Twin sides.
- Digital Twin TT, link on FA4 regarding design, construction, operation and management of railway infrastructures, including the energy management (shared also with the System Pillar) of the Energy Hubs integrated in the Smart Grid.
- Digital Twin TT link on FA4 concerning aerodynamic performance as it is crucial for the energy efficiency of the vehicles
- Digital twin TT for stations applications, supported by BIM (Building Information Modelling).

*Details of the exchange between the Flagship Areas can be found in Annex B*

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.
Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

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

#### *7.4.1.2 Who does what by stakeholder group*

Flagship Area 4 will align stakeholders across the railway supply chain in order to increase the sustainability of the European railway system, their asset and their operations.
Infrastructure managers and Railway Undertakings.

Infrastructure Managers (IM’s) and Railway Undertakings (RU’s) manage rail operations on the European network. They will ensure that the technologies proposed are relevant in a system view, including assets and operations, ensuring the right priorities are considered. They will support the development of the technologies by their engineering capacities, involving their knowledge in terms of asset behaviour all along the life cycle. Furthermore, they will support the testing of developments and host primarily the required demonstrators.
Manufacturers/Suppliers.

Manufacturers, integrators and service and technology providers will (1) develop solutions to be integrated in the exiting assets and (2) develop a new generation of assets to assist both rolling stock and infrastructure. The group of suppliers represents the core of the supply industry enabling the shortening of the development phase, easily adopting new technologies and integrating and migrating these into mainstream products.

Research Centres.

Research institutes and universities will support by their scientific knowledge the generation 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 being implementable to the railway system.

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

#### *7.4.1.3 Interaction with other Programmes, European and/or National*

Regarding energy storage system and H2 fuel cells, the FA4 activities will have to be coordinated with the European partnerships, BATT4EU and the Clean Hydrogen JU.

Regarding potential H2 activities, synergies with national and regional (especially European structural funds) investments for research and innovation will be considered, given the various prototypes, even little fleet of vehicles being financed all over Europe.

On alternative Traction system, we notice a difficulty for the railway sector to invest on freight new solutions. In particular, the need to replace Diesel Freight locomotives underlines a lack of actual alternative H2 solutions:

- Lack of compact (weight and volume compatible with locomotives limitations) high power Fuel-Cell systems (around 4 to 6 MW per locomotive)
- Lack of compact Hydrogen storage. Currently, US Diesel freight locos embark 18 000 litres of Diesel. That represent -at actual H2 350 bars compressed technologies- about 70 tons of H2 and H2 tanks. That's not very convenient for freight locos and better solutions are needed (like liquid fuels at Normal Conditions). On the other hand, new concepts for on board hydrogen storage (LOHC, cryo-compressed H2, etc.) are still being developed. In addition, impacts of more frequent refuelling could be explored/assessed.

The Clean Hydrogen JU will work on similar needs for Maritime and Road applications and FA4 will have interest to follow up the progress done by Clean Hydrogen JU, in particular in

- Heavy Duty Vehicles (HDV) and trucks FC systems and fuel storage: the power range is about the same as regional trains power pack (237kW for HDV; 300 kW for regional trains). HDV ramp-up is expected in 2026.
- Maritime developments: even if the driving profile are not the same it may be interesting to follow up the new 3 to 10 MW fuel cell systems .
- Any other developments for compact high power systems.

Moreover existing (2021) projects progresses will be taken into account: follow up of the ShipFC project (2MW and NH3), another project on 3MW PEM FC and LH2.

Some projects are also of interest in the aeronautic domain: officially Clean Sky JU will work also on Fuel Cells (FC) systems (250 kW FC on 2025) and high power (1MW+) FC and Liquid H2.

Of course, if Marine or Aviation developments are successful, they could be potentially transferred to railways if feasible (both technical and normative aspects will have to be evaluated).

Connection to the EU partnerships Built4People and New European Bauhaus must be considered for the stations topics.

Stations as energy hubs should be considered interacting with the activities proposed and granted by the Horizon Europe Cluster 5 and interactions are foreseen with other EU national programmes.

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### *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 oriented towards a more integrated and standardised Rail Power Smart Grid, integrating greener energies, cutting peak of energy consumption and allowing for a better control and management.

- Developments oriented towards a better energy management at station level (stations as energy hubs) providing more intelligent and integrated control systems and allowing for a larger energy flexibility and resilience of the Electrical Smart Grid.

For the holistic approach to circularity and resilience the following solutions will be provided:
- Technologies for a more sustainable and extreme hazard resilience design of railway infrastructures and rolling stocks, oriented towards the whole life cycle of the assets and supported by Digital Twin developments.
- Sector tools or platform for the efficient implementation of circular economy solutions in the railway sector (infrastructure, rolling stock and buildings) and for sharing and communicating of accurate environmental data towards stakeholders.
- Guidelines for the design of modular stations according to size and uses.

Some advanced electro-mechanical components are the support of the airless train, removing air management and the associated compressors on-board trains, increasing the energy efficiency, aerodynamic performance and reducing weight at train level. This great technical evolution should be considered as a revolution, leading to many evolution/simplifications of the rail operations.

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

- HVAC at the vehicle level with improved management of air flow easing the epidemic management (e.g. Covid 19 type) (TRL 8/9)
- Passenger flow management integrating variable health and safety measures (TRL 8/9).
- Covid proof and non-toxic materials among other solutions to fight against the dissemination of pathogens including a performance test protocol of the biocidal effectiveness by laboratory tests and comparison to real conditions on RS (TRL 7)
- Industrial standards (design, analyses methods…) for easing the quick adaptation of interiors (TRL 8), supporting a big increase of integration of the secondary raw materials and bio-sourced materials (TRL 6-7).

#### *7.4.2.2 Technical enablers: capabilities to achieve the targeted operational outcomes*

To achieve the operational outcomes targeted in this flagship area, several technical capabilities were identified. To develop flagship demonstrations, the technical enablers must deliver functions with enough maturity, indicatively above TRL7. An estimation of the technical readiness in 2025, 2027 and 2031 is proposed.

**1. Alternative energy solutions for the 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 in further energy optimisation models and systems considered by FA1 (e.g. Connected DAS) and FA2 (ATO driving curve).
- Standards (public and industrial).

Complementary to new on-board hardware and software solutions, methods and tools will be developed especially on multi-physics modelling, virtual simulation creating Digital Twins of on-board sub-systems and components, leading to virtual certification.

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| High performances **Batteries Electric Multi-Unit (BEMU) train**, with long autonomy (200 km targeted), 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 for a full acceptability by operators and train drivers. Standardised interfaces will be developed to ensure to the maintainers, cost efficient changes of the battery racks during the train's life. | 6/7 | 7/8 | 8 |
| **H2 hybrid trains**:<br>Design of heavy duty vehicle (with Gas H2, Liquid H2);<br>Assessment, safety analysis of new technologies for on board hydrogen storage (storage H2 vehicle for Traction unit or tank wagon);<br>Demonstration on infrastructure inspection/maintenance heavy duty vehicle and also hybrid H2 power loco for freight/passenger mainly focused on the management and reuse of the wasted energy | 6 | 7 | 8 |
| **Sub-urban catenary trains with on board ESS** with high level of braking energy recovery, energy autonomy for passengers' comfort & safety and traction to a nearby station. A direct connection between the ESS and the electrical engines has to be developed to ensure high efficiency with a mix between supercapacitor batteries (power) and Li-ion batteries (energy). | 6 | 7 | |

*Table 19 - Overview of capabilities enabling operational objectives 1*

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

The holistic energy management in the railway system including the increased use of renewable energy sources (RES), the use of energy storage devices and the smart energy management at the local level will improve the global mobility decarbonization, the energy efficiency of the railway system, associated to the definition of relevant standards.

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **Railway strategic Hydrogen demonstrator**<br>Application of solutions for the production, storage and refuelling of hydrogen for railway vehicles on the example of a prototype refuelling station. Development of a standard refuelling interface using algorithms to ensure optimum time and safety of the process. Provide scalability and future growth of the refuelling station depending on the demand for hydrogen. | 5/6 | 6/7 | 7/8 |
| **Rail Power Smart Grid** in different systems (e.g. 25 kV AC, 1,5 & 3 kV DC), including the Integration of various sources of renewable energy, energy harvesting technologies, superconducting, breaking energy recovery, parallelisation of the AC sub-stations, etc, as well as the integration of energy storage. All supported by the latest power electronics technologies (e.g. silicon carbide). Appropriate planning of the location and connection of RES generation sources, energy storages, as well as energy flow management, metering and cooperation of sources with traction loads, supported by AI (Artificial Intelligence).<br>Innovative Energy Management models and systems considering vehicles operating In the infrastructure in a system view that can be integrated in further energy optimisation models and systems considered by FA1 (e.g. Connected DAS) and FA2 (ATO driving curve) will be provided.<br>Typical use cases are mass transit systems or lines with low traffic level where the integration of local renewable energy sources, new technologies such as superconducting, power electronic enabling parallel sub-station operation are key enablers to increase the reliability and efficiency of the power supply capacity at a sustainable cost.<br>In DC electrified network, in which energy cannot be normally injected to the public grid, those works will avoid the investment in new substations.<br>In AC electrified network, significant factors will be improved decreasing LCC, control of unbalances in the external network (by using single-phase current), parallelization of substations, elimination of neutral zones, incorporation of renewable sources. | 5/6 | 6/7 | 7/8 |

| | | | |
|---|---|---|---|
| **Stations as Energy Hubs**<br>Railway stations are relevant energy nodes in the modern city's smart grids. A variety of energy loads (HVAC, PA system, lighting, offices, leisure/shopping spaces, etc), sources (e.g. RES such as PV or wind mills) and storage (e.g. reversible charging of electric mobility vehicles in the parking lot) converge at the railway station. This may be common features to airport terminal buildings. In addition to this, other two relevant energy items come into play at stations: the catenary, on the one side, interacting directly with the station energy hub, and the train itself with its ability to transfer braking energy to the station energy hub. The Figure X below illustrates the concept of Station energy hub.<br>The technological challenges to solve is to optimise the **energy management of the hub integrated in a smart grid** under the market rules, the recovery of braking energy and the prioritizing of RES and local consumption (aligned with energy communities' trends), and the market mechanisms to exchange energy under these conditions. | 5 | 6 | 7 |

*Table 20 - Overview over the operational outcomes 2*

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

| | **TRL in 2025** | **TRL in 2027** | **TRL in 2031** |
|---|---|---|---|
| **Adaptation to climate change**<br>• Climate database tool of past, present and future climate parameters (t°, rain, wind, etc with statistics as extreme values and standard deviations), applicable to the specificities of European railway activities (in categorised zones), taking into account IPCC scenarios.<br>• Risk assessment report (reliability, costs, etc) on railway assets: rolling stocks, stations, workshops, infrastructures, operations and work organisation.<br>• Report to implement adaptation strategies with time planning: preventive and corrective actions (technical or organisational), constraints to be applied on conception, maintenance or operations<br>• Identify existing solutions (in the World) and develop new ones for existing railway assets (retrofit) and future ones (new conception) to reduce climate-related risks, as needed. | 5 | 7 | 8/9 |

| | | | |
|---|---|---|---|
| **Smart Green Railway Stations** (incl. other railway buildings) Methodologies and guidelines for the optimal design of station layout, favouring modular and nature-based solutions and oriented towards carbon footprint reduction. Design of more robust and resilient infrastructures towards extreme climate change and other hazards.<br>Development of a BIM (OpenBIM standards) based DT of the station (incl. energy systems).<br>Use of the DT for life cycle and circularity analysis of the station assets and materials.<br>Use of the DT for the simulation of extreme hazards scenarios in order to achieve a more resilient performance.<br>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 | 6/7 | 7/8 |
| **Smart Transit Oriented Development (TOD)**<br>Development of tools supporting a multi-level grid-based system to achieve and maintain sustainable development and smart growth driven by rail assets and facilities holistically integrated into urban neighbourhoods. | 5/6 | 6/7 | 7/8 |
| **Eco-design holistic methodology and tools system**: new design solutions harmonised with regulations, standardisation of railway systems from an environmental point of view (infrastructure, stations, rolling stock) | 5/6 | 6/7 | 7/8 |

| | | | |
|---|---|---|---|
| **Reduction of noise and vibrations from railway infrastructure and rolling stock** including:<br>• Further improvement of noise source characterisation (e.g. aerodynamic noise sources) to improve procedures and methodologies for virtual certifications<br>• Development of noise perception indicator for rolling stock (including HSL) and simulation tools for noise emissions and propagation and their evaluation of the impact of noise exposure, (in potential combination with other pollutant emissions e.g. vibration)<br>• Investigations about noise & vibration emission over life span 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<br>• Use of optic fibre 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.<br>• Development of effective mitigation measures of ground-borne vibration from track or on the transmission path from the track to the receiver (i.e. buildings) including their prediction (insertion loss) for different environments or soils characteristics to be integrated in the ground-vibration prediction tool<br>• Reduction of curve squeal: Development of infrastructure-based solutions beyond friction modifiers and design guide and specifications for rolling stock (focus on city-lines) avoiding generation of squeal noise in a system approach. Research on test procedures for acceptance inspection of low-squeal noise rolling stock and to how be integrated in prediction and impact studies.<br>• Optimization of noise barriers: height reduction by diffracting elements on top of noise barriers, transparent noise barriers, optimizing the foundation of noise barriers to reduce closing times of tracks during installation.<br>• Innovative concepts for sound proof windows to increase their acceptance by the residents.<br>• Definition of low noise and low vibration track components (e.g. optimised railpads and rail fastening systems). Resilience of track components will also be addressed. It leads to definition of models supporting maintenance rules. Specific attention has to be paid to noise reduction technologies (e.g. rail grinding tamping...), which combine general track maintenance and assessment of the performance of the usual and next-generation track solutions while not increasing maintenance costs.<br>• Including ambitious targets for reduction of noise & vibration and their proof through vibro-acoustically optimized design in the (proposed) developments of components (e.g. HVAC-systems or bogie structures). | 5-6 | 6-7 | 7-8 |

*Table 21 - Overview over the operational outcomes 3*

**4 Improvement of electro-mechanical components and sub-systems for the rolling stock**

| | **TRL in 2025** | **TRL in 2027** | **TRL in 2031** |
|---|---|---|---|
| Airless Bogie/Brakes/Pantograph and suspensions (additional demos to C1 ones TBC)<br>Develop and introduce to the market electro-mechanical braking system, electro-mechanical pantograph and novel concept of suspensions control targeting 40% energy savings on the involved subsystems, reducing in size or even eliminating air compressors and the associated maintenance costs. Some of the advantages of the new system are the lower energy consumption, the more effective transfer of braking signal and improved accuracy through elimination of pipe leakage issues, the reduced overall system weight and layout complexity (associated to compressors and pneumatic piping), the better diagnostics. These brakes will also need to be more resilient than current breaks to natural and man-made hazards. | 6 | 7 | 8/9 |
| Vehicles weight reduction: lightweight eco-friendly **High Speed Train bogie** frame (conventional and based on independent rotating wheel), etc. to improve consumption or emissions ratios per passenger/km, and to increase resilience. | 6 | 7 | 8 |
| Eco-friendly HVAC system / HVAC system with green refrigerants or new cooling technologies low GHG<br>Deliver alternative technologies to replace hydrofluorocarbon refrigerants.<br>• New technologies like **magnetocaloric effect or water** as a refrigerant will lead to reduced energy consumption of HVAC systems (-30% compared to actual HFC technology) due to the better Coefficient of Performance (COP) in cooling and heat pump mode.<br>• tool and methodology to measure and optimize the energy consumption of HVAC units under real operating conditions<br>• The new HVAC technology will need to ensure lower weight and improved resilience to climate change and natural and man-made hazards. | 6 | 7 | 8/9 |
| Optimised motors and gearbox to improve energy efficiency, weight, noise reduction, following circular economy principles and using recycled materials | 6 | 7 | N/A |
| High performance bogie, gearbox, suspensions: high-capacity independent wheel **regional intercity bogie** | 6 | 7 | 8 |
| Virtual aerodynamic certification to reduce high amount of full-scale tests and therefore costs by introducing enhanced experimental and numerical methods | 6 | 7 | 8 |

*Table 22 - Overview over the operational outcomes 4*

**5. Healthier and safer rail system**

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| Air-distribution and air-flow management concepts for a more effective removal of contaminants from the passenger compartment while maintaining the thermal comfort | 6 | 7 | |
| Air-filtration and disinfection systems for an enhanced air cleaning in the HVAC system | 7 | 8/9 | |
| Enhanced surface materials for reduced virus/bacteria lifetime<br>Low-emission components and materials | 7 | 8/9 | |
| Passenger flow management to reduce contaminations' risks | 5 | 7 | |
| Standardized measurement protocol to assess the efficiency of technologies to improve air quality on board, in stations and tunnels, ensuring a reduced health risk for rail passenger and workers | 8/9 | | |
| Measurement and live visualization of air quality parameters to enhance passenger trust | 7 | 8/9 | |
| Evaluation of low-cost sensors & IA for spread out measurements and analysis of air quality on-board trains, in underground station and tunnels | 8/9 | | |
| Simulation tool of air quality in railway stations | 7 | 8/9 | |
| A standardised method to report the non-exhaust emissions emitted by the railway activities | 7 | 8/9 | |
| A measurement method to evaluate and report the efficiency of air pollutants reduction solutions in railway underground rights-of-way | 7 | 8/9 | |
| Solutions to reduce non-exhaust emissions at source: ex. low emission braking pads | 7 | 8/9 | |
| Solutions to collect historic non-exhaust emissions: ex. collector/filtering/treatment in underground railway stations | 7 | 8/9 | |
| Operational vacuum cleaner train to remove dust in tunnels and underground stations | 7 | 8/9 | |

*Table 23 - Overview over the operational outcomes 5*

**6. Attractiveness**

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| Interiors designed by modularity and plug and play fixation systems using materials with low environmental impact<br>• Facilitation of the refurbishment, especially at mid-life and based on circular economy principles | 6 | 8 | 8/9 |

| | | | |
|---|---|---|---|
| • Innovative sleeper concepts to re-use as day trains increasing economic viability of night trains – technical modularity feasibility<br>• Interior's adaptations: plug and play electrical and mechanical systems<br>• Easily adaptation of the rolling stock to face capacity including the relevant information devices | | | |
| Interiors designed by innovative low-tech and circular design<br>• Design and materials withstanding to obsolescence with an innovative low-tech approach<br>• Interior's atmosphere provided by new materials with low environmental impact.<br>• Facilitation of the refurbishment, especially at mid-life | 6 | 8 | 8/9 |
| Interiors designed by on-demand comfort<br>• Privacy, anti-thefts protections.<br>• Relative adaptation of the lighting and acoustic for each passenger or zoning of passenger 's room.<br>• Relative adaptation of thermal, lighting (natural and artificial) and acoustic characteristics adaptations.<br>• New holistic approach regarding the access, odourless, touchless, hygienic design especially for spaces with a high passengers flow and toilet for instance.<br>• Design of the entrance mechanisms, the doors to make safe embarking and disembarking movements. | 6 | 8 | 8/9 |
| Accessibility to Persons with Reduced Mobility (PRM):<br>• Access in full autonomy by PRM to vehicles all over the rolling stock life.<br>• Guidance for blind PRM from the platform to the right vestibule and seat. | 6 | 8 | N/A |
| New architecture<br>• One driver's cabin by train with new driving HMI.<br>• High-capacity single deck to challenge the double deck with better global cost by passenger and to facilitate to evolve the layout and services on board. | 6 | 7 | 8 |

*Table 24 - Overview over the operational outcomes 6*

#### *7.4.2.3 Demonstration implementations*

**Demonstration 1: Alternative energy solutions for the rolling stock**

- High performances BEMU (long range autonomy, optimised aerodynamic, environmental and LCC higher performances, circular economy included, interoperable, standardised charging interfaces and data protocol with infrastructure, standardised interfaces of battery racks).
- Sub-urban catenary trains with on board ESS:
    - High energy efficiency (-50%),

    - High level of braking energy recovery (-90% PM due to mechanical braking),
    - Energy autonomy for passengers' comfort & safety and traction to a nearby station,
    - Energy services as peak power shaving or load shedding capacity thanks to the ESS,
    - Lower LCC (traction chain, mechanical braking, reduced investment on substation reinforcement).
- Hybrid Catenary train with Batteries to reinforce service robustness
- H2 hybrid Batt vehicles used with Fuel Cells
    - Autonomous vehicle for infrastructure inspection (focused on the management of the wasted energy)
- Smart eco-mode train: Auto adaptive train energy consumption to various services situations/ Renewable energy sources produced on-board for permanent energy supply needs / Smart Energy Mode for hybrid train.

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

**Railway Smart Grid system.** Development and integration on real operational site of several solutions enabling smart energy management and improving energy efficiency. The demonstrators, being applicable to DC or AC electric network, will include:

- Integration of renewable energy sources associated to energy storage of different types for energy production, management and consumption within a local balancing area with developing tools for planning of types and locations of energy sources.
- Energy metering, measurement, data management and decision tools.
- High power/Energy storage along the track for grid/substation support.
- System development and implementation for parallel operation of 25kV substation.
- Specification, development and integration on operational network of superconducting cable.

**Station Energy hub integrated in the Smart (city) Grid.** Focus on smart grid solutions to develop and operate train stations as “Energy Hub”. It includes energy harvesting around the stations, local energy storage, local energy production including renewable energy, the deployment of monitoring and IoT systems (incl. energy metering), the development of models and AI tools for the optimal energy management of the station, including those linked to the other urban electric mobility systems.

**New refuelling station system**

- Demonstration and development of standardized and interoperable refuelling station for the hydrogen (use a local RES for production in-situ). Various interface will be considered for different type 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 standardized and interoperable charging installation for full batteries train.

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

**Net-zero emission rail**

Solutions to foster environmental advantages of rail and enable the transition of rail (infrastructure, rolling stock and buildings) from a linear to a circular economy for reducing all types of pollutants (noise, vibrations, air pollution, light, etc.) over the whole life cycle, with consideration of the whole logistics chain (methods, methodologies, tools, intelligent solutions, materials, ecolabel, eco-certification). Life-cycle extension in the railway sector based on circular economy (6R - Reuse, Reduce, Repurpose, Reinvent, Realise, Recycle), development of knowledge bases and collaborative tools for effective life cycle forecasting and whole life-cycle assessment including environmental, social and economic costs and impact.

- Artificial Intelligence for natural risk assessment 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)
- Industrialization, recommendations, rules to increase local, circular and re-use economy

**Removal of non-exhaust emissions**

Characterize and remove the non-exhaust emissions emitted by wear particles from brakes, wheels-rails contact, pantograph-catenary line contact, emitted by railway stations and from railway infrastructures (ballast abrasion, pollution during work, aging of the underground infrastructures) and historic pollution:

- Solutions to remove the particulate pollutants (vacuum cleaning train, on-board RS collector, on-board RS filtering/treatment solutions and underground railway stations filtering/treatment solutions) and measure the efficiency of pollutants reduction.
- 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 sub-station considering noise, vibration, Electromagnetic compatibility, materials, landscape integration, energy consumption.

Reduction of **noise and vibration** from railway infrastructure including:

- Demonstration of a low noise and low vibration track by inclusion of track components (e.g. optimised railpads and rail fastening systems) leading to definition of models supporting predictive maintenance recommendations.
- Consideration of the effects of noise and vibration on physical surroundings by the use of optical fibres alone or in combination with assisting technologies leading to simulation studies and models for protection and reduction of impacts on the physical surroundings (any buildings of concerns incl. stations). As results, models and physical demonstrators are developed leading to predictive maintenance recommendations for the infrastructure and the proposal of the physical concepts for the surroundings.
- Considering the squealing noise by wheel dampers, associated to the modifications of the rail geometry or the lubrication of rail heads, developing at the same the associated models.

**Smart Green Station:**

- Optimization of the layout of the station favouring modular and natural based solutions. BIM based design.
- Design of the energy systems of the station, BEMS. 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 circularity analysis. Use of the DT to simulate hazard scenarios and for a more resilient infrastructure and for a better preparation for contingency management
- Use of Smart TOD and DT support tools to demonstrate and evaluate the effectiveness of network-centric station group management areas in the Smart TOD model using a two-level balancing i.e. local and district.

**Demonstration 4: Improvement of electro-mechanical components and sub-systems for the rolling stock**

- Eco-friendly HVAC system (connections to capabilities 3 and 5)
  - Implementation of energy efficient, more resilient and lighter HVAC based on novel technologies and/or materials
  - Supporting temperature management of other subsystems as battery chiller / charger / fuel cell system (Connections to demonstrations 1 / 3 / 4 / 6)
- Technological solutions for the migration to the airless train (connections to demonstrations 1 / 3 / 6)
  - Electro-mechanical braking system
  - Novel electro-mechanical pantograph
- High performance bogie, gearbox, suspensions & materials (connections to capability 3) make the running gear cost and eco efficient, especially by the use of new technologies as 3D printing allowing totally new design and topologies.
- Aerodynamic demonstrator for drag-reduced equipment
  - Different spoiler and pantograph configurations are to be studied using CFD and experimental demonstrator.

**Demonstration 5: Healthier and safer rail system**

The demonstration of novel systems and technologies enhancing the air quality by air purification and air distribution while addressing the thermal comfort is proposed. It should address the topics of air quality, in term of pandemics (exceptional), virus/bacteria (seasonal) and fine particles (always) as well as the 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 the demonstration of a healthier environment in the rail vehicle, for both new designs of future trains and refurbishment of existing trains.

The single demonstrator is designed to tackle the following specific aspects:

- Concepts to reduce airborne spreading of contaminants
- Air filtering devices and air distribution systems
- Installation of disinfection systems
- Interior surfaces to reduce virus / bacteria lifetime
- Thermal comfort with modular interiors
- Assessment of available technologies and their adaptability to existing HVAC design
- Passenger flow management integrating variable health and safety measures

- Simulation tools to increase knowledge and optimize solutions
- Test protocol to evaluate the efficiency of the solutions
- Improvement of maintenance costs (heat exchangers) and effects on train reliability (HVAC in heat wave conditions)
- Predictive health monitoring and live visualization of air quality and other HVAC related parameters
- Providing a database for standardization work regarding air quality

These can be comprised in three main demonstrator pillars, firstly the air handling (air purification and distribution), secondly surface treatment and thirdly passenger flow management.

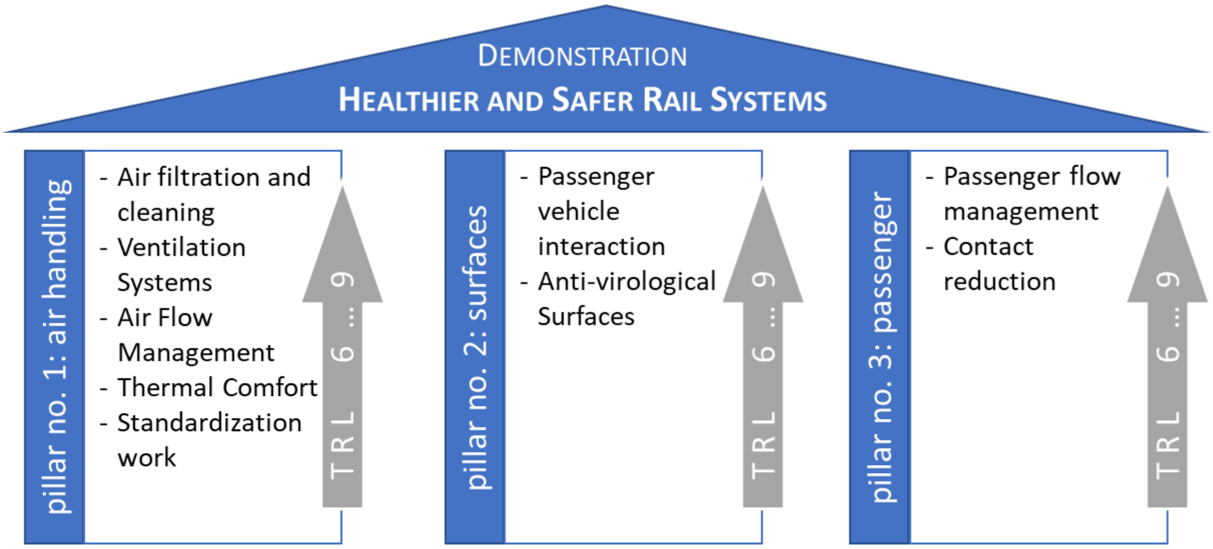


*Figure 13 - Main Demonstrator Pillars*

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 parallel activities of the collaboration partners are desired all contributing to a healthier and safer passenger rail-systems in terms of air quality in the vehicle and pandemic resilient passenger transport. To achieve highest impact of all specific demonstrators, joint contributions of the relevant stake holders, i.e. train operators, (train) manufactures, (HVAC) suppliers and scientific institutes are envisaged.

**Demonstration 6: Attractiveness**

- Independent intermediate activities for 2025 are proposed, using preferably Augmented reality/virtual reality, 3D model, numeric simulation, technical mock-ups
    - Interiors demonstrator with attractive low-cost and low-tech design
    - Interiors demonstrator with modular interiors providing on-demand comfort
    - Attractive, safe & performant dwell time mass transit interiors demonstrator
    - Interior’s demonstrator designed by the user’s perception
    - Interiors demonstrator with attractive circular design

- integrated demonstration for 2027 integrated to the extent feasible with train demonstrators from FA4 or other flagship areas.
  - real scale fix mock-up to offer the maximum of freedom for new design (not real environment)
  - A real environment demo of a high-speed vehicle demonstrator
  - An operational demonstrator in an existing train to test parts of innovations

### *7.4.3 Impacts*

#### *7.4.3.1 Description of the impacts against existing rail services*

| | |
|---|---|
|  | Meeting evolving customer requirements<br><br>FA4 will aim to further decrease the environment footprint of the whole railway system. It will provide green solution through zero emission, low noise solutions while providing better quality of services and comfort for the customers. Solutions to ensure the high level sanitary requirements are also covered in FA4 in order to ensure a safe and healthy journey for the customers. |
|  | Reduced Costs<br><br>Beyond the sustainability benefits coming from the solutions the cost efficiency needs to be carefully assessed. Energy storing system (batteries…) and H2 have to be considered coming from the other modes of transport and adapted to the rail environment in order to optimise the investment costs. This is also applicable for the charging infrastructures for refuelling solutions. |
|  | More sustainable and resilient transport<br><br>In this FA sustainability plays a central role. Some areas of innovations are selected contribute significantly to improve the environmental performance of the railway system. For HVAC, regulations enforce the use of sustainable gas. Activities will provide new adapted technologies easing the adaptation of the rail system to such unavoidable service to the customers, especially considering the hotter temperature in longer durations planned all over Europe.<br><br>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. This has to be accelerated regarding the engagement towards a zero CO2e emission rail system.<br><br>This flagship area will also accommodate innovative solution that mitigate noise and vibration and other emission levels. |
|  | Improved EU rail supply industry competitiveness<br><br>Rail is considered as one of the most environmentally friendly mode of transport, but in order to keep the environmental performance the current political and societal expectations, the rail sector should continuously improve its environmental footprint to keep its competitive advantages compare to the other modes of transport. This objective will be fully supported by the technologies developed within this flagship area by introducing technologies such as new proportion system, |

| | |
|---|---|
| | Industrial standards will ease quicker and greener transformation of the European rail vehicles and support the transformation of the rail system in a circular economy model.<br><br>Health and safety requirements are also relevant especially in the current COVID-19 pandemic, in order to provide to the customers, the maximum sanitary conditions. |

*Table 25 Descriptions of FA4 impacts related to the intended impacts in the Master Plan*

#### *7.4.3.2 Quantitative KPI demonstrated in this FA*

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

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

| | KPI Title / Type of impact | Dimension / KPI | Baseline / Expected improvement |
|---|---|---|---|
| | Autonomy. Linked to sustainability via $CO_2$ reduction on Diesel regional trains | Extended reach (km) | Baseline 80km and target 200km for regional trains |
| | Physical energy consumption (train, infrastructure, station) | kWh/passenger.km<br>kg C02/year.m2<br>kg $H_2$/vehicle.ton.km | 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 $CO_2$ equivalent emissions (LCA) linked to new propulsion systems, stations and infrastructure | kg C02/passenger.km<br>kg C02/year.m2 | Up to 30% for specific use cases (e.g. different fleets on specific railway lines, reduction to 0% for regional trains on non-electrified lines by substitution of Diesel by battery/$H_2$ and heavy duty inspection vehicles) |
| | Noise emitted by train, infrastructure at component level | dB(A) | Between 3-8dB for specific use cases on existing electric railways, Diesel, Hydrogen trains, infrastructure, stations. (e.g. brakes (compressor), HVAC subsystems, pre-heating operations, depots facilities) |
| | Life Cycle Costs reduction | % | Between 5-10% for specific use cases including externalities costs |

*Table 26 - This FA quantified KPI*

#### *7.4.3.3 Exploitation, deployment and migration considerations*

Within the Flagship Area 4 it is foreseen the development of a set of technologies which overall goal is to minimize the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier, more attractive and to provide resiliency against climate change.

These technology developments imply very important investments from the organizations involved in the Europe's Rail Joint Undertaking and from the European Commission. Although the involvement of a large community from both the user side as well as the supplier side is a good starting point for a wide deployment, a set of measures should be established to ensure its future exploitation. These measures are listed below:

- Integrated approach in the demonstration scenarios so the new products and services are not island but are integrated with other ones and the impact is larger.
- Development up to TRL7-8 so it is ready for commercial exploitation.
- Involvement of final user that can be used as references for commercial exploitation.

In addition, currently the products and processes which are being used in the railway system aiming to minimize the overall energy consumption and environmental impact are not prepared for “cooperating” with the new technology deployments. Thus, deployment and migration from nowadays situation to the future one must be considered. To overcome this situation the following points should be established:

- Coordination with System Pillar to define a set of data exchange format / CDM, especially for the energy management at different levels, at a local level (e.g. interfaces in Rail System Smart Grid to ensure integration of different suppliers) and at a system level by connections between sub-systems (e.g. TMS with energy management).
- Definition of specific European regulation to be adopted by the member states for enforcing or enabling the adoption of new technologies (e.g. eco-design, recycling, etc.).

## 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, opportunities opened and associated risks*

The European Commission not only sets the objectives and opportunities for rail freight with the EU Green Deal, the EU regulation 913/2010 concerning a European rail network for competitive freight as well as with the “**Sustainable & Smart Mobility Strategy, 12/2020**: “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 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 e.g. with Digital Automatic Coupler (**DAC) which is one cornerstone and is enabling more functionalities in freight (via power and data supply even more use cases can be realized which will positively impact SWL, block trains, combines transport, etc.)** to increase network capacity in a smart way for all types of rail freight transport) as well as **significantly improved cross-border operations** (as around half of total rail freight in Europe is cross-border) and multimodal **customer services**. Increased capacity is the key factor to enable a shift of transport volumes to rail, reducing substantially the related GHG emissions.

FA5 tackles these challenges by having **2 clusters** which are interlinked but still distinct: “**full digital rail freight operations**” is focused on increasing substantially the productivity, quality and capacity of rail freight by full digitalization and automation of operational functions and processes incl. innovative freight assets. The second cluster "**seamless rail freight**" is focusing on important aspects to increase the efficiency of the immaterial (information/data) layer of transport and to gain time and save costs by ensuring a seamless environment (between different actors/countries/modes for planning/execution/management) on long term, but especially also including short-/medium term achievements and quick wins. Both clusters are fundamental to achieve the EU Green Deal the objectives of the European Union and will only together secure a significant improvement of rail freight. FA 5 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**" is aiming to boost operational rail freight performance (transport time, quality, information and volumes) in order to meet customer requirements by full digitalization and automation of operational functions and processes (e.g. Yard/Depot/Terminal automation and control) based on enabler technologies (Digital Automated Coupler and related automation components), additional sub-systems and components (e. g. systems for the intelligent freight train such as, energy management distributed systems (harvester and storage) as well as freight wagon development and the upgrade of the locomotives for the related DAC-functionalities incl. the interfaces to ATO technologies.
- "**seamless rail freight**" is aiming to significantly further increase productivity (including average transportation time and capacity utilisation), reliability and flexibility, by fully digitalizing planning and management functions as well as easing 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 as well as dispatch in connection to TMS). This includes an easy access to the service offers, including multimodal journey planning, booking and transport companions. Additionally this cluster is targeting consistent data flow from customer order to train preparation along all handover points (yards/borders/recipients). The planning and management of fully automated shunting operation (ASO) enables fully automated marshalling yard operation and more efficient last mile distribution and collection of wagons.

These freight focused innovations especially in combination with FA1, FA2 and FA3 developments, and respective investments in their implementation, will enable Rail freight traffic – in particular along European Rail Freight Corridors - to increase by 50% by 2030 and double by 2050, hence support the ambitions of the Sustainable and Smart Mobility Strategy of the European Commission.

Building Blocks need to be embedded into a set of new solutions resulting into the improvement of the entire railway system (e. g. DAC as an enabler for ETCS moving block) environments. By integrating building blocks, large-scale demonstrators integrating the different components in an interoperable way will be realised in order to leverage results from past and ongoing initiatives enabling the transformation to full digital freight train operations in Europe in daily operations for 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 eased operations at e.g. borders to build up “seamless freight operations”. This will also include seamless data flow between different stakeholders i.e. customer, suppliers, employees, IMs, RUs, etc. along the supply chain and esp. at handover points. Hence, there is a special focus on the elimination of manual processes and an exchange of resources driven by capacity. It needs to be assured that all technologies contribute to the increase of productivity, efficiency and service quality (“use-case driven”) resulting in seamless freight planning and shipper-tailored intermodal transport services including offering and booking and thus, in increased competitiveness of rail freight. As seamless freight results into less stops at borders, it will also have positive impacts on energy consumption.

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

- Unclear and changing business cases as well as 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 from legacy systems as starting point for European and interoperable solutions.
- All functional requirement specification from an operational point of view will not be ready and agreed (e.g. brake test target of operators, shunting, etc.) for mid of 2022 (some later) in order to meet TRL targets regarding technical enablers
- Delay of ERA authorisation process (exceeding 7 months) or no capacity from ERA side for authorisation
- Also the number of different systems to be connected and the complexity of the systems can be a risk in standardising and harmonising processes, technologies and cross-border systems and can slow down the objective of European interoperability of systems.
- Iteration process in terms of development, underestimated requirements – with failure to achieve authorisation/certification could result into higher investment costs
- In combination with authorization processes and the national reluctance to replace/update legacy systems, as well as 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 underestimation of the complexity of adaptation may be a risk especially in combination with missing harmonized and clearly identified operational rules and missing technical regulations and standards.
- Aspects of human-machine-interface (HMI) have to be considered and carefully looked upon, especially in highly automated customer-centered last-mile operations.

#### 7.5.1.2 Innovation beyond state of the art, including 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 European DAC Delivery Programme (EDDP), and tested and demonstrated in the overall 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 with the aim 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.

| | **Full Digital Rail Freight Operation** |
|---|---|
| State of the art and S2R results | The relevant topics addressed at S2R IP5 are: 'Fleet Digitalisation and Automation' (TD 5.1) through, Digital Automatic Coupling that now is on the verge of implementation, Freight Automatic Train Operation (ATO) and Connected Driver Advisory Systems (C-DAS), 'Smart Freight Wagon Concepts' (TD 5.3) through next generation intelligent freight wagons for Core Market and Extended market sectors, including of innovative freight bogies and better aerodynamics and telematics supporting CBM for instance; 'New Freight Propulsion Concepts' (TD 5.4) focusing on operation in non-electrified and in electrified lines, distributed power locomotives control providing train lengths up to 1500m as far as allowed by the infrastructure and also fine-tuning the system with Energy management and power peak shaving concepts; Special attention can be given to the European DAC Delivery Programme (EDDP) enabled by S2R (TD 5.1), outcomes are to be considered as S2R results. The EDDP provides preliminary specifications for DAC mechanical, pneumatical, data/energy, preparatory works on additional automation components (ep brake, technical wagon inspection, train, automatic brake tecting, and much more), works on migration, cost benefit analyses, etc. serving as a basis for FA5.Since full digital freight train operations also include additional components for which the DAC is the enabler, past or current works on those also have to be reflected.[12]. |
| Further/new results | What still needs to be realised within the flagship project is the proof of concept, further developments and practical testing as well as the further development of the missing parts of the technical enablers of the EDDP theoretical proposals, followed by the adaptation and the seamless functionality of those systems on the backbone including authorization. Towards the goal of reaching the highest level of automation (DAC5 automated decoupling for freight cars and locos), the |

[12] S2R has been working in the past years, on various R&D projects which have been initiated by Shift2Rail's Freight Innovation Programme (S2R IP5). Those results (ARCC for e.g. yards, FFL4E for locos, FR8RAIL on DAC, CBM, intelligent wagon, etc,, INNOWAG, DYNAFREIGHT on longer trains, SMART on marshalling yard management, OptiYard on yards, and other projects) will be subject for further developments in case those are assessed to be followed up

| | |
|---|---|
| | DAC might serve as needed steppingstone to enable an early migration. The implementation of the DAC and interlinked additional components will affect the day-to-day operations of e.g. RUs, infrastructure managers, customers along the logistics chain. The required changes will enable a transition to full digital intelligent freight train operations affecting the operations, as well as processes at yards (achieving also full automation demonstration) or border stations . |

*Table 27 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail*

| | **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 & management, digital resources planning & data exchange) are focused on national specifications rather than on the SERA, thus, leading to inefficient, complex and expensive operations for example at border crossings. There are initial concepts for internationalization but these are not yet prepared for market ready innovations and products. Management and production systems are existing partially but legacy systems are on one side not interoperable and on the other side not prepared to act as part of a dynamic seamless system, due to missing interfaces and real-time optimization components.<br>The main results from Shift2Rail IP5 which can be used as input for seamless freight comes 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 decision support in real-time, including yards and terminals, yard management, and the Intelligent Video Gate using artificial intelligence to recognize signs on the wagon such as dangerous goods (IVG). Innovations for seamless freight operation shall also use results from studies and projects from the Rail Freight Corridors, such as European Capacity and Timetable Management, Rail Collaborative Decision Management (Rail-CDM) as well as results from T4R or other projects. Substantial results achieved towards TMS and ATO in S2R IP2 as well as 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 the Digital Capacity Management (DCM) and Timetable Redesign (TTR) as well as for the exchange of commercial documents in the Digital Transport and Logistics Forum (DTLF) shall be also 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, in some cases also the innovative adaptation of national components will be required making them compatible with EU systems. Besides internationalization with the focus on a real integrated SERA, also new capabilities like technologies for digitalizing current manual tasks as well |

| | |
|---|---|
| | as automatic cross-border slot finding will be developed and demonstrated. The same applies to various specific stand-alone systems of the different participants that must be effectively enabled and linked with each other, including various optimization functions considering the newly available comprehensive data/information. The aim is to extend the optimisation from planning to the real-time operations applying a system view with agreed rules and roles, to enable optimized 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 information from the involved stakeholders about resource/slot availability for short term requests or adaptations. An easy and European digital platform will be connecting the customer with the rail transport providers and ease the access to rail freight services, including intermodal transport services. |

*Table 28 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 2*

#### *7.5.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

All activities of **FA5** will contribute to the **system pillar** of EU-RAIL JU and benefit from its input for interface and system integration management related to “full digital freight train operations” and “seamless freight”.

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the

architecture and resultant specifications and associated system outputs to be delivered by the Programme.

Several activities within FA 5 require transversal cooperation with other EU-RAIL JU Flagship areas.
Seamless Freight is closely linked to **FA 1** ”TMS+” when it comes to providing a European solution for network management planning and control as well as mobility management in a multimodal environment. FA5 will provide all needed requirements to FA1, where the TMS technology will be developed also for freight specific needs. FA5 will therefore not develop any main line TMS technology but integrate it in the RS/infra and use in its demonstrations the technology developed in FA1.

To ensure technological consistency of the developed solutions, coordination and potential collaborations will also be setup with **FA 2** “ATO+” on digital & automated train operations of both passenger and freight rail transportation. In general the relevant technical enablers such as new ATO technology solutions, automating functions, such as train preparation as well as remote driving and command will be developed in FA 2. FA5 will provide all needed requirements to FA2, furthermore FA5 will work on special functions e.g. for the automatic and autonomous shunting operation / train protection system for shunting as well as reaction system (push/pull functions).

To promote the use of digital technologies by means of digital twins and predictive maintenance within the railway sector, collaborations on data provision from FA5 for CBM will be setup to ensure coherence with **FA 3** “Smart & integrated digital life cycle assets management”.

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

By nature, the **FA TT** “Transversal Topics” will be linked to FA5 for potential coordination and collaboration on digital twin as well as data models and any kind of other transversal enabler.

*Details of the exchange between the Flagship Areas can be found in Annex B*

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.
Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- Conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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 actors (RU/IM/IO/TO, supplier and R&D) is crucial.

The operators will host and organize the framework for these demonstrators. For demonstration and implementation of the aforementioned developments, operational solutions, technical enablers, guidelines and standard protocols potentially delivered by the System Pillar are leading. However, the deployment in a short/medium timeframe require the technical solutions are aligned with essential railway operational rules and standards that at national level have not yet been harmonized. Consequently, the operators will play a key role in the development process, by specifying their output requests, verification and validation process, and by coordinating the demonstration in most cases, whereas the decision regarding specific technical developments and implementation is in the hands of the technology suppliers.

- **RU/IM:** The rail operators and infrastructure managers (as well as in specific cases the Terminal and Intermodal Operators and others like the wagon owners), define use cases and play a strong role for demonstrator/pilots. They describe the needs, carry out safety analysis–preparing for and test the developed products. RUs eliminate inefficient processes, bringing automation to the next level, by this increase productivity, quality & capacity leading to higher competitiveness and new market opportunities and offer 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 service that makes running trains “as easy as running trucks”.
- The **Suppliers and Technology Providers** propose respective developments/solutions and provide innovations going beyond state-of-the-art, based on the needs of their customers. They develop and integrate new products and systems and contribute to the standardization also on normative level to ensure a sustainable exploitation of the developments for 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.
- The **research institutes and academics** study the economic impact of innovations with the help of quantitative transport models and simulation tools identifying the optimum design of multimodal transport networks and optimal employment of resources. Additionally research institutes will play an important role in basic research on new

technologies such as hybrid locomotives for freight applications and transport logistic services. They assess the impact of innovations. Researchers provide necessary scientific input (including methods and R&D simulation tools to analyse and optimize efficiency of freight transport) that is needed for scalable business oriented solutions.

- **Authorities provide** a level playing field for rail (e.g. regulations, financing).

#### *7.5.1.5 Interaction with other Programmes, European and/or National*

The research and innovation activities considered within FA5 are expected to interact with other programs and initiatives at European and national level. It is worth mentioning the following European programs:

3. In Horizon Europe Pillar II, Cluster 4 (digital, industry and space) the European Partnerships of AI-Data-Robotics for data analysis and work automation.
4. In Horizon Europe, Pillar II and IV, Cluster 5 (Climate, Energy and Mobility) the road transportation and waterborne transportation to achieve a multimodal transportation.
5. In Horizon Europe, Pillar III (Innovative Europe) the European Institute of Innovation and Technology has two specifics knowledge and innovation communities such as EIT manufacturing for new manufacturing techniques and EIT Digital for the digitalization of freight transportation.
6. Connecting Europe Facility, Life and Digital Europe where large-scale demonstration can also be funded.
7. Horizon Europe partnership for Clean Hydrogen

Finally, it is also foreseen the interaction with national programs (e.g. German national program of the BMVI, Spanish CDTI Misiones, Austrian national R&D program of the BMK) and other non-European countries such as UK or Switzerland which also have freight transportation by rail as a priority.

Beside the coordination activities within EU-RAIL JU to ensure a system approach and the competitiveness of Rail Freight, also external activities like the work of ALICE on the Physical Internet of Logistics will be taken into account to ensure the best integration of rail in 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 against road transport. On the one hand, the organisation of transports is not flexible and quick enough for 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-actor/cross-border coordination prevents an optimization of the rail operations and often results in quality and reliability levels below the requirements of the logistics market, also in regard of 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 Flagship Area cover the entire rail freight logistic chain, increasing its sustainability, safety aiming at a significant modal shift to rail. The aim is to allow better planning and operation of trains themselves as well as through better integration in multimodal transport chains. Also the identification of suitable transport options and their booking and monitoring will be key for attract more customers for rail based services. In particular operational solution outcomes, shown in the table below will be covered. Nevertheless, even though high TRL are targeted for 2025 and 2027, further technical development will be needed to extend the scope of the solutions.

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

- 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-actor planning, coordination and (traffic) management
- Non-integrated train path and service planning (unattractive international train paths)
- Difficult integration in just-in-time supply chains
- Demographical change incl. declining attractiveness of jobs in rail sector
- Limited overview for available multimodal transport services and difficult booking for the customer
- Limited customer transparency on punctuality and other quality issues including last mile, terminals operations and other modes involved in intermodal transport
- Limited flexibility to handle short term demand changes

There is a clear vision which functionalities/enablers will enhance daily operations and overcome challenges of the rail freight sector; those functionalities are outlined in the chapter 2.2. By full digitalisation and automation of operational functions in combination with seamless rail freight as an holistic approach there is a substantial increase in productivity, quality and capacity utilization of the rail freight system contributing to EU Green deal objectives. This use case driven approach will be followed up, meaning technology will follow the functionalities that need to be improved, ensuring European wide interoperable usability and rail industry standards.

The table below present how the application of the output from FA5 work will impact operations.

| | **Operational solutions outcome** |
|---|---|
| Full Digital Freight Train Operation | For efficient and productive operations due to full automation and digitalization of operational functions and processes through technology development for the reduction of manual work; respective automation components need to be driven to high TRL and embedded in a fully integrated system, so that an improved service quality for e. g. customers can be assured. This includes :<br>• 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<br>• Freight wagons/loading units for multi-modal transport applications (based on customer needs' analyses)<br>• Telematics for monitoring solutions<br>• Yard automation and digitalization |

| | Operational solutions outcome |
|---|---|
| Seamless rail freight | To ensure seamless and efficient transport services and cargo flows the transport and operations management as well as the routing and booking options, will be transformed from a fragmented and national or stakeholder specific approach to an international/European comprehensive system approach, meeting the shippers requirements of a flexible, dynamic and reliable transport offer, which can be easily accessed and booked. This is including the entire freight chain, in particular<br>• **Planning**<br>  o Seamless, aligned and eased planning of rail freight services via integrated cross-border timetable planning, management and path ordering systems covering all planning horizons and especially the specific needs of ad-hoc services<br>  o Integrated/connected slot planning and booking functionalities for last mile services<br>• **Operation**<br>  o Dynamic dispatching tools including cross-border and last mile operations. Innovative, smart and harmonized concepts for (cross-border) operations and concepts for an efficient and effective resources management in case of deviations, and reduced response time for ad-hoc European paths request/re-planning<br>  o Intermodal monitoring and prediction systems<br>  o Improvement of operation across borders and areas/stakeholders (main line, connection line, yards/terminals) by increased accuracy of predictions (e.g. ETA) and target times leading to a significant significantly decrease average transportation time;<br>  o Standardized European Railway Checkpoints at border crossings or other operational stop over points, digitalization of manual processes<br>  o Innovative, smart and harmonized process for technical wagon inspections (e.g. additional inspections at borders for non-ATTI trains)<br>  o Multi country licensed loco driver<br>  o cross-border management reducing time for train preparation in particular at border crossings (ATTI, inspections, multi-license loco driver)<br>• **Management/Selling/Booking**<br>  o Seamless multimodal integration with easy access to (intermodal) rail service<br>  o Fully digital European customer solutions (services, interfaces) as well as solutions for multimodal transport planning and booking platforms to integrate rail freight in modern supply chains, as easy as it is to offer and order a multimodal passenger journey; seamless & harmonized data exchange of railway checkpoints for smooth European rail freight operation<br>  o |

*Table 29 - Impact of the application of the output from FA5 work in operations*

*7.5.2.2 Technical enablers: capabilities to achieve the targeted operational outcomes*

To realize the operational solutions, it must be assured that technical enablers 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 technical enablers, which are often depending on the successful realization of R&I undertaken in other FAs, being FA5 more oriented to the demonstration part:

| Cluster | | | **Technical enabler** | **2025** | **2027** | **2031** |
|---|---|---|---|---|---|---|
| Full digital freight train operations | DAC backbone | Digital Automatic Coupling<br>Link with other FA: TT<br>*Note: The use case driven DAC energy supply & data/communication solution, being the backbone, will enable to enlarge to further functionalities in the future. | | | | |
| | | | DAC type4 (incl typ5 updgradability) | **8/9** | | |
| | | | DAC (hybrid) coupler for loco | **8/9** | | |
| | | | DAC energy supply & data/communication solution/backbone* | **8/9** | | |
| | DAC based/enabled applications | Digital Automatic Uncoupling | | | | |
| | | | DAC type5 | **8/9** | | |
| | | | automated parking brake system<br>Link with other FA: data transmission to FA1, FA2 | **7/8** | **8/9** | |
| | | DAC based digital train preparation | | | | |
| | | | train composition detection/management system | **8/9** | | |
| | | | automated/automatic brake test system,<br>Link with other FA: data transmission to FA1, FA2 | **8/9** | | |
| | | | digital wagon inspection (incl. RST+INF assets)<br>Link with other FA: data transmission to FA1, FA2, FA3 | **7** | **8/9** | |
| | | DAC based further digital applications<br>.<br>Link with other FA:<br>• FA3 algorithms and methodology on CBM;<br>• TT: harmonized data formats & protocols for data exchange to FA1,2,3-technologies e.g. on damages/dangerous goods; or assets conditions for CBM; | | | | |
| | | | for customer requirements (goods monitoring) | **7** | **8/9** | |
| | | | for asset performance management /CBM | **7** | **8/9** | |
| | | | for safety related applications | **7** | **8/9** | |
| | | DAC based Train Operations<br>requirements to FA1 for driving and energy management.<br>Link with other FA:<br>• all developments on TIMS done in FA2 to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | • all development on the efficient driving and energy management in term of TMS done in FA1.<br>• Data on safety transmitted to FA1<br>• FA 5 Requirements/feedback / + adjustments that may become necessary for the use of the DAC | | | | |
| | | | DAC based train integrity + train length determination | **7** | **8** | **8/9** |
| | | | efficient driving and energy management | **6/7** | **7/8** | **8** |
| | | | distributed power concepts and solutions | **7** | **8/9** | |
| | | | electro-pneumatic brake | **7/8** | **8/9** | |
| | | DAC based Yard Operation (specificities, but on the basis of FA2 outputs)<br><br>Scope of the FA5 work: mainly limited to demonstrations, but also some specific 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.<br>Link with other FA:<br>• All development on movement automation technologies (e.g. GoA2,4 | | | | |
| | | | Fully automated shunting loco movements (GoA 4) | | **7/8** | **8/9** |
| | | | Yard digitalization for full automated train composition and dispatching (Automated Shunting Operations) | **8/9** | | |
| | | | Yard automation equipment | **5/6** | **7/8** | **8/9** |
| | | | Wagon identity system allowing automated shunting | **8/9** | | |
| | | | Integrative deployment of video gates, way side check points, visual recognition methodologies and AI-Tools for yard automation | **7/8** | **8/9** | |
| | | DAC based wagon concepts incl. multi-modal transport applications<br>Link with other FA: FA3,4 | | | | |
| | | | DAC wagon retrofitting (in particular special wagons, e.g. T3000) | **8/9** | | |
| | | | Low-weight, low-energy, low-noise, high performing wagon concepts | **8** | **8/9** | **8/9** |
| | | | Self-propelled wagon | **5** | **6** | **7** |
| | | | automated/autonomous loading/unloading technologies for last mile distribution, and new market needs (e.g. hydrogen storage/transport) | **5/6/7** | **7/8** | **8/9** |

*Table 30 - Overview of capabilities enabling operational objectives*

| Cluster | Technical enabler | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | **Seamless planning of rail freight services**<br>• Integrated cross-border timetable planning, management and path ordering systems covering finally all planning horizons (Digital Capacity Management) and especially the specific needs of short-term path requests for (international) freight services<br>• Integrating and connecting the last mile (accession lines/shunting/yards/ terminals) slot planning directly or via interfaces<br><br>Scope of the FA5 work: limited to demonstrations + some specific freight developments and requirements to FA1 for TMS.<br><br>Link with other FA:<br>• All general development of planning systems within TMS is done in FA1 | TRL6-7<br><br>TRL6 | TRL7-8<br><br>TRL7 | TRL8~~-9~~<br><br>TRL8 |
| | **Dynamic dispatching tools including last mile operations**<br>• Harmonized real-time interfaces between TMS and e.g. yard/terminal management systems and agreed data structure/quality<br>• Dynamic yard/terminal management systems upgrade with optimization functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1).<br>• Dynamic freight specific real time functions for the interaction of various TMS (FA1) and with other management systems<br><br>Scope of the FA5 work: limited to demonstrations + some specific freight developments for terminals /yard incl. interfaces and requirements to FA1 for TMS.<br><br>Link with other FA:<br>• All general development of TMS is done in FA1 | TRL6-8<br><br>TRL6<br><br>TRL4-5 | TRL7-8<br><br>TRL7<br><br>TRL 6-7 | TRL8-9<br><br>TRL7/8<br><br>TRL7-8 |
| | **Intermodal monitoring and prediction system**<br>• Real-time gathering and processing of influencing data<br>• Connection with rail TMS systems and other resource management systems<br>• AI based prediction models<br>• Accuracy and computational learning functions | TRL7<br><br>TRL5-7<br><br>TRL7 | TRL8-9<br><br>TRL6-8<br><br>TRL8 | TRL8-9 |

| | | | | |
|---|---|---|---|---|
| | | TRL7 | TRL8 | |
| | **Standardised European Railway Checkpoints at borders or other operational stop points**<br>• Digitalisation and partial automation of manual processes through innovative sensors, video gates and handheld devices, based on a process analysis<br>• Interoperable IT-systems for data management and processing<br>• Harmonized procedures & regulation | TRL8<br>TRL8<br>TRL7 | TRL8-9<br>TRL8-9<br>TRL8 | |
| | **Multi-country licensed loco driver**<br>• Certified secured translation tools (incl. training)<br>• Simulators (local line knowledge)<br>• Harmonised cross-country operation and rostering concepts | TRL8-9<br>TRL8-9<br>TRL7 | TRL8-9<br>TRL8-9<br>TRL8 | |

*Table 31 - Overview of capabilities enabling operational objectives 2*

| Cluster | Technical enabler | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | **Seamless multimodal integration**<br>• 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) with tools for transport planning (including pricing information if available) with easy booking functions<br>• Demand responsive transport network planning, routing and capacity management algorithms<br>• Ad-hoc dynamic capacity allocation depending on resource availability<br><br>Link with other FA:<br>• All relevant traffic influence data information should be openly available to FA1 for TMS<br>• Possible alignment of technological basis to be foreseen with FA1 | TRL6-9<br>TRL4-6<br>TRL4-5 | TRL 8-9<br>TRL5-7<br>TRL5-6 | TRL8-9<br>TRL6-8<br>TRL7 |

| | | | | |
|---|---|---|---|---|
| | **Seamless data availability/exchange using the platform of platform approach where applicable**<br>• Increased availability and quality of data by reduction of technical barriers for the generation and exchange of data<br>• Agreement on common data structure as far as possible otherwise appropriate interfaces, converter, verification, management, security<br>• Connected via the platform of platforms approach<br><br>Link with other FA:<br>• All relevant traffic influence data information should be openly available to FA1 for TMS<br>• Possible alignment of technological basis to be foreseen with FA1 | TRL6-8<br><br>TRL7-8<br><br>TRL7 | TRL7-8<br><br>TRL8<br><br>TRL8 | TRL8<br><br>TRL8-9<br><br>TRL8-9 |
| | **Technology upgrade of legacy/national systems to provide/consume/process harmonized data from international (European) applications/innovations**<br>• Advanced converters into standard formats<br>• Dedicated real-time interfaces<br><br>Link with other FA:<br>• All relevant traffic influence data information should be openly available to FA1 for TMS<br>• Possible alignment of technological basis to be foreseen with FA1 | TRL7<br>TRL6-7 | TRL7-8<br>TRL7-8 | TRL8-9<br>TRL8-9 |

*Table 32 - Overview of capabilities enabling operational objectives 3*

#### *7.5.2.3 Demonstration implementations*

Within the field of full digital freight train operations, on the basis of the developed, tested and specified technology (e.g. DAC and Hybrid Coupler for Locos as well as further components), demonstrators and pilots in Europe (incl. CEE/SEE) are to be organised to validate, assess, evaluate and show the required functionality and added value of the new solutions, technologies and the numerous additional train functions that will be possible through automation and digitalization. Tests in daily operational conditions will prove the functionality and demonstrate market readiness for freight operation enhancing harmonised operations. This will be 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 program will consist of two main focus areas, being operations (associated to e. g. preparation and train run) 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 for 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 operation as well as common platform interfaces with customers, potentially using the Rail Freight Corridors as facilitators to ensure the European interoperable use of the innovations. All demonstrations should be transferable to other countries/regions ensuring a benefit for the European Railway, the Single European Railway Area sector and the society.

The demonstration of harmonized processes with a systematic approach includes interaction of stakeholders at handover points (e.g. borders or at any other operational milestone/stop) as well as interfaces between stakeholders and also customers.

Suitable locomotive prototypes with integrated DAC or Hybrid coupler will be tested under various operational scenarios. By collecting as much return of experience as possible for all participating DAC manufacturers, a service proven product for DAC and Hybrid Coupler for Locos shall be achieved. The same is foreseen for fully-digitalized freight wagons for dangerous good transport (e.g. hydrogen).

The following table gives an overview of timeline for potential demonstration implementations,. As a general approach it is foreseen to set up already in the first phase demonstrators which combine specific selected components/parts/modules of the technical enables, which can reach a high TRL level already until 2025 for various reasons. This shall facilitate the smooth and early start of the migration phase especially for DAC and also the generation of early benefits for the IMs, RUs and freight customers. In the second and third phase additional functions and components will be added to the demonstrations or the TRL level of the initial demonstrations will be increased.

Since several technical enablers depends on the output of other FAs, the demonstration plan has also link with the other FAs, in particular on the TRL implementation level.

| | Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| full digital freight train operations | **Demonstration of European full digital freight train operations I**<br>Large-scale demonstrator trains testing in different European regions under real operational conditions the technical enablers:<br>• DAC type4 (incl typ5 upgradability)<br>• DAC (hybrid) coupler for loco<br>• DAC energy supply & data/communication solution/backbone | TRL8/9 | | |

| | Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | • DAC type5<br>• train composition detection/management system<br>• automated/automatic brake test system<br>• DAC wagon retrofitting (in particular special wagons, e.g. T3000)<br><br>With specific focus on proofing<br>• full functionality (added value for the sector respecting/meeting customer needs),<br>• safe system integration,<br>• interoperability,<br>• harmonized (cross-border) operation.<br><br>For preparing European-wide roll-out and finalization of standardization.<br>• Note: All technical enablers will be considered in the definition of the target architecture of the intelligent freight train, in order to assure a full functional future system preventing parallel and isolation solutions outcome. With this we can assure that the development of the components starting partly from the beginning and others later, are still coherent and seamless to be integrated in the future full digital freight train operations.<br>• This will be 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.<br>• The use case driven DAC energy supply & data/communication solution, being the backbone, will enable to enlarge to further functionalities in the future. | | | |
| | **Demonstration of European full digital freight train operations testing further components II**<br>Upgrading large-scale demonstrator trains testing in different European regions under | | TRL8/9 | |

| | Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | real operational conditions the technical enablers:<br>• automated parking brake system<br>• digital wagon inspection (incl RST+INF assets)<br>• DAC based telematic applications<br>  o for customer requirements (goods monitoring)<br>  o for asset performance management /CBM<br>  o for safety related applications<br>• distributed power concepts and solutions<br>• electro-pneumatic brake<br><br>With specific focus on proofing<br>• full functionality (added value for the sector respecting/meeting customer needs),<br>• safe system integration,<br>• interoperability,<br>• harmonized (cross-border) operation.<br><br>For preparing Europe-wide roll-out and finalization of standardization.<br>• Note: All technical enablers will be considered in the definition of the target architecture of the intelligent freight train, in order to assure a full functional future system preventing parallel and isolation solutions outcome. With this we can assure that the development of the components starting partly from the beginning and others later, are still coherent and seamless to be integrated in the future full digital freight train operations.<br>• This will be 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.<br>• The use case driven DAC energy supply & data/communication solution, being the | | | |

| | Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | backbone, will enable to enlarge to further functionalities in the future. | | | |
| | **Demonstration of European full digital freight train operations testing further components III**<br>Large-scale demonstrator trains testing in different European regions under real operational conditions the technical enablers:<br>• train integrity + train length determination<br>• Rail freight operation with ATO (with FA2) Low-weight, low-energy, low-noise, high performing wagon concepts<br>• Self-propelled wagon<br>• automated/autonomous loading/unloading technologies for last mile distribution, and new market needs (e.g. hydrogen storage/transport)<br>With specific focus on proofing<br>• full functionality (added value for the sector respecting/meeting customer needs),<br>• safe system integration,<br>• interoperability,<br>• harmonized (cross-border) operation.<br><br>For preparing European-wide roll-out and finalization of standardization.<br>• Note: All technical enablers will be considered in the definition of the target architecture of the intelligent freight train, in order to assure a full functional future system preventing parallel and isolation solutions outcome. With this we can assure that the development of the components starting partly from the beginning and others later, are still coherent and seamless to be integrated in the future full digital freight train operations.<br>• This will be provide valuable findings for various TSI revisions that will come up during the EU-RAIL JU period, enable necessary safety analysis or safe system | | | TRL 7-9 |

| | Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|---|
| | integration followed by authorisation prerequisite for deployment.<br>• The use case driven DAC energy supply & data/communication solution, being the backbone, will enable to enlarge to further functionalities in the future. | | | |
| | **Demonstration of a fully digitalized and automated yard IV**<br>• Fully automated shunting loco movements (GoA 4)<br>• Yard digitalization for full automated train composition and dispatching (Automated Shunting Operations)<br>• Yard automation equipment<br>• Wagon identity system allowing automated shunting<br>• Integrative deployment of video gates, way side check points, visual recognition methodologies and AI-Tools for yard automation<br>• | TRL8/9 (certain functionalities) | TRL7-8 | TRL8/9 |

*Table 33 - Link of the demonstration plan with the TRL implementation level*

| | Demonstrator | 2025 | 2027 | 2031 | Alignment with other FA |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Seamless rail freight | **Seamless freight corridor showcase**<br>The comprehensive innovations for planning and operation of cross-border freight trains will be demonstrated on up to two European corridors. The seamless interaction across borders and involved stakeholders will be shown by pilot implementations of key enablers like:<br>• Integrated cross-border timetable planning, management and path ordering systems covering all planning horizons (Digital Capacity Management) and especially the specific needs of short-term path requests for (international) freight services<br>• Integrating and connecting the last mile (accession lines/shunting/yards/ terminals) slot planning directly or via interfaces<br>• Harmonized real-time interfaces between TMS and e.g. yard/terminal management systems and agreed data structure/quality<br>• Dynamic yard/terminal management systems with optimization functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1).<br>• Dynamic freight specific real time functions for the interaction of TMS (FA1) and other management systems<br>• Real-time gathering and processing of influencing data<br>• Connection with rail TMS systems and other resource management systems<br>• AI based prediction models<br>• Accuracy and computational learning functions<br>• Standardized European Railway Checkpoints at borders or other operational stop points & digital showcase of further manual processes at border crossings resulting in border crossing <5min.<br>• Digitalization and partial automation of manual processes through innovative sensors, video gates and handheld devices, based on a process analysis<br>• Interoperable IT-systems for data management and processing<br>• Harmonized procedures & regulation | TRL 4-8 | TRL 5-9 | TRL 5-9 | FA1, FA2, |

| | Demonstrator | 2025 | 2027 | 2031 | Alignment with other FA |
|---|---|---|---|---|---|
| | • Multi-country licensed loco driver through certified secured translation tools and simulators for gaining local line knowledge<br>• Harmonised cross-country operation and rostering concepts<br>The demonstrations will be stepwise extended in scope and functions, building up on each other and the initial results, increasing the TRL level or adding additional enablers to be demonstrated. Therefore the indicated TRL level is not applicable for all enablers, but should be reached by some of the components. | | | | |
| | **Seamless customer freight showcase**<br>The seamless planning. management and booking of multimodal rail based transport integrating multi-actors, will be demonstrated by combining the key enablers to an innovative open system. Besides the enablers for multimodal integration<br>• 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) with tools for transport planning (including pricing information if possible) with easy booking functions<br>• Demand responsive transport network planning, routing and capacity management algorithms<br>• Ad-hoc dynamic capacity allocation depending on resource availability<br>And for seamless data availability and exchange<br>• Increased availability and quality of data by reduction of technical barriers for the generation and exchange of data<br>• Agreement on common data structure as far as possible otherwise appropriate interfaces, converter, verification, management, security<br>• Connected via the platform of platforms approach<br><br>also these enablers will be partly used in this demonstrator | TRL 4-8 | TRL 6-9 | TRL 6-9 | |

| | Demonstrator | 2025 | 2027 | 2031 | Alignment with other FA |
|---|---|---|---|---|---|
| | • 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)<br>• Technology upgrade of legacy/national systems to provide/consume/process harmonized data from international (European) applications/innovations<br>• Advanced converters into standard formats<br>• Dedicated real-time interfaces<br>The demonstrations will be stepwise extended in scope and functions, building up on each other and the initial results, increasing the TRL level or adding additional enablers to be demonstrated. Therefore the indicated TRL level is not applicable for all enablers, but should be reached by some of the components. | | | | |

*Table 34 - Link of the demonstration plan with the TRL implementation level 2*

### *7.5.3 Impacts*

#### *7.5.3.1 Description of the impacts against existing rail services*

**Full digital freight train operations** enabled by key technologies for transforming the European Rail Freight sector will increase productivity (time and cost reduction), efficiency (through process automation : faster, simpler and more efficient processes) and service quality, all of that leading to an increase of competitiveness. Together with a "smart" increase of capacity, more freight traffic can be shifted to the European rail system, significantly contributing to the EU Green Deal and additionally increasing workers safety and value creation for Europe. The development of innovative freight assets (e.g. innovative freight wagons, last mile solutions, terminals) allow to further improve the competitiveness of rail freight by reducing LCC, operational costs and also increasing the level of automation of operations and e.g. wagon loads/intermodal terminals, solutions for low volume.

A **seamless rail freight** with a significantly reduced average transportation time based on an agile, interoperable and open environment within integrated and harmonized European mobility networks which interacts with other businesses; an environment in which companies can optimize their operations; for railway undertakings, this results into higher productivity, better capacity utilization, improved planning possibilities and, through the reduction of cross-border barriers and multimodality, faster transport handling, altogether resulting into higher reliability. In addition, comprehensive multimodal and transparent customer information in combination with easy booking and managing functions, lead to an increase in customer satisfaction and easier access to rail based services. Being based on harmonized European data this leads to higher predictability and planning possibilities for infrastructure managers. These improvements will enable railway undertakings to derive new and better transport services for customers that will be more efficient, more flexible and capable of competing with road freight, and it will be much easier for customers to use and integrate rail in their supply chains.

| | |
|---|---|
| | Meeting evolving customer requirements<br><br>The improved freight operation coming from the programme will support more flexible and punctual freight services by reducing the overall transportation time. It will increase the customer satisfaction and ensure that customer needs such as tractability of goods, more efficient cross-border services. |
| | Improved performance and capacity<br><br>FA5 will considerably increase productivity and capacity by the introduction of key features like DAC which will help also improve reliability and flexibility by fully digitalizing 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<br><br>the FA5 solutions and improved freight operation will increase the profitability of the freight services. A specific example the Digital Automatic Coupler is, aside the mechanical connection of wagons, basically a platform for many applications on the intelligent freight train developed – being fundamental for significant overall increase in attractiveness and cost-efficiency for rail freight. |
| | More sustainable and resilient transport<br><br>FA5 will deliver innovative solutions which target to optimise energy consumption and reduce the associated environmental footprint for the rolling stock. |
| | Reinforced role for rail in European transport and mobility<br><br>FA5 solutions will support that rail is easily integrated in 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 Digital Automated Coupling) to increase the level of exploitation of existing rail infrastructure and improve operational functions and processes while enabling harmonization in rail freight. |
| | Improved EU rail supply industry competitiveness<br><br>Digital and automated solutions will modernise the rail freight market and it will support reduce the cost of the freight vehicles, increase the punctuality and availability of the freight services. |

*Table 35 Descriptions of FA5 impacts related to the intended impacts in the Master Plan*

### 7.5.3.2 *Quantitative KPI demonstrated in this FA*

The fundamental aim of the research program is to enable rail freight to achieve a radical increase in the rail freight market share. It should be noted that the KPIs will need to be estimated in advance of the implementation of the innovations produced by the research, and thus a forecast is needed. Effects will be constantly quantified during demonstrator projects and the effects on a European broad scale will be measurable before 2030 as soon as technologies will be deployed. It is suggested to model KPIs taking as input freight service today and improvement after technology implementation so as to better estimate impacts and readjust priorities. KPIs will mirror customer requirements and are aimed to control how rail freight services as a whole will be transformed to a higher service level. The following list provides an initial indication of potential KPI (tbc) which can be properly measured.

**Specific KPI**

More specifically Flagship Area Freight aims to achieve the following quantitative KPI. Conditions on how to measure/quantify KPIs need to be developed in the project. FA5 need to develop a model how to calculate/quantify if the KPI on the best case of Europe has been met on level of the demonstrator (not full Europe). The Baseline for KPI is 2018-2022, considering the need to neutralize the C-19 impact and subject to availability.

**Demonstrate European full digital freight train operations**

- Decrease train formation/decomposition (shunting/coupling/uncoupling) time:
  - Expected time reduction targeting 40-50%.
- Decrease train preparation/ departure process time:
  - Expected time reduction targeting 40-70%.
- Demonstrate increased average train length [m] up to maximum length in existing infrastructure limitations or higher loads:
  - Train length increased up to 1.500 m.

**Develop seamless rail freight**

- Reduce average transportation time on reference corridor
  - Time reduced targeting 10-20%.
- Reduce operational dwell time at borders and other handover points:
  - Dwell time reduced targeting 50%.
- Reduce the number of additional operational stops (limiting also the energy consumption):
  - Reduced number of operational stops targeting 20%.
- Reduce handling/response time for ad-hoc cross-border path requests
  - Reduced time by targeting 70%.
- Reduce handling/response time for connected comprehensive intermodal offers
  - Reduced time by at least 50%.
- Reduced energy consumption and reduced footprint through less stops at borders
  - Reduced energy consumption by a minimum of 10%.

### 7.5.3.3 *Exploitation, deployment and migration considerations*

**Exploitation, deployment & migration considerations Full Digital Freight Train Operation**

Rail freight have a low degree of implementation of innovations mainly due to low margin in business and fragmented technical approaches both having to boost progress in an interoperable, connected rail system where systemic innovation can only be achieved in a joint way. There is a need for a system approach with regards to both digitalisation of e. g. customer support systems as well as network/yard optimization tools. Furthermore the system approach is absolutely needed in the digitalisation and automation of the system (full digital operations). Rail freight is facing a multitude of challenges e. g. capacity constraints, domination of manual interventions or insufficient customer information and the automation of freight trains has hardly changed for decades. Inefficient, non-atomised nor digitalised processes clearly need to be changed. The solution “full digital freight train operations”, based on what will be developed in strong cooperation with key stakeholders of FA5, will lead to a significant increase of productivity, efficiency and service quality, resulting in increased competitiveness of European rail freight. Exploitation, communication and dissemination of FA5 results are essential for a successful achievement of the objectives, achieving the overall acceptance and implementation of full digital freight train operation results. We need to assure to facilitate acceptance of the project outcomes by the European rail freight sector.

One special characteristics of the rail freight in Europe is the exchange of wagons. Also the full digital freight train will consist out of wagons from different owners especially in the area of single wagon load. Therefore, the interoperability between the wagons from different operators and wagon owners has to be ensured. This requires an intense standardization work, creation (or adaptation) of standards as well as modification of the relevant TSI. For these activities the System Pillar should take care.
The full digital freight train with its automatic coupler and the digital applications on board is not compatible with the screw coupled wagons of today. This requires a migration of the existing wagon and locomotive fleet. During the migration period trains with both coupling systems had to be operated leading to an increased number of trains and requiring increased capacity in yards. It should be the aim of the System Pillar to define a migration concept balancing the operational constraints with the available production and workshop capacity to install the equipment of the full digital freight train onto the wagons and locomotives.

The system pillar is an important interface to this process, harmonized operational procedures as well as accurate CBA assessments. This will enable to make the target picture for the European railway sector more concrete, which is a prerequisite identifying the value creation for Europe. This is will imply investments from the policy level for successful deployment. A unified European full digital freight train operations framework is needed tackling technical specifications for technical enablers, guidelines, system architecture, operational procedures, standardised training all in line by interaction with the System Pillar and other alignments including funding possibilities for paradigm changes. The effective migration, including strategic planning, implementation and management for achieving a coherent functioning/implementation of the intended operational solutions outcomes, incorporating the technical enablers for which the European demonstration (highest TRL including customers) as a steppingstone, will successfully allow the transition from the current situation towards full digital freight train operations.

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 the individual elements need to be worked out in parallel to the development work, depending on which vehicle fleet and which transports are concerned by the outcomes and if separated migration is feasible or if a network-wide migration is required. The development cycle needs to take into account the respective feedback to potentially adapt the results to migration needs.

**Exploitation, deployment & migration considerations Seamless Rail Freight**
Since traffic does not usually start and end on a border/railway freight corridor exclusively, efficient and harmonised interfaces to the existing processes and tools of individual IMs, RU and other freight stakeholder (e.g. ports, yards, lorry operators) are needed. The solution, based on what will be developed in strong cooperation with the supply industry and academia in FA5 will lead to a significant more competitive rail freight – resulting into less emissions and higher customer satisfaction.
Migrating the results from FA5 will not only be in some cases a challenge due to the fact that RU are competing but also due to needed harmonisation and standardisation of R&D results. For the latter, a strong interaction with the System Pillar is required. To secure a smooth migration and to acknowledge the European approach of this, demonstrators/pilots in FA5 should already have a clear Europe-wide focus – such as an on the Rail Freight Corridors ScanMed RFC, Baltic Adriatic RFC or NorthSea-Mediteranean RFC.

## 7.6 Flagship Area 6: Regional rail services / Innovative rail services to revitalise capillary lines

### *7.6.1 Objective and level of ambition*

#### *7.6.1.1 Targeted objective, opportunities opened and associated risks*

**Problem statement & objective**
Regional railway (lower usage lines or secondary network) play a crucial role not only in serving Europe´s region but also as feeder lines for passenger and freight traffic for the main/core network. Hence, having an essential function as green transport as well as connecting other public transport services (e.g. bus) as well as first & last mile services such as car, bike sharing, cycling, walking from railway stations to remote locations. However, these railway lines need to be revitalized or even regenerated to make them economically, socially and environmentally sustainable and meet the current customer needs. The overall objective of this flagship area is to ensure 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 offering a high quality of service and operational safety. In addition, the aspired results aims to increase customer satisfaction and to become an attractive and preferred choice of transport mode.

These goals are expected to be achieved through a concept tailored to regional railways that includes digitalization, automation and utilization of mainstream and emerging technologies for signalling and trackside components, rolling stock and customer information. Cost drivers including infrastructure and energy components, e.g. trackside train detection (axle counters, etc.) and level crossing control systems, should be replaced by less costly wireless and energy self-sufficient components. Furthermore, a modular and standardized concept for vehicles that specifically addresses the requirements of regional lines are needed. Hence, the following key objectives will be pursued:

- Lowering CAPEX system costs
- Increasing productivity - OPEX (unit costs per train kilometre)
- Improving customer satisfaction

While the initial investment costs might be substantial, the migration should assume a complete system overhaul instead of retaining the existing technology with high OPEX.

Digitalization, in addition, offers possibilities 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 for specific regional railways that are not functionally / operationally connected with mainline network might apply or for the purpose of pilot applications with the perspective of a further development for global application. Large numbers of legacy systems and technologies, as well as integration complexity of the proposed solutions, may complicate its successful adaptation. For this Flagship Area 5 main clusters have been identified: Regional System Solutions, CCS & Operations, Regional Railway Assets, Rolling Stock and Customer Service which are described in detail in the following chapters.

Nevertheless, to enable suppliers to develop technologies at competitive costs and allow an effective implementation and use by the operators, certain potential gaps and risks have to be taken into account and have to be eliminated or minimized. Possible gaps and associated risks include:

- insufficient definition of a harmonised regional system solution may lead to a multitude of heterogeneous systems, harmonisation with a high level of complexity which hinders standardization and harmonization,
- The lack of suitably adjusted technologies on time for regional lines may provide limits to FA6 planned demonstrations and pilots,
- Insufficient alignment with ERJU System Pillar and other Flagship Areas
- insufficient alignment with TSI-revision cycles
- Lacking standardization and harmonization
- The migration from a brownfield environment and underestimation of the complexity of adaptation may be a risk especially in combination with missing harmonized and clearly identified operational rules.

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

| | **Regional System Solutions** |
|---|---|
| State of the art | CCS and TMS systems originally developed for light rail but that also will have low-density line applications. |
| S2R results | Shift2Rail results include developments on formal methods, GNSS positioning systems and similar technologies.<br>Ontology/sematic 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 ERJU System Pillars, functional blocks and interfaces will be investigated in order to identify all the possible needs and solutions applicable for low density lines.<br>• Design and development of flexible forms of rail services and their intermodal (rail-road) integration are considered and supported by migration strategies and socio-economic evaluation of innovation. |

*Table 36 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail*

| | **CCS & Operations** |
|---|---|
| State of the art | Centralised Traffic management encompassing controlling comprehensive parts of the network . Automated conflict resolution systems for train route setting enabling mitigation to avoid or minimize delays. |
| S2R results | Moving blocks, Automatic Train Operations, Systems for train integrity. |
| Further/new results | • Traffic management system encompassing the overall control of the line and supporting innovating technologies, including ATO, autonomous or remote controlled driving, adapted / simplified for the specific features of low-frequency traffic<br>• CCS / ERTMS Level 3 based safety layer aiming to reduce signalling assets (lateral signals, trackside train detection systems, level crossing treadles …), integrating interlocking functionalities and TMS<br>• Cost-efficient onboard equipment matching the needs of the operational requirements as well as guaranteeing a minimum necessary compatibility/interoperability with mainline CCS (ERTMS)<br>• Development (in collaboration with System Pillar) of adapted operational rules and procedures for regional lines supported by advanced TMS features; possible update of the CCS and OPE TSI |

*Table 37 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rai 2l*

| | **Regional Railway Assets** |
|---|---|
| State of the art | Codes and regulations have been developed over the years to meet requirements of main lines whilst needs for lines with low traffic volumes have been relatively neglected. Flexible interpretation of standards, improvisation, and proven experience are today basis for urgent maintenance needs of not intensively used lines. Improvements of regulations tends to aim at increased track quality in order to reduce total cost for lines with dense traffic as track availability is the most limited parameter and therefore costly. Management of lines with low traffic volumes has different limitations. Here track availability for maintenance is |

| | |
|---|---|
| | higher, optimal quality can be tailored for regional needs. Today scientific support for such tailored management is missing or not practically implemented |
| S2R results | Relevant frameworks for analysis have to some extent been developed within S2R. Input for regional conditions and safety calibrated limitations are missing. IP2 SWOC. |
| Further/new results | With the aim to develop cost-efficient (OPEX, CAPEX) the aim is to use results of other FA and adapt them for regional usage, aiming for:<br>• … assets that will be (further) developed to reduce unit costs per train kilometer and increase operational safety on regional railways,<br>• … a particular focus on interoperability of assets, making use of technologies developed in other FAs while being simplified/adapted,<br>• … technologies with a high level of scalability (economies of scale) which will be harmonized for all operators and infrastructures across Europe. |

*Table 38 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 3*

| | **Rolling Stock** |
|---|---|
| State of the art | At the moment there are no vehicles especially developed for the requirements of regional railway system available. The used vehicles are either (adapted) mainline or tram based vehicles. Relevant bus and light ferries technologies. |
| S2R results | Lightweight materials, active suspension, silicon carbide traction equipment, flexible and light weight user-centered interiors, light weight doors, airless brakes |
| Further/new results | The goal is<br>• … to develop a common vehicle architecture, which will be harmonized for all operators and infrastructures across Europe.<br>• … to develop vehicle modular interiors to adapt easily to the different needs of each service, considering different spaces to offer several uses (including transport of goods)<br>• … to identify requirements for a low-cost design of the vehicle with the aim to reduce the acquisition cost (CAPEX) of vehicle, taking advantage of economies of scale while reducing OPEX of the global system.<br>• … to define and develop the best compromise between service, performance and vehicle costs with a systemic view.<br>• ...to develop solutions for small size vehicles (e.g. 100 pax) with alternative propulsion systems<br>• … to agree the same requirements for such vehicles for the wider area of use across Europe, allowing faster type certification/authorisation<br>• … to analyze the requirements for safety and interoperability with the aim to adapt them to the needs of low-density lines in order to reduce the cost. That will most likely result in a set of proposals for the standardization as well as TSI updates (LOCPAS, CCS, OPE) in the upcoming revision cycles |

*Table 39 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 4*

| | **Customer Service** |
|---|---|

| | |
|---|---|
| State of the art | There is a multitude of digital journey assistants, ticketing and time tabling applications on the market where one can plan, book, pay 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 travels, utilisation of augmented reality to enhance the travelling experience. |
| Further/new results | The goal are customer solutions for regional railways such as<br>• standardization and creation of a modular, safe & secure railway station, connecting different modes and including PRM-aspects aiming to:<br>o Reinforce interchanged services: improving hubs management for multimodal and autonomous mobility to guarantee full sustainable value chain multimodal mobility flows including freights distribution in sparsely populated areas<br>o Develop a remote and automatic asset management for lighting systems, safety and security to integrate business continuity with emergency recovery and disaster preparedness initiatives<br>o Develop a tailored and sustainable new distribution chain for new energy (i.e for electric vehicles or Hydrogen ones) common for road and rail in rural areas<br>• Passenger information system (PIS):<br>o Information systems (on-board and/or at the station), infrastructure and service integration with other regional/municipal transport modes (buses, trams, metro, taxi, carsharing) and with additional services such as bicycle rental and information for tourists<br>o Develop a Digital integration with a distributed computing model across the shared transport modes, implemented as a platform that monitors and provides a digital abstraction of all mobility resources and allows the development of new coordination capabilities that match mobility demand to available mobility supply in an efficient and flexible way.<br>• … and passenger services spanning from high speed internet access on board on a common FRMCS infrastructure, ticketing to on-board services as well as last mile will be developed – for integration of both multimodal regional services and long distance journeys |

*Table 40 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail 5*

#### *7.6.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

Several activities within FA 6 to be realised require transversal cooperation with other EU-RAIL JU Flagship areas as some of the enabling technologies including train integrity, moving block, advanced and safe train positioning and intelligent and efficient maintenance will be developed in FAs.

However, it is important to note that regional railways have their own characteristics and requirements. Enabling technologies developed for regional railways must certainly take such characteristics into account. Most importantly, regional railways operate under tight

economic conditions. Hence, applied technologies should be modularized with a reduced set of functionalities (whilst respecting high safety requirements without being cost driven).
The relationship between FA6 and other FAs can be summarized as follows:

**System Pillar:**
This flagship area provides input for system pillar by generating a clearly defined set of constraints and requirements and in turn operates within the proposed framework set by system pillar. Hence, input received from SP is fundamental for the development of technological enablers.

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

- **FA1**: FA6 specifies the requirements for regional railways and **uses the enablers developed in FA1** adapting a simplified TMS and on-demand passengers services requesting flexible timetabling.
- **FA2**: FA6 specifies the requirements for regional railways and **uses the enablers developed in FA2** adapting cost-effective CCS and ATO solutions for functions such as highly accurate fail safe train positioning, train integrity, train length detection as well as 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 life-cycle costs and decrease OPEX .
- **FA4**: **FA6 uses the enablers developed in FA4 where relevant**, including alternative low carbon, low weight and energy efficient systems to achieve cost efficient decarbonization and resilience.
- **FA5** and **FA7**: Multimodal shared-mobility solution, DAC as an essential prerequisite for single staffed last mile shunting operations and a better integration in multimodal transport chains, 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 as a kind of a transversal enabler. A further development of the ontologies and specific regional line applications on digital twins and automation processes.

*Details of the exchange between the Flagship Areas can be found in Annex B*

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.

Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- Conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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 be also seeking for input from outside Europe´s Rail Joint Undertaking such as the Hydrogen Joint Undertaking 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 find the right balance. Technologies should provide 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*

IM's/RU's are primarily responsible for the collection of requirements. They also provide the required infrastructure for testing the feasibility of proposed solutions and the demonstration of results.

Suppliers are mainly responsible for developing and providing regional system solutions and tools based on the operating community requirements and specifications.

Research institutions are in charge of transferring results from the basic research and other research fields to required applications for regional railways as well as providing methods to both IM's / RU's and suppliers. They will support a development of technologies based on requirements from RU/IM and industry as well as any possible scientific or methodical issues that may arise during the execution of this flagship area and will participate in demonstrations (in particular evaluation of testing).

#### *7.6.1.5 Interaction with other Programmes, European and/or National*

The research and innovation activities considered within FA6 are expected to interact with other programs and initiatives at European and national level. This flagship area has interactions with two major programs. On the one hand, it is linked (input/output) to and interacts with the system pillar. It also interacts with 5Grail in the framework of the H2020 – ICT- 2020. The Future Railway Mobile Communication System (FRMCS) will define the worldwide standard for railway operational communications, conforming to European regulation as well as responding to the needs and obligations of rail organisations outside of Europe. The work on functional & technical requirements, specification & standardisation in 3GPP as well as regarding harmonised spectrum solutions is currently led by UIC, in cooperation with the whole railway sector.

In addition, there is a strong connection with the Hydrogen Europe JU for the perspective implementation of the alternative fuel on regional lines and with the BATT4EU for the possible use of battery powered light vehicles. Last but not least, FA6 takes into account national R&D programmes from e.g. France and Austria ("Mobilität der Zukunft", The Austrian Research Promotion Agency) which have been recently set up to launch R&D for regional railways or CCS deployment initiatives aiming to increase safety level of low-density lines like in Czechia.

### *7.6.2 Results/Outcomes*

#### *7.6.2.1 Operational solutions outcome*

The main outcome of this flagship area is a low-cost technical and operational framework for low density lines to reduce the cost per kilometer both in terms of CAPEX and OPEX as a well as an increase in customer satisfaction, which should be applied as an European solution. While the framework and provided solutions must be adapted to specific requirements of regional railways, their interoperability must 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 as well as safety and asset management. In addition, a passenger information system will benefit from the solutions available for mainline services while integrating data from regional railways with other modes of transportation and local services and offers added value for customers. The focus of the passenger information system is offering value added services through data integration. In case already available solutions do not provide the required functionalities a new passenger information system will be developed.

A regional system solution, aligned with SP, will be proposed to integrate developments from other FAs on infrastructure, CCS, TMS and vehicles as well as a data sharing and analysis platform.

This flagship area will also develop cost efficient components including wireless and energy self-sufficient infrastructure components to decrease the operational and overhead cost, standardized, modular railway stations as well as energy supply. Due to low density and lower capacity needs of regional lines compared to mainlines, a zero-emission vehicle concept for both passenger and freight tailored to regional lines will be also developed, e.g. modular, low cost light rail train – with well defined modules and their interfaces and ensuring interoperability.

To further optimize operations and reduce operational costs, tools and methods in the areas of predictive maintenance and asset localization will be put in 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 a European level, securing the scalability of solutions as well as added European value.

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| • **Low cost framework for regional/low density lines** | | | |
| ○ **Suitable Regional System Solution** | 6 | 7 | 8 |
| ○ **Cost efficient performing CCS system ( ATO, ATP, comms, TMS, IXL, positioning, train integrity)** | 6/7 | 7/8 | 8/9 |
| ○ **Optimized railways assets (field elements, SWOC, fueling)** | 7 | 8 | 8/9 |

| | TRL in 2025 | TRL in 2027 | TRL in 2031 |
|---|---|---|---|
| ○ **Sustainable Rolling Stock (light, cost-efficient, modular, flexible)** | 5 | 6 | 7/8 |
| ○ **Suitable customer services (PIS, congestion management)** | 7 | 8 | 8/9 |

*Table 41 - Overview over the operational outcomes*

#### *7.6.2.2 Technical enablers: capabilities to achieve the targeted operational outcomes*

In order to achieve the envisioned goals, several technical enablers must be provided including cost-effective, highly accurate/advanced train positioning as well as train integrity system, e.g. with satellite-based or fibre-optic based localization capabilities. Communication systems should enable the transmission of CCS data over to public operator services (such as Mobile Network Operators). To remove the cost of cabling and installed wayside equipment, elements such as object controllers and field elements will be radio connected and locally powered. Hence, Smart Wayside Object Controllers (SWOC) from 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 as well as autonomous or remote-controlled movements and virtual coupling. ATO should be able to detect obstacles on the track and be 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 output from the FA6 and assess the impact on current European TSIs (and where applicable national NNTRs regulations). The regulatory impact will be discussed together with the System Pillar to make suggestions on changes needed in-order to deploy the innovative technology.

While Flagship Area (FA6) will have to create various tailored solutions, it remains closely connected with the design and development in other FAs.

For this reason, the level of TRL in the different periods of the project is linked to what will be achieved in the other FAs. It is supposed that the minimum TRL of the indicated components are to be more or less equal to the corresponding one implemented in the original FA, also considering the effort for possible adaptation for the FA6.

It is crucial that FA6 provides the input to the other FAs based on the specific needs of low density lines. Similarly, FA 6 will also use inputs, like from FA TT, on conceptual data models and digital twins, as a common approach on definitions and processes to be applied on its specific uses cases. This approach will not only allow for being aligned in terms of technical enablers but it will also benefit from contribution from partners in other FAs. FA6 will provide the specifications for technical enablers 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 technical enablers (needed capabilities, which TRL will be when needed, link with other FA with alignment on TRLs). The development of technical enablers, TSI-revision plays a crucial role and needs to be taken into account.

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| Regional System Solution | **System specification for regional lines**<br>In the first step, overall System functional blocks and interfaces will be investigated in order to identify all the possible needs valid for regional applications in cooperation and alignment with System Pillar and the other FAs. The work includes analysis of effective deployment of interoperable radio-based ATPs (e.g. ERTMS/ETCS up to Level 3), following the most effective principles (e.g. centralized vs distributed architecture, train centrol principles,) that will allow to control and power wayside assets with the overall goal of reaching cost-effective solution (e.g. reducing cabling and wayside infrastructure).<br>Effective balance between rule-based safety and technical safety will be considered. Moving block and virtual coupling should be investigated in terms of application (pros/cons/impacts) and customization in a typical Regional Line. In the second step, following the consolidated requirements, the signalling functions will be integrated and implemented, including interfaces to interlocking and TMS. | 6 | 7 | 8 |
| CCS & Operations | **Interlocking / RBC for regional lines**<br>Interlocking and radio-based ETCS solutions adapted for regional line railways following SP evolution and migration plans.<br>Alignment with FA2 and SP needed. | 6 | 7 | 8 |
| | **ATO over ETCS adapted to regional operations**<br>Progressive evaluation and implementation of driver advisory systems / radio-based, all-weather ATO over ETCS up to GoA3/4 applicable and adapted to regional operations, including an obstacle detection systems. Aspects to be considered include energy savings, optimization of driving schedule and remotely controlled trains, especially, albeit not only, in shunting areas or last mile movements.<br><br>Scope of the FA6 work: limited to demonstrations + requirements to FA2 for regional specificities.<br>Link with other FA: | 5/6 | 7 | 8 |

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| | • all developments on ATO done in FA2 | | | |
| | **Hybrid L3, moving block** and relative braking distance<br>Scope of the FA6 work: limited to demonstrations, requirements and developments for regional specificities, in coordination with FA2.<br>Link with other FA:<br>all developments on MB done in FA2 | 5/6 | 7 | 8 |
| | **Cost-effective communications**<br>Cost-effective use of dedicated railway mobile networks or communication infrastructures owned by a third party (e.g. 4G,5G, satellite comms and IoT communications) for the innovative ways to exchange of the information between the regional railway subsystems (e.g. Train to Train, Train to Trackside – wayside assets, Trackside to Trackside). Special attention will be provided to aspects of multibearer platforms and their use (building on Shift2Rail results on ACS and FRMCS), transmission of vital CCS data over public networks, new communication service features and their application in regional railways and to cyber security aspects. The objective is to provide 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 for connecting rolling stock and wayside elements.<br><br>• Aspects related with dedicated railway mobile networks in the remit of FA2, and the rest including investigation of public networks on FA6 remit.<br><br>Scope of the FA6 work: limited to demonstrations, requirements and developments for regional specificities, in coordination with FA2. | 7 | 8 | 8/9 |
| | **Traffic Management Systems and C-ITS for regional lines**<br>Traffic Management Systems for regional lines improving resilience of a connected rail network, optimising train operations including disturbing events. Multimodal Timetables integration e.g. tactical planning through simulation and optimization with other transport modes to ensure multimodality via integrated management of rail and other services (buses, trams, metro, taxi, carsharing, | 6 | 7 | 8 |

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| | bicycles, P+R) from a single command post with the link of C-ITS services. Managing real-time on-demand optimized timetable, re-scheduling and route setting.<br>•<br>Scope of the FA6 work: limited to demonstrations, requirements and developments for regional specificities, in coordination with FA2 and FA1.<br>Link with other FA:<br>• All general development of planning systems within TMS is done in FA1 | | | |
| | **Cost-effective fail-safe highly accurate train positioning**<br>Cost-effective, interoperable, fail-safe, highly accurate train position based on among others hybrid, multi sensor (including GNSS, FOAS) technologies, digital maps, onboard database, as a mean to reduce balise installations, increase operational efficiency and decrease TCO in the context of regional lines.<br>• FA6 requirements will be submitted to FA2<br>• FA2 will develop the solution<br>• FA6 validates & applies the solution for demonstrator<br>• | 6 | 7 | 8 |
| | **Cost-effective fail safe on Board Train integrity**<br>Cost-effective, fail safe on board train integrity to verify the completeness of train while train is in operation.<br>• FA6 requirements will be submitted to FA2<br>• FA2 will develop the solution<br>• FA6 validates & applies the solution for demonstrator<br>• | 6/7 | 7/8 | 8/9 |
| | **Cost-effective fail safe Train Length Detection**<br><br>**Cost-effective, fail-safe train length detection to determine the beginning and end of the train and detect its length.**<br><br>• FA6 requirements will be submitted to FA2<br>• FA2 will develop the solution | 6/7 | 7/8 | 8/9 |

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| | • FA6 validates & applies the solution for demonstrator | | | |
| | **Wayside Elements**<br>Infrastructure components and wayside elements for regional railways including signalling, level crossings, switches and track vacancy detection which 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. | 7 | 8 | 8/9 |
| | **Smart Wayside Object Controller (SWOC)**<br>Further develop (if needed) the concept of Smart Wayside Object Controller (SWOC) from the Shift2Rail programme and apply it. | 7 | 8 | 8/9 |
| | **Digital platforms for CCS validation & TSI certification in the regional line domain.**<br><br>Technology infrastructures available to the actors involved in regional line APIS (Authorization for placing into service) processes will provide integral solutions to speed up related activities and reduce associated costs, with special focus on the application of digital certification in this line typology.<br><br>Inspired on *Zero on Site Testing* EC strategy these platforms aim bringing to a digital twin a range of CCS tasks in fields like design, testing, inspection, or maintenance tasks and processes…, including working conditions traditionally performed on-site at different life cycle phases. This will allow advancing potential integration issues at early stages of a project<br><br>Scope of the FA6 work: limited to demonstrations, requirements and developments for regional specificities, in coordination with FA2.<br>Link with other FA:<br>• All development is done in FA2 | 6 | 7 | |
| | **New propulsion train refuelling /recharging station**. | /6 | 6/7 | 7/8 |

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| | Alternative fueling solutions for regional railways such as hydrogen, e-fuels, battery fueling (dynamic and static charging). Activities should aim at developing solutions for road/rail fueling/charging stations along regional lines.<br><br>Scope of the FA6 work: limited to demonstrations, requirements and developments for regional specificities, in coordination with FA4.<br>Link with other FA:<br>• All development is done in FA4 | | | |
| | **Virtualisation in RS design**<br>Replacement of HW functions with SW and Electronics: Design oriented to replace Hardware functions (pneumatics, electro-pneumatics and mechanics) with Software and Electronics as this has positive impact on cost, including maintenance cost. in close relation / deriving from FA4 | 7 | 8 | 8/9 |
| | **Cost-efficient RS system design**<br>Overall Cost-efficient and modular RS system's :<br>• Specify & develop a concept of a light vehicle base and various modular concepts to be adapted for flexible rail passenger (up to 100 passengers) services with particular focus on the development of a light, modular vehicle architecture for interiors, allowing easy customization of lay-out, suitable for various operators and line characteristics as well as on-board information systems.<br>• Efficient Electric Motors: Direct drive and hybrid powertrain (battery and hydrogen) with high power density converters (possible reuse of FA4 technology, if relevant)<br>• Wireless solutions: Design oriented to reduce cabling, distributed both inside the Car and along the whole Train (reusing for demo purposes work already achieved in S2R IP1) | 7 | 8 | 8/9 |
| Customer Service | **Passenger Information System**<br>Passenger information system: comprehensive regional travel planning integration with ticketing services, multimodal transportation, external data sources (e.g. touristic data sources), holistic passenger information on-board and/or at stations: free seats info, bike racks, ride | 8 | 8/9 | |

| Cluster | Technical enabler | TRL | | |
|---|---|---|---|---|
| | | 2025 | 2027 | 2031 |
| | sharing, charging stations. This may contribute to additional work on the ontology networks that have been produced in previous Shift2Rail projects to align with CEN standards like Transmodel, FSM, ODSM, TRIAS, etc., as well as with the connections to National Access Points.<br>**High speed Internet access WiFi on train**<br>High speed WiFi access is the basic service and infrastructure for any further services (PIS, etc,...) on train. **(TE) cost-effective communication** requires synergies between this FRMCS passenger service infrastructure and the FRMCS infrastructure for critical and performance services. | | | |
| | **Congestion Rate Monitoring and flow optimisation**<br>Applications at Stations and Intermodal Hubs such as people & goods management and integration through gathering real-time flow data through advanced technologies (e.g. IoT, machine vision) for applications such as congestion Rate Monitoring and passenger flow. | 7 | 8 | 8/9 |

*Table 42 - Overview of Technical Enablers*

#### *7.6.2.3 Demonstration implementations*

Regional Lines connect rural areas to larger rail transportation hubs typically situated on main lines or urban areas, transporting both passengers and/or freight. They have typically, with some exceptions, low capacity needs. Regional lines can be grouped (notwithstanding different national line categories) according to their level of connectedness to the mainline:

- Group 1: Regional Lines with a significant connection to mainline traffic or to urban areas.
- Group 2: Regional Lines with no or limited connection to mainline traffic.

While group 1 has the same safety requirements as mainlines, group 2 can– due to the low-density and the traffic patterns might have reduced interoperability and safety requirements, when allowed by national and European rules, which can lead to different traffic management (radio systems and CCS functionalities) as well as rolling stock specification than those in group 1. Due to interoperability and compatibility requirements of connected regional lines (group 1) with main line, this group offers more potential to develop a European solution with added value. On the other hand also *group 2* lines brings an EU value added until the solutions are scalable and ensure standard interfaces with other FAs components (e.g. the simplified TMS in *group 2* should respect the protocols defined in FA1 to exchange data with the larger TMS controlling wide geographical networks). The approach and developed prototypes can be demonstrated in several locations different geographically. In this way several Issues can be addressed and demonstrated simultaneously, among others:

- Demonstration of the feasibility of proposed technical solutions

- Issues regarding operational adaptation of the proposed solution in different settings
- Demonstration of the possibility of scaling up as a European solution

The aim is to demonstrate all solutions under real operational conditions in different regions in Europe. The regional railways used to demonstrate the results under real operational conditions in FA6 may be also used for other demonstrators with the main focus in other FAs. Hence, a strong involvement of all relevant actors (RU/IM, industry and R&D) is crucial.

Demonstration under real operational conditions (at high TRL) is crucial for checking the 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 migration plans to the new solutions.

The following table[13] gives an overview of timeline for demonstration implementations. The demonstration which have been defined for 2025, 2027 and 2031 respectively for both Group 1 and Group 2 of Regional railways:

Since several technical enablers depends on the output of other FAs, the demonstration plan has also link with the other FAs, in particular on the TRL implementation level as FA6 will need to integrate in infra/RS assets those enablers for the demonstrations.

| Demonstrator | 2025 | 2027 | 2031 |
|---|---|---|---|
| **Demonstrator cluster 1**: regional lines with significant connection with mainline (Group 1)<br>Based on the current TSI CCS and ERTMS specifications **(TE)[14] System specification for regional lines**, but also using technological developments and new specifications coming from other FA and System Pillar, which might be introduced in upcoming TSI CCS and OPE updates, this cluster will demonstrate how these technologies can be used in European regional/low density lines connected to main railway network to reduce the Total Cost of Ownership. Topics include but not limited to:<br>- Use of radio-based ETCS with special focus on field element reduction (e.g., signals, track circuits, etc.), supported by **(TE) Hybrid L3, moving block and relative braking distance**<br>- Use of (**TE) ATO over ERTMS adapted to regional operations up to GoA4** to optimize energy consumption and achieve higher punctuality | 5/6 | 7 | 8 |

[13] The aim of the FA6 demonstrator is to integrate and to characterize 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 the demonstrators requires an accurate analysis of the systems/products developed in the related FAs, of the TRLs and their suitability to be implemented in the Regional framework. So the final definition of the demonstrators and of the related essential and necessary implementations, is expected to be produced once this analysis is performed.

[14] Technical Enabler

| | | | |
|---|---|---|---|
| - Use of (**TE) cost-effective fail-safe train positioning** system and virtual balise concept based on e.g. hybridation of sensor including GNSS to minimize the use of Eurobalises<br>- Use of cost-effective multibearer platforms radio communication technologies **(TE) cost-effective communication)** allowing the transition towards future FRMCS specifications for critical, performance and passenger services, but also wireless connection with several field elements<br>- Apply harmonized and simplified operational rules coming from System Pillar allowing a significant engineering cost reduction<br>- Use of **(TE) Interlocking / RBC for regional lines** explore new architectural and technological proposals such as interlocking/CCS virtualization, not forgetting its applicability and migration path for regional lines and current installed base<br>- Interface of the solutions with TMS to explore the benefits of multimodality, dynamic regulation, smart conflict resolution,etc. in line with **(TE) Traffic Management Systems and C-ITS for regional lines.**<br>- Apply concepts of CDM and Digital Twins in the Project Life Cycle to ease the exchange of information between stakeholders, data preparation, validation and testing **(TE) Digital platforms for CCS validation & TSI certification in the regional line domain**<br>- Implementation of a digital process of Data Preparation, Validation, and Operational and ESC testing **(TE) Digital platforms for CCS validation & TSI certification in the regional line domain.**<br>- Explore energy self-sufficient and/or wireless enabled components for **(TE) wayside elements**, and/or applicability of **(TE) Smart Wayside Object** Controllers<br>- Use of **(TE) Passenger Information System** to offer added value services and increase attractiveness of regional railways<br>- Use of **(TE) cost-effective fail safe on board train** integrity to ensure integrity of the train.<br>- Use of **(TE) cost-effective fail-safe train length** detection to detect train length. This can be used among others for autonomous operation of wayside elements such as level crossings to reduce TCO.<br>- Implementation of a cost-effective solution for sending Level Crossing status information to the ETCS Trackside | | | |
| **Demonstrator cluster 2:** regional lines with no or limited connection with mainline (Group 2)Regional lines in cluster 2 requires the strongest reduction of CAPEX and OPEX costs (-40%). For this reason | 8 | 8/9 | |

| | | | |
|---|---|---|---|
| a more aggressive approach toward simplification is needed addressing the interoperability<br>Such aggressive approach is also possible thanks to the fact that there is no need of interoperability since the trains to be managed does not exit these regional lines<br><br>Key elements include but are not limited to:<br>- A simplified architecture to be added to the System Pillar architectures. Such architecture may be different from the interoperable one of the main network only where it gives a real added value supported by business case analysis (otherwise other FAs results/solutions will be used). **(TE) System specification for regional lines**<br>- The demonstrator will guarantee a standardization, respecting also protocols and interfaces to exchange data with the systems deployed in the Main lines (keeping full alignment with other FAs and the System Pillar): e.g. 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 envisage both the primary traffic management based on the rail system and the connection of the rail traffic management to the already established regional mobility centre<br>- “Zero” wayside equipments (with the exception of wireless controlled switches) **(TE) wayside elements**<br>- Energy self-sufficient components which do not need an external power supply and/or cabling for power transmission. **(TE) wayside elements**<br>- Low cost train positioning based on radio technology (GNSS, xG etc.) (**TE) cost-effective fail-safe train positioning**<br>- Low cost wireless communication including public networks **(TE) cost-effective communications** for FRMCS critical, performance and passenger services.<br>- Tailor-made & integrated regional interlocking / ATP system to specifically address the requirements of regional railways in a moving block signalling environment **(TE) Interlocking / RBC for regional lines**<br>- Autonomous or remote controlled movements e.g. shunting and last mile to reduce operational costs and human intervention | | | |
| **Sub-Demonstrator**: modular light rail vehicle / jointly integrated into Cluster 1 & Cluster 2 demonstrator<br>• Concept of modular (light) rail vehicle architecture with alternative propulsion system **(TE: light, flexible and modular vehicle)**.<br>- Application of a force-flow optimised modular lightweight design | 7 | 8 | 8/9 |

| | | | |
|---|---|---|---|
| - Implementation of a system for **(TE) multimodal on-board facilities** & personal thermal comfort<br>- Testing of weight and track force reduction, while being tolerant to higher unevenness of the tracks<br>- Demonstration of **(TE) cost-efficient and modular RS system design:** effective wires reduction on Train together with effective reduction of the pneumatic components, replaced by Electronic and Software functions.<br>- Demonstration of Safety and in particular demonstration of no jeopardization of Safety.<br>- Finally, demonstration of effective cost reduction due to above mentioned innovations.<br>- **TE: Virtualisation of HW functions**<br>- An early mock-up demonstrator could be available by 2025)<br>- **TE: New propulsion train refuelling /recharging station**. | | | |

*Table 43 - Link of the demonstration plan with the TRL implementation level.*

The locations for the test lines for demonstrator clusters 1 and 2 are to be chosen in the way guaranteeing geographical balance. This, in connection with the vehicles matching the needs of the demonstrator cluster 3 will enable simulations of various scenarios and a cross-testing under different socio-economic conditions.

### *7.6.3 Impacts*

#### *7.6.3.1 Description of the impacts against existing rail services*

Regional railways provide an important public service in terms of transportation and providing 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, associated costs must be reduced and its economic viability and competitiveness enhanced. The development of technological and innovative solution using ICT and other mainstream and emerging technologies makes operation of regional railways more cost efficient. The developed technologies and tools should not remain limited to regional railways. They also may find application in mainlines and reduce the overall cost of operation and investment. We expect to reduce the cost even further by decreasing the required field staff through digitalization 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 and hence their attractiveness for customers.

This Flagship Area will have a positive impact on competitiveness, sustainability and life-cycle costs.

The challenge is, as highlighted in the chapters above the status quo requiring innovative solutions to improve the state of the art safety, for attractive customer solutions – resulting into affordable LCC, hence more customers & more frequent services.

| | |
|---|---|
|  | Meeting evolving customer requirements<br>FA6 development such as new vehicle design and cost- efficient signalling system will enable to improve the safety, the performance and the capacity of the existing lines while making the solutions more affordable for the customers. The services with the TMS system will adapt based on the request demand and provide a better quality of service. |
|  | Reduced costs<br>The main goal of this flagship area is to ensure the long term competitiveness of regional railways by ensuring their economic viability and reduction of costs. The main indicator of success is to reduce the total cost of ownership per km which should not include only implementation costs (CAPEX) but also operational costs (OPEX).<br>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<br>While revitalizing the regional rail services, it will support that people and goods would be transported by more sustainable means of transport. It would reduce the CO2 end exhaust emissions of transport sector at European level. The technologies defined will improve the energy performance of the system by introducing lighter and more adapted Rolling Stock designs for the regional services. |
|  | Reinforced role for rail in European transport and mobility<br>The revitalization of regional lines is relevant to support a sustainable solution of the multi-modal transport mobility. This will enable achieving economies of scale and lower costs, as well as create seamless links with the rest of the rail network and other modes of transport. It will create competitive solutions by providing more affordable and attractive solutions for the passengers while adapting the services to meet the required demand. |
|  | Improved EU rail supply industry competitiveness |

| | |
|---|---|
| | The Sustainable and Smart Mobility rail objectives require not only a transformation on the Trans European Network, but across the whole rail network where rail services are sustainable. These lines cement social cohesion and inclusiveness, enable public transport to touch a high number of the population and give opportunities for businesses to emerge everywhere across Europe. A coherent, unified, interoperable vision of how those capillary lines will seamlessly connect with the rest of the European network and with other modes of transports is needed. |

*Table 44 - Descriptions of FA6 impacts related to the intended impacts in the Master Plan*

#### *7.6.3.2 Quantitative KPI demonstrated in this FA*

To ensure delivery of the aforementioned impacts, close monitoring will be implemented using key performance indicators (KPIs). The definition of the KPIs will also take into consideration possible frameworks from which to extract the relevant indicators needed.

Within FA6 a set of High level KPIs has been identified, targeting the main impacts foreseen for the flagship area. It is worth noting that intentionally, KPI’s related to other FAs enablers to be used in FA6 are not considered to avoid overlaps and misalignments. The Baseline for KPI is 2018-2022, considering the need to neutralize the C-19 impact and subject to availability.

**Demonstrator 1 & 2: Regional System Solutions, CCS & Operations and Regional Railway Assets**

- Reduced CAPEX of the CCS system, while maintaining or increasing the present safety level:
    - Expected decrease by targeting 25%.
- Reduced the CAPEX of radio network and allowing for higher savings due to the utilization of public radio network in low density lines:
    - Expected decrease by targeting 15%.
- Increased system availability due to reduced trackside asset failure and more reliable CCS (Average delay minutes per assets and singalling failures):
    - Expected increase by targeting 10%.
- Reliable cost-effective fail safe on board train integrity, train length detection and train positioning:
    - Increased reliability by targeting 15%, reduced OPEX and CAPEX by targeting 15%.
- Optimized energy consumption and higher punctuality through ATO over ERTMS targeting GoA4:
    - Expected decrease of energy consumption targeting 10%, increased punctuality targeting 15%.
- Reduced OPEX costs/km (reduction expected due to trackside asset decrease) for trackside railway assets:
    - Expected reduction of targeting 30%.

- Increased energy efficiency for trackside railway assets (as part of the OPEX saving above, not to be added on top):
    - Expected increase by targeting 15%.

**Sub-Demonstrator: Rolling Stock & Customer Services**

- Reduced vehicle CAPEX & OPEX through innovative, modular and lighter design. The vehicles for low-density lines must be designed to deliver the service at these lines at a significant lower CAPEX/OPEX:
    - Targeting 50% reduced CAPEX and OPEX, in a LCC perspective.
- Notwithstanding the previous KPI, passenger vehicles development should aim for step changes in weight reduction and track force reduction, while being tolerant to higher unevenness of the tracks:
    - up to 60% of weight reduction.

It should be noted that the KPIs need to be estimated in advance of the implementation of the innovations, and thus a forecast is needed. Effects will be constantly quantified during demonstrator projects and the effects on a European broad scale will be measurable after 2030 once the technology is deployed. In order to set the right priorities, it must be clear how the KPI improves after utilization of technologies compared to the current operations of regional railways KPIs need to show how regional rail services as a whole will be transformed to significant lower costs.

#### *7.6.3.3 Exploitation, deployment and migration considerations*

Utilization of new technologies developed, demonstrated and validated in FA6 will benefit infrastructure owners, operators as well as travelers and freight customers. This will be demonstrated in use cases for new and yet untried signalling systems that are safe and that can support cost-effective services, traffic management that is flexible with remote controlled meeting stations, track constructions that are tailored to the history and the needs of these types of lines. Vehicles and digital solutions that are suited for low-density rural lines with low OPEX and CAPEX and still attractive to end customers.

FA6 will build on R&I conducted in other flagship areas and in collaboration with them seek solutions that are simpler more affordable whilst at the same time meeting the safety requirements that apply to railways. Solutions should be up scalable or use down scaled main line solutions.

Implementation of the technologies, tested and tried in FA6, takes place in several different ways. Manufacturers of tracks, switches, signal safety systems and vehicles will be able to offer operators and infrastructure managers new products with lower system costs that match customers' expectations and willingness to pay.

The FA6 demonstrators should also be seen as the early implementations of the new system approach following the 2027 TSI revision where the FA6 outcomes may be embedded. In such a way the proof of the viability of the new solutions can be performed and an accelerated migration will be enabled. This will also be supported by a set of proposals for an update of relevant standards reflecting upon the new regional system approaches and the concept of modularization.

On the side of RUs the deployment will thus not only take place when operators procure new vehicles but also in the connection 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 seek actively cooperation with roll-out funding such as CEF to ensure that solutions will be timely rolled-out.

## 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 the future mobility in a multimodal context, as presented in the ERRAC Rail 2050 Vision[15]. Furthermore, it foresees that new opportunities for radical changes in the transport system will appear. 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 including full integration with other modes of transport. The foreseen changes include even totally new types of railway-based transport, such as ultra-high-speed trains and/or personalised vehicles or "*transport vessel*" (hereinafter referred to as a *Pod*) capable of being transferred across modes via *Pod Carriers* based on e.g. rail, road, water and even air transportation. Two symbolic examples are a *Pod*-based passenger system and vacuum-tube based freight system shown in artists views in Figs. 1 and 2.

*Figure 14 - Concept for a „Multimodal Mobility Hub"-based on Pods by Siemens Mobility (Fig.: Siemens)*

*Figure 15 - Vacuum-tube based freight system (Fig.: Virgin Hyperloop)*

[15] ERRAC Rail 2050 Vision

The objectives of FA7 is to explore non-traditional and emerging flexible and/or high-speed guided transport systems, as well as to create opportunities for innovators to bring forward ideas for shaping those future systems via a scientific approach into an existing rail system. This shall provide socio-economically efficient and long-term sustainable transport for citizens and businesses throughout Europe. The main aspects for such systems are the reduction of energy consumption, noise and pollutant emissions and land consumption, the use of sustainable raw materials and energy sources and the sustainable use of existing infrastructures. This work will create the opportunity to recognise that innovation is vital and economically relevant for the evolution of rail transport and mobility, concretely via engaging and responsibly generating new ideas, preserving technological neutrality with a due diligent and consistent programme approach. This includes identifying the solutions to the key obstacles and estimating the appropriate time and resources that can support the evaluation of feasibility and development of such emerging concepts.

The vision of the FA is to develop the next generation of railway transport systems as well as guided transport systems based on a fully automated multi-modal mobility system for passengers and goods which is sustainable, interconnected, digital, on-demand, standardised, scalable and suitable for all transport modes. It should consider the actual needs of the end user and the actual traffic situation across different modes (Fig. 3 shows an example of this idea). While FA7 is generally open to all innovation on new approaches for guided transport modes, the focus will be on solutions which allow higher flexibility through multi-modality such as a transition to intermodal-connected moving infrastructure by centrally coordinated, innovative purpose-built vehicles and on ultra-high speed energy efficient and environmentally friendly train systems. Any innovation in FA7 needs to fulfil the requirement of being an Open Platform, based on common standards and standardised interfaces, connecting all the transport modes, and be able to provide disruptive Operation and Business Models.

*Figure 16 - Use Case “Living & Working” (Fig.: Siemens)*

The innovations shall be able to provide seamless operational and physical integration between modes of transport. This is what is herewith proposed, as one of the keys for the future mobility networks to a reliable and convenient passenger and freight transport, which remains the backbone of sustainable urban and rural area development. It provides safe, sustainable, energy efficient and affordable low noise mobility options day or night for everyone and ensures easy accessibility.

Maximum convenience through a unique journey and maximum reliability of the journey by the usage of all available transportation modes with "*Moving Infrastructures*" are advantages for passenger and freight transport brought forward by FA7 in a future where climate adaptation will be required to establish a robust railway system. Further, the adoption of higher speed technologies such as maglev-derived and vacuum tube systems (eventually in superposition to and/or in synergy with the railway infrastructure) can pave the path to an upgrade of the railway and mobility network allowing high-quality connections among cities and towns, not only along high speed railway corridors, but also along current secondary lines, fostering socio-economic development and territorial integration of the concerned areas, towards a single European mobility area. This will provide the grounds for a modal shift from private to public transport for passengers and a road-based to multi-modal means of transport for freight.

As a result, positive effects on the environment are foreseen, as the journey will be fully decarbonised and a reduction of land usage can be reached through a more efficient exploitation of the railway resources. By taking the challenge of developing a new balanced, organised and well worked-out transition, in eight to ten years a maximum efficiency can be achieved. An increased degree of automation in terminals, ports, logistic centres, parking facilities, and at borders will contribute to a more efficient freight handling, fewer operational error and reduced costs. The integration of railway with other modes of transport and the combination of passenger and freight traffic will create the new 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 based on disruptive modes like moving infrastructures, *Pods*, magnetic levitation, air levitation, and vacuum tube technique bring a lot of advantages and can be an important and possibly unavoidable component of the mobility of the future. However, like most disruptive technologies, this may bring possible gaps and associated risks that should be addressed beforehand for the system to be most effective

Firstly, a technological maturity is more difficult to reach for such innovative systems compared to the evolution of existing systems. For example, even though being disruptive in its operational concept, *Pods* as transportation units allow for a TRL up to 7-8 because of their adjustment to the existing railway infrastructure. The same holds for maglev-derived systems, while for vacuum tube vehicles, being the most disruptive technology, development up to TRL6 level is possible. In terms of operations and traffic coordination of the innovations in FA7, simulation tools will be most valuable to develop guidelines and to evaluate their performance, as the full systems will not be operational, to have real-world tests. Therefore, a TRL up to 5 can be foreseen.

Additionally, in due time there needs to be migration plans established to secure running operations in transition periods. One of the challenges here are to convert the existing land use and infrastructure from today's modes and railway mobility to future solution. A practical solution has to be found to create an implementable transition as new techniques are needed in the nearby future. New techniques must connect one way or another to the existing daily train operation system for the purpose of constructing sustainable intermodal transportation and robust transportation lines. Since these new forms of transport require large investments in infrastructure, the initial demonstrators are preferably replicated - via an agile approach - on a small scale to assess the POC (proof of concept) and the overall feasibility of the solution.

Further, if this system is foreseen to be used across Europe providing a sustainable and seamless means of transport for a connected EU, technological aspects emerging from the cross-border transport issues should be addressed.

Secondly, as the technologies tackled in FA7 are rather disruptive, still a lot of gaps related to creation, establishment and consolidation of legislation are open. A delicate balance needs to be found between having the technologies mature enough to define standards and regulations and setting up a regulatory framework as soon as possible to ensure that the developments fit the required legislation in matter of safety and to obtain the 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, operations legal framework, interoperability and standardisation, and evaluation of conformity, including certification. For instance, "*Pods*" are multipurpose elements that share the risks derived from the regulatory status of autonomous vehicles as can be seen in Fig. 4. The adoption by the EU of the regulation Addendum 78: UN Regulation No. 79 for the development of autonomous vehicles can be a boost for adaptation of the legislation to technological synergies in this field[16].

[16] 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: UN Regulation No. 79, Revision 3. 14 September 2017.

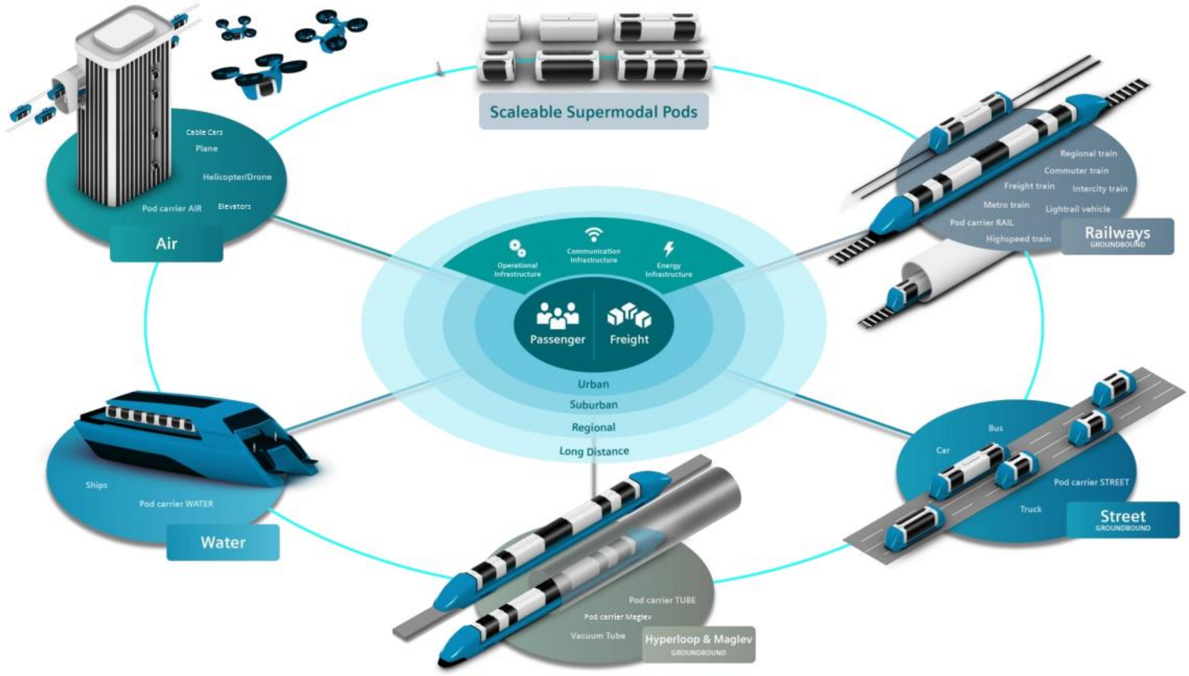


*Figure 17 - Concept for Podimised Multimodal Mobility (Fig.: Siemens)*

Also, there are still gaps to cover in relation to standardisation. CEN and CENELEC announced recently the launch of a new Joint Technical Committee, CEN/CLC/JTC 20, dedicated to vacuum tube technique (known as "Hyperloop") systems standardisation. But until 2023 there will not be a first normative base nor a certification model. And the regulatory bases of the certifying entities and security entities are yet to be defined. One of the members of ADIF/CEDEX candidature is in fact the President of the Hyperloop Spanish Technical Committee of UNE (Spanish Standardisation Body) and he is the head of the Spanish delegation in all the meetings celebrated by the CEN JTC-20, where e.g. also Trafikverket is represented. Therefore, the cooperation between CEN JTC-20 and EU Rail JU is guaranteed and all the progress done in this Technical Committee will be taken into consideration by Europe's Rail JU.

And thirdly, there are several difficult issues linked to the sustainable construction of intermodal transportation and/or robust domestic or cross-border transportation lines. They are for example: (i) how to handle many different domestic legislative and national processes on how to change land-use or implementing changes in the infrastructure of the European railway system; (ii) the choice between the need for transportation by e.g. hyper-speed, and other need of the local, regional, national or European society, and also (iii) how the way of transportation will cope with the coming climate changes.

#### *7.7.1.2 Innovation beyond state of the art, including integration of S2R results*

This FA starts from several references and results coming from S2R and EU research and innovation programmes.

Because of the technology 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 into the desired goal. Nevertheless, there are a couple of results from Shift2Rail as well as from other projects outside Shift2Rail, which are likely to be used within the scope of FA7. Those include, but are not limited to:

- Results from Shift2Rail:
    - Development and demonstration of energy efficient drives, alternative energy supply with batteries and fuel cells etc.
    - Development and demonstration of ATO, Virtual Coupling/Platooning, etc. as well as integrated Information systems for passenger services
    - In2Rail[17]: Smart Infrastructure, Intelligent Mobility Management (I2M), and Power Supply and Energy Management Systems
    - X2Rail3[18] and MOVINGRAIL[19]: Virtual Coupling
    - RAILS - Roadmaps for A.I. Integration in the Rail Sector[20]: Artificial Intelligence approaches in the rail sector; roadmaps for next generation signalling systems, operational intelligence, and network management
    - IMPACT-2[21]: Future needs, markets, trends and customer requirements analysis, key obstacles finding, development and assessment of trends and scenarios, creation of system platform demonstrators
- The emergence of enabling technologies, such as artificial intelligence, the "internet of things", robotics, vehicle-to-vehicle and vehicle-to-infrastructure communications, autonomous driving and block-chain will provide a wide range of possibilities for innovation in the rail system and to change the way it operates. The way of success is related to the flexibility, practical implementation power and average high efficiency of the proposed key elements, while integrating the development and deployment of other innovative vehicle combinations which follow the same objectives in a complementary manner.
- Interdisciplinary projects including the InSecTT project[22] (Intelligent Secure Trustable Things (Internet of Things and Artificial Intelligence)), i4trust[23] (Boosting innovative services around new data value chains in multiple sectors) and SNCF tech4Mobiliy (New collective and shared mobility solutions, with focus on ultralight modular trains and door to door trains for sparsely populated areas).
- Several concepts for small railway units in the sense of the Pods discussed in the transforming project TP8 "Non-traditional and Emerging Transport Models and Systems" of the SRIA[24] have been presented recently with separate Pod Carriers for

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17 Innovative Intelligent Rail European Project (In2Rail, GA ID: 635900) (2015) [Viewed: 7/7/2020] Available at: www.in2rail.eu/www.in2rail.eu/

18 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) Available at: https://projects.shift2rail.org/s2r_ip2_n.aspx?p=X2RAIL-3.

19 Moving Block and Virtual Coupling Next Generations of Rail Signalling (MOVINGRAIL, GA ID: 826347 ) (2019) Available at: https://movingrail.eu/.

20 Roadmaps for AI Integration in the Rail Sector (Rails, GA ID: 881782) (2019) Available at: https://projects.shift2rail.org/s2r_ipx_n.aspx?p=S2R_RAILS

21 Indicator Monitoring for a new railway Paradigm in seamlessly integrated Cross modal Transport chains – Phase 2 (IMPACT-2, GA ID: 777513) (2017) Available at: https://projects .shift2rail.org/s2r_ipcc_n.aspx?p=IMPACT-2.

22 Bringing Artificial Intelligence and Internet of Things Together (InSecTT, GA ID: 876038) (2019) Available at: https://www.insectt.eu/

23 Incubator of Trusted B2B Data Sharing ecosystems of collaborating SMEs linked to Digital Innovation Hubs (i4Trust, GA ID: 951975), Available at: https://cordis.europa.eu/project/id/951975

24 Rail Strategic Research and Innovation Agenda (SRIA), December 2020.

different infrastructures e.g. by Siemens[25] , Doppelmayr[26] , A-Train[27], DLR[28] or as integrated solution, e.g. by Max Bögl[29] or RWTH Aachen University[30].

- The Hypernex project[31] is a clear reference for the vacuum tube technology. It delivers an observatory to clarify who does what in Europe, considering the vehicles, infrastructure, energy supply and management, communications, levitation technology, and what are the minimum common understandings for Hyperloop in terms of inter-modality, urban development, long distance development and integration in existing infrastructures. Hypernex also compiles the available technical information, which will allow to analyse the different scenarios that may arise during the start-up process of new transport technologies, including the vision of safety and operation.

Furthermore, one major task in FA7 will be the continuous scouting for new potential solutions that can fulfil the objectives of the flagship area. A mechanism to have a structured process for scouting should be considered for each project of FA7. Such project based mechanisms can be complemented by an overarching mechanism through e.g. a dedicated tender or a working group in the Scientific Committee.

#### *7.7.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

As FA7 is focussed on innovative systems with a lower TRL, the interaction with other FAs is less intensive. Also, because of the openness of FA7, the interactions with other FAs cannot specifically be identified, yet. Nevertheless, there are certain topics for which an alignment between FA7 and some other FAs is pretty likely. With FA1 a cooperation about the introduction of the specific capabilities of the innovative systems in the overall TMS will be needed. Further a close link to FA2 is expected as it is foreseen that a number of technologies developed in FA2 will be used for solutions developed in FA7 and are likely to need adaptions. For example, as long as the solutions targeted in FA7 are operating on regular lines, they are under control of the DATO from FA2 or DATO and virtual coupling would need to be adapted for high-speed solutions. Additionally, to integrate FA7 solutions into a holistic mobility approach, constant alignment with FA5 and FA6 will be needed.

Naturally, there will be also a connection to the System Pillar, which will define requirements and architectures to be used in FA2 and hence for the FA7 solutions.

Nevertheless, the strongest connection of FA7 will be established with the Exploratory research. A direct link to the Exploratory research needs to be ensured, so that recent developments or results from projects will be taken into consideration as soon as possible.

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[25] Future of multi-modal mobility: One4All Pod system, SIEMENS, available at: https://www.youtube.com/watch?v=jDc5MSqI7JU&t=158s

[26] Future urban concept, Doppelmayr, available at https://www.youtube.com/watch?v=bUKgkLSsAWI

[27] A-Train: http://www.railahead.nl

[28] Futuristic vehicle concept, DLR, available at https://www.youtube.com/watch?v=ZJtopEtaGeU

[29] Die Zukunft des Nahverkehrs (TSB) (The future of public transport), Max Bögel, available at https://www.youtube.com/watch?v=hwz2aaaSrvM

[30] Institut für Schienenfahrzeuge der RWTH Aachen: Artikel (rwth-aachen.de)

[31] Ignition of the European Hyperloop Ecosystem (Hypernext, GA ID: 101015145) (2020) Available at: http://hypernex.industriales.upm.es

*Details of the exchange between the Flagship Areas can be found in Annex B*

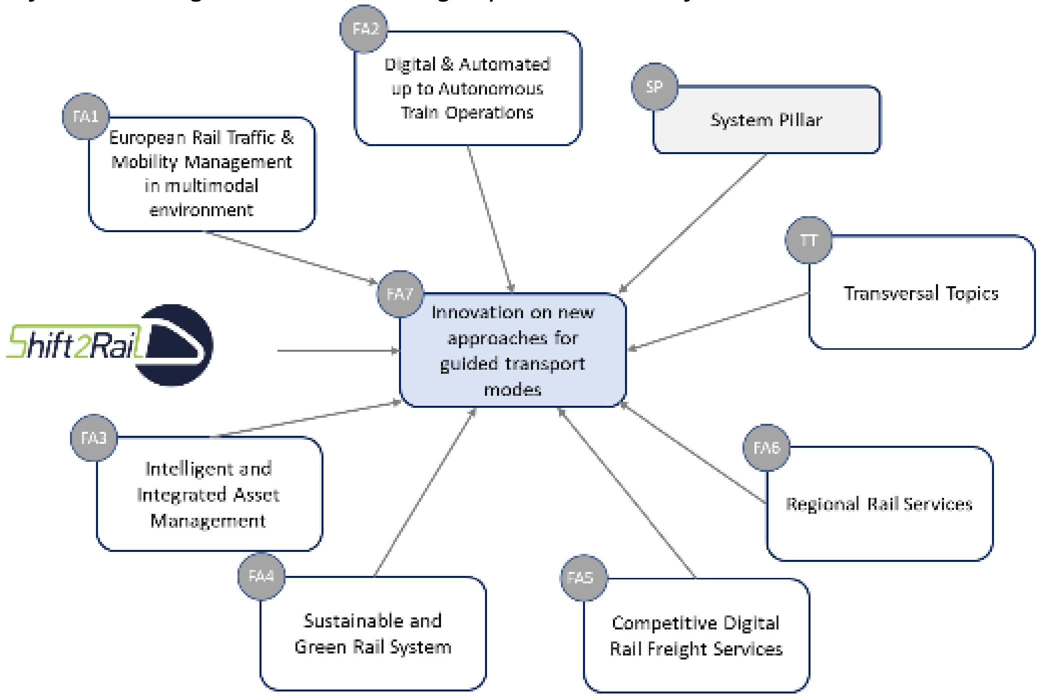



*Figure 18- Interaction with other FA, TT and SP*

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

At the latest by 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:

- As early as possible, the System Pillar and each Flagship Area will review together Annex A to facilitate the ramp-up phase of the future activities;
- The two Pillars will interact in a closely synchronized 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 on the granularity of the

architecture and resultant specifications and associated system outputs to be delivered by the Programme.

*Details of the exchange between the Flagship Areas can be found in Annex B*

The advanced solutions developed in Flagship Areas will be ultimately integrated to implement innovative operational processes at the Rail System level. The availability of digital representation of Rail System with its constituting elements expressed in Data makes it possible to integrate Flagship Area results in a convincingly cohesive manner.

Therefore, the Flagship Areas generate a set of requirements and specifications of the data resources needed for

- System Integration
- System Interoperability and
- application processing inside the Flagship Area

These data resource specifications are developed according to guidelines established by System Pillar at the overall Rail System architecture level, and by TT in terms of

- Conceptual data model,
- reuse of common foundation libraries of digital models
- Cyber Security provisions

The common tooling developed by TT on the basis of these specifications will be used by Flagship Area 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 share in research and innovation of the IMs and RUs can essentially be seen in the following points:

- 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 help with collection of requirements and the demonstration of results, try to carry out safety analysis for authorizing bodies, and testing the developed products
- analysing the interoperability as a service to ensure a fluent continuity of services for the passengers and cargo, maximizing intermodal connections with other transportation systems, such as planes, cars, local public transportation, and other freight and delivery services

On the part of the suppliers, the following points are seen in the context of research and development activities:

- research and development of the relevant hardware and software components
- design, construction, and production of the necessary prototypes
- equipping the test modules with the necessary equipment

The following points may be relevant for all parties involved, including the research institutions:

- participation in studies in the field of feasibility, profitability, technology and standardisation etc. (e.g., identification of the technical as well as regulatory aspects to be standardised for a fully automated "Moving Infrastructure", preparation of first concepts for their standardisation process)
- developing a viable and risk-free transition strategy
- definition of scenario simulations e.g. of transport coordination systems
- definition and compilation of the safety and test specifications
- standardisation of technical as well as regulatory aspects, incl. approval process
- definition of the test sites, test procedures and test setup design and implementation
- active involvement and securing of the relevant site tests
- training of the relevant personnel for the test execution
- compilation of the test results and test report
- evaluating impacts on assets, investments, on operations, on the normative/regulatory framework and on the organisation and the processes of the railway system based on technical results obtained from tests
- involving relevant stakeholders, especially among national/regional/local institution to disseminate the technical evolution of mobility solutions and evaluate jointly the possible implementation of the most mature innovative ones and, eventually, related migration plans and the evaluation of socio-economic impacts and economic development induced by the insertion of technology in the territory

#### *7.7.1.5 Interaction with other Programmes, European and/or National*

As already described in Chapter 1.1.2 there are several national and European projects and programmes related 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 are:

- Spain plans to promote in the next years *(2022-2029)* the construction of a vacuum-levitated hyper speed test track at a reduced 1:2 scale. *The length of this test track will be around 4-5 kms and it is expected to reach a speed of 600 km/h*[32]*.* The ADIF/CEDEX Hyperloop test track, is planned to be made available to EU-RAIL JU for testing auxiliary systems developed by EU-RAIL JU partners on the "vacuum tube technique trains" topic.
- The Norwegian Hyperloop test site will be implemented in Trondheim, Norway. Length of the test track is 140 meters. It can be used to test vehicles but also different

[32] National Spanish Hyperloop program

environmental materials such as aluminium along the track. It will be made available too, to other projects.

- Air levitation carrier[33] (A-train) scaled tested technique in laboratory at Dutch technical universities. Floating on pressed air running on existing infrastructure construction with extra concrete plates between the rails and on the existing concrete sleepers is possible to reach high speed train connection. Demonstrator carrier on real scale is proposed by the Netherlands and to be built at Railcenter, in Amersfoort, the Netherlands. This test-field can be used by all EU Rail JU parties as an open platform.
- Dutch Pods design for combination of freight (e.g. super express postal packages in a few hours) and passengers within operating passenger trains of today. Turboplan2020 investigate to use seats/passenger space, while these seats are mostly not occupied during the full day, for freight Pods transport[34].
- Italian railway test ring of Bologna S. Donato and related assets. On the Italian test ring full-scale testing (in stages/phases) of the upgrade of existing railway infrastructures with maglev-derived technologies would be possible.
- Siemens Test Ring Wegberg-Wildenrath contains 28km of test tracks in two loops and three test tracks and is open to innovative test projects as e.g. in the past the Cargomover initiative or FlexCargoRail.
- The German test site "Digital Rail Living Lab" in Saxonia is as well open to innovative projects as e.g. shown with the remote control and hybrid level 3 tests in the past.
- Hyperloop Development Program[35] is a public-private partnership in the Netherlands. Open platform (e.g. HARDT is involved). First start will be 2022 in Groningen, the Netherlands.
- The European Innovation Council has awarded October 2021 Hardt Hyperloop[36] with €15M as Brussels' first-ever hyperloop investment package and is based on the Dutch Hyperloop Development Program. The funding from the @EUeic will accelerate the development of a fast and cost-effective, pan-European, emission-free hyperloop network to supplement cars, trains, and planes, and decarbonize mobility. It also enables the realization of the European Hyperloop Center, to achieve its first test in 2023. Public sector leadership is essential for the hyperloop to become reality. This endorsement from the European Commission is a great acknowledgment for the hyperloop as a sustainable alternative for transportation, and will therefore be a tremendous accelerator to help secure additional backing and support from local and national governments across Europe and beyond.
- Land bridges dimensioned for 360 km/h (up to 435 km/h) with prefabricated elements are being developed in Sweden[37].

### *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

[33] www.youtube.com/watch?v=0zNxBxFD7K4
[34] https://mission-innovations.com
[35] https://hyperloopdevelopmentprogram.com
[36] https://hardt.global
[37] Trafikverket, "Rambroar – ett koncept för industriell byggd landbro och längrebroar", ("Viaduct- a concept for industrially built land bridges and longer bridges"), TRV 2021/122214.

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 Chapter 1.4.

#### *7.7.2.1 Operational solutions outcome*

As described before in Chapter 1.1.1, even though FA7 should maintain openness in regards to the innovations developed, solutions for more flexibility through multi-modality as well as solutions for energy-efficient high-speed rail systems as well as guided systems are foreseen to be the main focus points.

Those could be reached through moving infrastructures, *Pods*, magnetic levitation, air levitation, and vacuum tube technique, but also through other solutions, the rail sector might even not be aware of at this point in time. As these solutions vary widely in their technical implementation, general assertion about the operational solutions outcome cannot be made.

#### *7.7.2.2 Technical enablers: capabilities to achieve the targeted operational outcomes*

Depending on the targeted solution, needed capabilities and technical enablers can vary widely. As described in Chapter 1.1.2 there are certain enablers, which are rather likely to be used by innovations of FA7 for example autonomous train operation, Virtual Coupling, AI etc.

Also, as explained in 1.1.1, the TRL level reachable within the span of the programme will be highly dependent on the targeted innovation and its degree of freedom from the existing railway services as well as developments for the same concept outside of the EU-RAIL JU.

Thus, for FA7 a close cooperation with further programmes rail-related as well as outside of the rail sector, e.g. the IT or aeronautic sector, will be key to its success.

#### *7.7.2.3 Demonstration implementations*

During the duration of EU Rail JU complete demos or demos in collaboration with other projects/programmes e.g. on national level that can provide the test site, infrastructure and vehicles will be carried out depending on the available resources. Demonstrations targeting issues of interoperability and demonstrations, which provide advantages through EU-cooperation in comparison to national activities, should be especially focused on.

### *7.7.3 Impacts*

A conscientious analysis of the impacts should be included in every proposal answering to project calls of FA7. Because of the openness of FA7 a detailed impact description for the whole area is not feasible. Nevertheless, a couple of broader aspects will be described and examples for certain possible solutions to be targeted in FA7 can be found in Chapter 1.4.

#### *7.7.3.1 Description of the impacts against existing rail services*

Dependent on the innovation on new approaches for guided transport modes targeted in FA7, both an integration on existing rail services and infrastructures and a new building of infrastructures to either supplement or substitute existing rail offers are possible. Anyhow, to reach the next level of guided transport modes there is a fundamental need for a smooth transition strategy.

In case of the usage of existing infrastructures, this can be implemented only when the infrastructure of today has to be modified to a minimum accompanied by standardisation, regulation, as well as cross-mode integration. A full system approach to fit in the train mobility must be a fact to be successful.

In either way, it is especially important for the innovations of FA7 to have a strong focus on the goal of shifting transport to rail. It should be avoided to develop new guided transport modes that simply cannibalise the existing rail services.

##### *7.7.3.2 Quantitative KPI demonstrated in this FA*

As the *blue-sky* FA in the EU-RAIL JU, FA7 has a broader scope and is specially focussed on technology openness and interoperability of new approaches for guided transport modes within Europe. As described especially in Chapter 1.2.2, FA7 will mainly focus on bringing different technologies, developed in other programmes (including other FAs of the EU-RAIL JU), together to form new guided transport modes than targeting the development of new components. Thus, KPIs for FA7 could only be focusing on the performance of the ensemble of the final system. As FA7 is targeted at developing several promising or interesting approaches, rather than bringing a single technology to a high TRL level, defining quantitative KPIs for FA7 would be misleading and hindering the objective of technology openness. Studies to further understand the impact of different concepts on relevant KPIs should be included in the projects of FA7.

##### *7.7.3.3 Exploitation, deployment and migration considerations*

Generally, the considerations for deployment of the innovative solutions provided by FA7 include adaptation of the current framework e.g. related to regulations, standardisation, adoption to climate change, long time periods for land-use planning and inventory of relationships where the technology is profitable and can be introduced.

These considerations will deliver a future-oriented approach for the introduction of innovative solutions enabling the EU Green Deal.

#### *7.7.4 Possible research fields in Flagship Area 7: Innovation on new approaches for guided transport modes*

##### *7.7.4.1 Automated Multi-Modal Mobility-System*

###### 7.7.4.1.1 Results/Outcomes

###### 7.7.4.1.1.1 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*) through the use of standardised *Pods* for the different needs of the people traveling or transporting goods. *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. In case of 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, heating, ventilation and air conditioning, safety and emergency systems, diagnostic equipment and autonomous repair processes (see e.g. Fig. 6 and 7). The *Pod* will also offer the ability for long distance travelling at night. For freight services the Pods can be understood as innovative containerized solutions.

*Figure 19 - Use Case “Podimised Passenger Transport” outside view (Fig.: Siemens)*

*Figure 20- Use Case “Podimised Passenger Transport” inside view (Fig.: Siemens)*

The *Pod Carrier* itself is the "moving infrastructure". The *Pod Carrier* contains all 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 as well as global and local transport coordination. And all of this also adapted to all climate and adverse weather conditions (e. g. winter). The *Pod Carrier* should be able to carry out a completely autonomous operation on the rail network with low noise-emission and 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, which is ensured by the facilities on the *Pod Carriers* as well as by the communication between the *Pod Carriers* with each other, with any infrastructure-side devices that may be available (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 their monitoring, since all the logic would be located onboard.

Figure 21 - Mock-up of intermodal passenger and freight Pods (Photos: DLR)

The "transport vessel" *Pod* can quickly switch from a *Pod Carrier* (for example for road transport or a cable car) to another via a reloading device which is to be developed (see Fig 8). As a consequence, stations and mobility hubs will need adaptations to constant loading/unloading of *Pods* on/from *Pod Carriers* and new concepts will be designed and developed. Hereby, standardised interfaces should ensure the mechanical securing of the *Pods* on the *Pod Carrier* as well as 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*, for example on the road (example in Fig 9), for cable cars or for water transport. Similar development activities are to be coordinated in cooperation with related transport organisations and industries.


Figure 22 - Intermodal passenger Pod with road Pod carrier (Fig.: DLR)

The objective here is to produce flexible and performant operational models. Flexibility is necessary in order to provide a highly adaptive answer to time varying operational scenarios during the whole service period. The idea is to avoid predetermined fixed operational scenarios and to be compatible with a pseudo on-demand service. The transport of freight should also be addressed and integrated in the overall system. There is much unused capacity on passenger trains as of today, specifically outside of rush hours. In off-peak times there is low or very low capacity usage, so looks like “almost only warm air” transported (e.g. in COVID period) by passenger trains. Hence, by providing tailor-made transport solutions the efficiency can be improved and would make the system economically superior compared to other transport modes.

Another objective is to propose a scalable and modular structure for the system in order to be as close as possible to the user needs with a minimum allocation of resources by providing small autonomous units which can come together as 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 times. For the rolling stock, it is achieved with a disruptive change of scale to smallest units, and this approach should also be applied to the supervision system.

Furthermore, alternative multimodal concepts could be developed such as smoothly travelling on existing rail tracks or loaded/unloaded on trains as moving infrastructures. There will be a continuous effort in this flagship area to scout for promising multi-modal concepts in order to see if they can deliver on the objectives more time and cost-effectively.

7.7.4.1.1.2 Description of the needed capabilities and technical enablers

The introduction and operation of *Moving Infrastructures or Pod Carriers* in a multi-modal mobility-system environment involving arbitrary vendors needs an integration of existing or additional infrastructure, rolling stock, service providers, stations, yards/platforms, etc. To achieve this open standardised platform and interface concept as well as standardised development, test and certification, processes and platforms are needed, too.

The following challenges must be addressed in the context of enablers:

1) Interfaces between *Moving Infrastructures* and technical open concepts for *Pods* and *Pod Carriers* and the full operational aspects array, too.
2) Different operating modes should be possible, flexibility in use (beside the rush hours, cohabitation passengers/freight etc.), different speeds, and standardised different dimensions of *Pods* and *Pod Carriers* (passengers and/or freight).
3) *Pod Carriers* are to be developed for operation on main lines, secondary lines, tramways, existing and new possibilities in the rail system, all conditions and safety requirements.
4) Sensoring, operations, control/communication systems, and monitoring technology are required for fully autonomous driving in the near future. Transition and migration to this new level must be taken care off as well.

Besides those capabilities directly enabling operational objectives, which are displayed in the table below, a couple of preparatory related works need to be carried out, such as:

- Studies to examine the existing transport systems, their interfaces, legal framework conditions, transitions, etc. within the respective transport system as well as between different transport systems as a basis for further work, but also for creating methods for evaluating appropriate solutions.
- Inventory and evaluation of Communication systems as these play an important role with direct communication between modules and also between module and the residual trackside components.
- Interfaces with other modes need to be defined and developed.
- Obtaining developments concerning virtual coupling and autonomous driving should be operational as a technical key to bring the targeted operational flexibility.

- Loading/unloading technologies and facilities needs to be investigated and stations and mobility hubs need adaptations to consent loading/unloading operation of *Pods* on/from *Pod carriers* automatically and seamlessly.

An estimation of the technical readiness level of the capabilities in 2025, 2027 and 2031 is provided in Table below.

| **Capabilities enabling Operational objectives** | **TRL in 2025** | **TRL in 2027** | **TRL in 2031** |
|---|---|---|---|
| development of Coupling System for the connection of Pod Carrier and Pod | 2 – 3 | 3 - 6 | |
| development of loading/unloading technologies | 2 - 3 | 3 - 6 | |
| development of Pod Carrier | 2 – 3 | 3 - 6 | |
| development of Pod/Capsule | 2 – 3 | 3 - 6 | |
| Development of a fully automated multi-modal mobility system | 2 - 3 | 3 - 6 | 5 - 7 |
| prototype of an autonomous Pod and Pod Carrier in a test environment incl. loading/unloading | | | 5 - 7 |

*Table 45 - Estimation of the Technical Readiness Level of the capabilities in 2025, 2027 and 2031*

Analogously, in the case of interoperable pods with integrated pod carriers that can run both on roads and railway lines or can be loaded/unloaded on trains as moving infrastructures, the corresponding vehicles, infrastructures (including stations/hubs and switches) and interface technologies (e.g. command, control and signalling systems and/or TLC systems) need to be identified in order to guarantee the access of the vehicles to the network safely and smoothly.

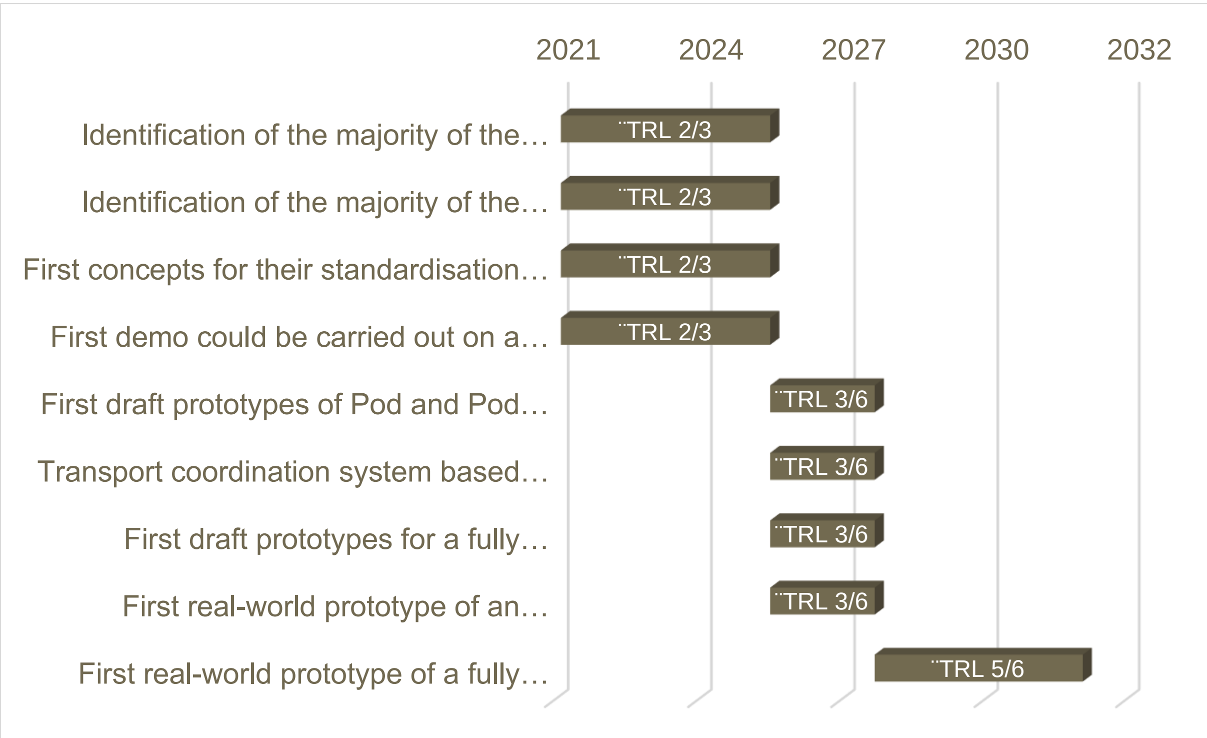



*Figure 23- GANTT Diagram for the multi-modal mobility systems. Cells with a "TRL" mentioned are marking a milestone ( ◆)*

A constant screening of latest developments should be established so that the goals of interoperability and technology openness is ensured while avoiding doubling the development work.

###### 7.7.4.1.1.3 Demonstration implementations

The demonstration of the system should expediently take place in several independent steps, e.g.:

- Demonstration of the functionality of the standardised interfaces for transfer devices and coupling system between *Pod* and *Pod Carrier* in a separate area of a test site
- Demonstration of the functionality of the coupling system between *Pod* and *Pod Carrier* and cable car in a specially installed test area for cable cars
- Demonstration of prototypes of the identified aspects for a fully automated multi-modal mobility system in a virtual environment / simulation
- Demonstration of the transport coordination system in a virtual environment / simulation
- Demonstration of a prototype of an autonomous *Pod* and *Pod Carrier* within a defined test area (e.g. Test and Validation Centre's in Germany or Czech Republic)
- Demonstration of prototype of a fully automated multi-model mobility system implements the standardised hardware/software concepts within a defined test and automation environment
- First trial run on a selected branch line in freight traffic with a change of transport modes transport between rail and road
- First trial run on a selected branch line in passenger traffic with a change of transport modes between rail and road

### *7.7.4.2 Impacts*

#### 7.7.4.2.1 Description of the impacts on existing rail services

The *Pod* guided system will lead to a more flexible and demand-oriented service to the passengers, reduction of changes during the trip and higher economy of the system as only trains run, especially on regional lines with low demand, when needed. They will imply a feeling of security to the users: "when I need a *Pod* – one will come and pick me up".

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.

| | |
|---|---|
| | More flexibility and punctuality for passengers / freight<br>The *Pod* guided system will lead to a more flexible and demand-oriented service to the passengers, reduction of changes during the trip and higher economy of the system as only trains run, especially on regional lines with |

| | |
|---|---|
| | low demand, when needed. They will imply a feeling of security to the users: “when I need a *Pod* – one will come and pick me up”. |
| | Reinforced role for rail in European transport and mobility<br>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. |

*Table 46 - Descriptions of FA7 impacts related to the intended impacts in the Master Plan*

###### 7.7.4.2.2 Quantitative KPI

To be defined based on the objectives of the specific projects.

###### 7.7.4.2.3 Exploitation, deployment and migration considerations

The aspects of the Automated Multi-Modal Mobility System described in section 1.2.1 offers a multitude of possible use cases that can create new possibilities for railway and be gradually integrated into an existing railway system and implemented 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 the transport offer in rural areas with fully autonomous operation. Additionally, the offered solution should be made more readily available by making it more economical as well as to provide continuous connections from door to door and to extend mobility beyond the railway infrastructure even for remote regions in connection with traffic on the road or by means of cable cars. The transport of freight could also be addressed with dedicated *Pods*. This first step with dedicated railway routes will make the deployment easier.

Another possibility for implementing the R&I results is the integration of such a system in the inner-city public transport for cities and municipalities with difficult terrains. Systems could be implemented that combine aspects of tram traffic, bus traffic, shipping, or cable cars, which offer users greater comfort and enable door-to-door solutions.

In both cases, the necessary technology must be integrated into the railway lines as well as for the corresponding logistics systems (booking, use, payment, route planning, disposition, depot, maintenance, etc.) to enable safe, fully autonomous driving and the installation of the necessary reloading technology for changing from one type of transport to another at selected points.

In a next step, mixed operation on main lines with conventional trains and autonomous systems and the introduction the corresponding required technologies can be implemented. Feeder routes between larger junctions and branch lines are ideal here.

In any case, the legal requirements for autonomous operation and for modal intersection (at the crossing of the requirements specific to each mode) must be created (legal certainty) and the normative and regulatory requirements for approval of the system must be ensured.

And last but not least, necessary adaptation to the existing railway stations need to be considered.

### *7.7.4.3 Fast track-bound transport systems*

#### 7.7.4.3.1 Results/Outcomes

##### 7.7.4.3.1.1 Operational solutions outcome

The fast track-bound transport systems are referred to as a mode of land transportation capable of high speed and driverless operations for passengers and/or cargo, in which a vehicle is guided through a fast track. It shares the basic principles of the classical rail systems but it provides advanced performance in certain domains (e.g. higher speed, reduced noise emissions, reduced energy consumption and $CO_2$ emissions). An example can be seen in Fig. 11. As these systems share the same conceptual principles as rails, they should be developed under a railway program.

*Figure 24 - Example for a magnetic or pressed air levitation system (Fig.: A-train)*

Having the ability to move people and/or goods very quickly can be of great interest in the context of the 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 CO2 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. *Fast track-bound transport systems* combined with the existing high-speed and conventional rail, could provide a fully green European transport system in the future.

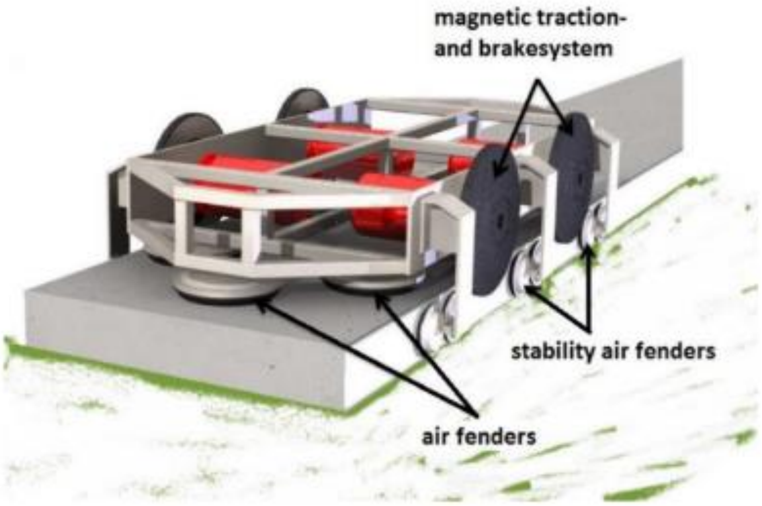


Figure 25 - Schematic concept Bogie from the A-train project

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 realization 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 produce the following main outcomes:

- Build System Architecture
- Create laboratory testing environments
- Define and develop technical solution for sensing, communications, safety and integrated data processing
- Define System Requirement Specification
- Develop Socio-economic assessment in order to explore where transportation lines with *fast track-bound transport systems* generate socio-economic value and where results could be established with a on-site validation / testing can be carried out
- Draft Business Cases
- Identify needs of standardization, safety and security legislation, interoperability
- Identify needs of testing infrastructures
- Identify potentially, specific technologies and subsystems derived for *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.

- Identify Technical solution and their cost
- Produce feasibility studies and use cases
- Run reduced scale and/or full-scale testing 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)

7.7.4.3.1.2 Description of the needed capabilities and technical enablers

New high-speed transport systems (passenger and/or cargo) are emerging by the adoption of magnetic (passive/active) and air levitation technologies. Equivalent to traditional railway systems, in magnetic levitation or air levitation approaches (e.g. in the vacuum tube technique like the “Hyperloop”), there can be three areas of innovation, with their corresponding technical enablers, identified as:

1) The vehicle/pod/capsule (hereinafter referred to as a *Capsule*), which is the structure, including the aerodynamic fuselage, the flexible and comfortable interior for passenger or freight transportation, and the power supply system. Although the construction of the *Capsule* is out of the scope of this FA, it is expected to establish a collaboration with other fast track-bound transport programmes and initiatives (see Sect. 7.7.1.5) in which the *Capsule* is/will be built.

The scope of this FA is rather focussed on the interaction between the *Capsule* and the infrastructure

2) The infrastructure, which includes the structures for support and guidance through which the *Capsules* move and the systems needed for levitation and propulsion of the *Capsules*, switches, and – for the vacuum tube approach - the tube itself through which the *Capsules* move and pressure maintenance systems etc. as well as necessary climate adaptations of the tube and other infrastructures to create a robust mode of transportation. As for the *Capsule*, the construction of the infrastructure, levitation and propulsion systems for commercial lines is out of the scope of this FA. A collaboration is expected to be established with other fast track-bound transport programmes and initiatives leveraging test sites and assets built outside the EU Rail JU, such as those proposed in 1.1.5, for which EU Rail JU can provide resources for further development through implementation of innovative technologies and systems. Power supply availability will condition the operation, also in degraded scenarios.

The scope of this FA is focused on the design and specifications for the necessary infrastructures, and the test and validation of these infrastructures to foster development toward commercial maturity. In addition, guidelines and traffic coordination concepts will be established to foster the application of such technologies.

3) Command, control and communication system and safety equipment and automation system, including sensors, communication, data processing, etc. for the purpose of safe and efficient operation and cost-effective maintenance. Virtual coupling and autonomous driving will be also a technical key to bring the targeted operational flexibility.

Especially, those technical enablers related to **sensing** at ultra-high speed are very important. These are needed for example to locate the *Capsules* and collect information from the infrastructure such as temperature, deformation, vibration etc. and should consider the specific requirements coming from the speed but also from the materials used to build the tube and the *Capsule*. All the information generated and the sensors should be managed in an integrable way. For this integration, the main technical enabler that is proposed is an IoT platform for **monitoring, supervising and managing** the sensors, as well as integrating all the information coming from them, including predictive algorithms to detect for example potential equipment failures in advance. In relation to **safety and signalling systems**, technical enablers for automation of the operations will be provided, such as Automatic Train Protection (ATP) systems and safety systems to prevent accidents. An important enabler of realising the activities of FA7 are traffic coordination concepts and command, control and signalling systems (both centralized and distributed options) will be covered. These will be supported by the required, automation of the operation and also communication systems, to overcome challenges such as those related to the operational environment (i.e. a metal low-pressure tube) and the extreme-high speeds involved with respect to the latency.

Furthermore, these new systems sometimes will need new infrastructures, but other times they can share infrastructures in coexistence with the traditional railway system. The re-use of existing infrastructure and civil structures like bridges and tunnels would saves costs incurred and time spent on the possible construction of new infrastructure.
An estimation of the technical readiness level of the capabilities in 2025, 2027 and 2031 is provided in Table below.

| **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 - 6 | 7 -8 |
| Development of the A-Train Bogie | 3 | 4 | 5 |
| Full scale fully automated Maglev-derived system | 2 - 3 | 4 - 6 | 7 -8 |
| Scaled 1:2 fully automated Vacuum tube-based system | 2 - 3 | 4 - 5 | 5 - 6 |

*Table 47 - Estimation of the Technical Readiness Level of the capabilities in 2025, 2027 and 2031*

The developments in this area are expected to be aligned with the works done in complementary initiatives, and could be tested in the facilities mentioned in 7.7.1.5 as well as aligned with the business plan of the chairman by the CEN/CLC/JTC 20 N 78[38].

A constant screening of latest developments should be established so that the goals of interoperability, technology openness and not doubling development work is ensured.

[38] CEN/CLC/JTC 20 N 78: Updated Businessplan of the Chairman. CEN/CLC/JTC 20 "Provisional: Hyperloop systems". 5.10.2021

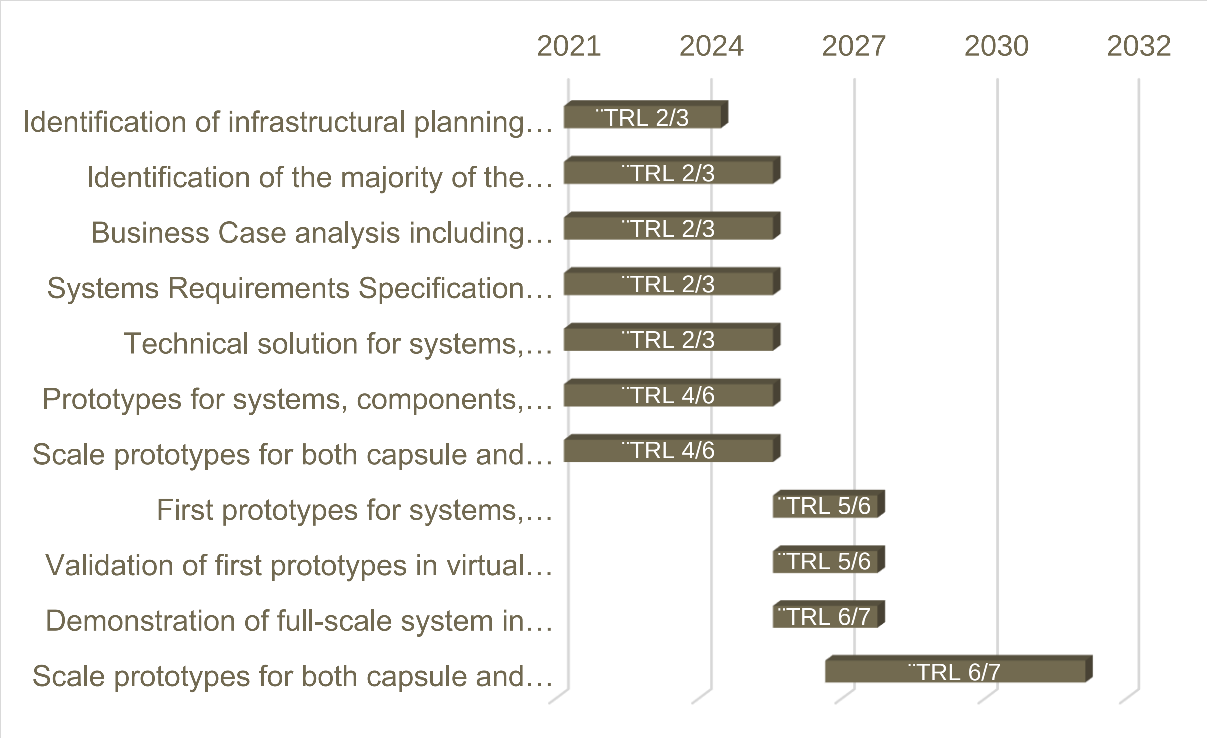



*Figure 26 - GANTT Diagram for the fast track-bound transport systems. Cells with a "TRL" mentioned are marking a milestone ( ◆)*

*with the assumption that other complementary programs, such as the ones mentioned in 7.7.1.5, make available their facilities (including capsule and tube) for testing

7.7.4.3.1.3 Demonstration implementations

Demonstration will include operability aspects and challenging topology across Europe to show and assess the full impact of fast track-bound transport systems. The demonstration of the system should expediently take place in several independent steps and will further be distinguished for "Maglev-derived system" and "Vacuum tube-based system":

For the "Maglev-derived systems":

- Demonstration of the technical as well as regulatory and safety related aspects to be standardised for a Maglev-derived system at least in a virtual test environment;
- Demonstration of integration of technical solutions for systems, components, sensing, communications, safety and integrated data processing and validation of the whole system at least at scale and at least in laboratory environment;
- Demonstration of a first real world prototype of a Maglev-derived system and validation of the whole full-scale system within a defined and relevant test environment.

Also, 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 adequately equipped for maglev-derived technologies both from the infrastructure and vehicle side, eventually in order to assess the compatibility with the existing underlying railway system. Since the basic technologies for maglev-derived applications are already available at different stages of development, the demo will be the chance to test them along with the technical enablers (in particular switches) on a full scale and systemic application in relevant environment.

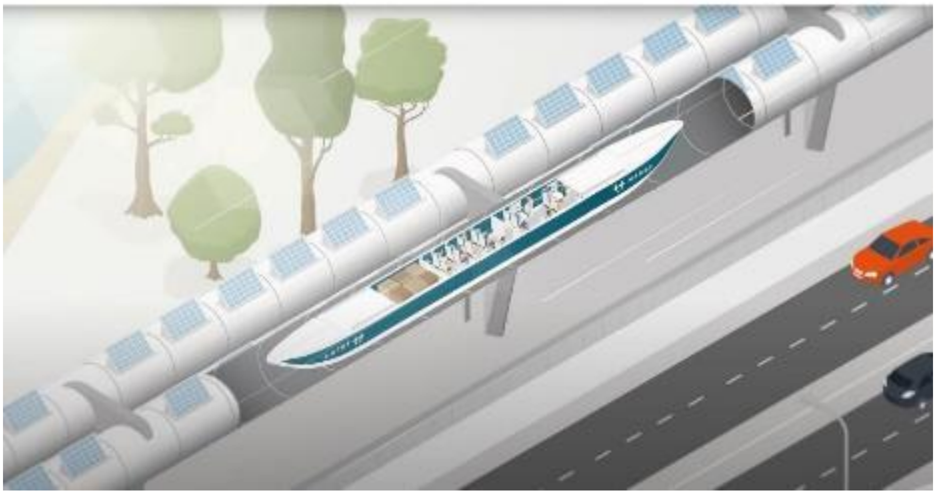


*Figure 27 - The „Hyperloop" concept by Hardt Hyperloop (Photo: Hardt Hyperloop)*

*Figure 28 - The „Hyperloop" test track in Castilla la Mancha (Spain) will be a 1:2 scale (Source: CEDEX)*

For the "Vacuum tube-based system" (figs. 14 and 15):

- Demonstration to verify some aspects of signalling and automation within a laboratory simulator
- Demonstration of the functionality of the technical aspects as systems requirements, system architecture, sensing, communications, safety and integrated data processing, as well as regulatory aspects, to be standardised for a fully automated "Vacuum tube-based system" at least in a virtual test environment at lab and on site if possible
- Demonstration of integration of components and validation of the whole system at least in laboratory environment
- Validation on site for a scale prototype can be carried out within complementary projects/initiatives as mentioned previously

Obviously having sections available in which to carry out tests in real environments would be the best (Figs 16 and 17) 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 which could be set up in shorter timeframes should be considered as well.

*Figure 29 - Inside view of a future passenger Capsule (Photo: Hardt Hyperloop)*

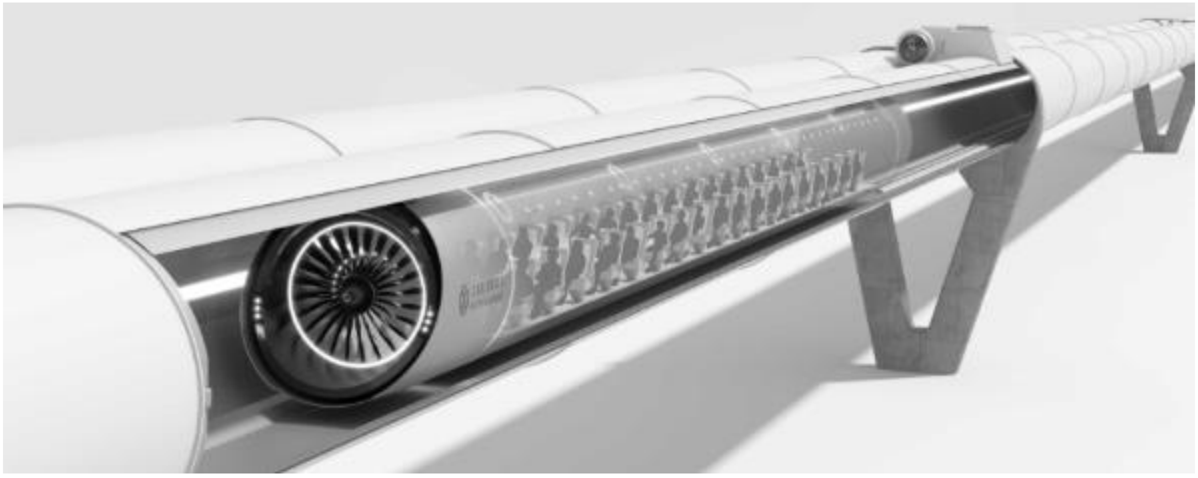


*Figure 30 - Tube and capsule view of a Vacuum-Tube system (Photo: Zeleros)*

7.7.4.3.2 Impacts

7.7.4.3.2.1 Description of the impacts on existing rail services

| | |
|---|---|
| | **Improved performance and capacity**<br>Provided that the projects start in 2022 and all partners playing a key role in the development process are involved, as well as considering the fact that the R&I projects outlined above are essentially in the area of the preliminary development of a completely new transportation system, a variety of positive effects are imaginable, but because the *fast track-bound transport* systems solutions are rather disruptive, predictions of positive effects are rather vague. |

| | |
|---|---|
| | **Reinforced role for rail in European transport and mobility**<br>Nevertheless, the most promising positive effect is a decreased travel time which not only leads to higher customer satisfaction in passenger and freight transport but also enables competitiveness to air transport. |

#### 7.7.4.3.2.2 Quantitative KPI

To be defined based on the objectives of the specific projects.

#### 7.7.4.3.2.3 Exploitation, deployment and migration considerations

As related to the *fast track-bound transport systems* deployment, there are still many questions to be answered. The first one is the technical feasibility of this kind of transport, that should be answered by means of developing test sites as the ones considered in this flagship area. The technical behaviour of these demonstrators will figure out the doubts related to technical challenges of this transport. Additionally, these test sites will determine more precisely the current and actual costs of such infrastructure and all the associated subsystems.

The determination of these costs is essential to develop a business model based on real data and not on insufficiently substantiated hypotheses. This business model should consider not only the associated cost but also the externalities of this transport which eliminates the direct $CO_2$ emissions from very high emission transport modes (i.e. the aviation).

The future success of these *fast track-bound transport systems*, at least in Europe, is therefore depending on these three conditions: 1) Demonstration of technical feasibility 2) Firm political decision to ban $CO_2$ emissions from transport and 3) That other solutions such as electric or hydrogen aircraft are not being introduced before *fast track-bound transport systems*. If these three conditions are met, the *fast track-bound transport systems* will be a feasible solution for very high-speed transport and combined with the current high-speed trains could achieve the challenge of a zero-emission high-speed transport system.

Innovation must provide answers to future challenges, and therefore the development of *fast track-bound transport systems* test tracks is justified, both in providing these answers and in developing numerous parallel technologies that justify the high investment required.

## 7.8 Transversal Topic: Digital Enablers

### *7.8.1 Objective and level of ambition*

#### *7.8.1.1 Targeted objective, opportunities opened 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 characterized 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-to-cloud continuum’ or a ‘railway digital enabler’ environment for the entire Rail System, supporting the development of advanced transformational digital capabilities such as the digital twin.

Digitalisation is of major importance for all the FAs hence it is organised as a transversal topic (TT) to have all elements of the system play together in a coherent and interoperable way. The digital enablers from this work area – mainly the digital twins, innovative processes enabled by interoperable data sharing as including conceptual data model (CDM) will serve suitable demonstrations in the FAs.

Therefore, the establishment of a holistic integrational element such as the “railway digital enabler” as described in section 2, will create an ecosystem in which data from all applications will be aggregated in a standardised way, so that applications will increase their performance levels and can be combined with application data or digital twins from other fields within the railways (e.g. combination of railway operation data with maintenance information). These digital enablers manifest themselves as federated and distributed edge and cloud components and will serve as environment for creation, modelling, editing and processing the data within one of the most important concepts of digitization within the railway sector: A new dimension of “digital twin” of railway assets. Although this digital infrastructure creates an edge-cloud continuum for complex digital objects to live in. The main objective of this flagship area remains the creation of standardised concepts for digital twins, that enable the users of these twins to use them in an interoperable way. Digital Twins from one part of the railway system shall be fully compatible to digital twins of other railway applications (e.g. operations, maintenance, passenger services, etc.) to enable co-simulation. By this approach architectures of different scopes are created and coupled together via respective interfaces, such as:

- Architectures for digital environments for digital twins to life in
- Architectures describing the inner structure of a digital twin, like data structures, services APIs and application logic
- Modular descriptions of interfaces to link this digital environment with the overall system architecture from the system pillar

Furthermore, the railway digital enablers will allow the linking to other technological initiatives and to join forces within different rail application.

*By definition a digital twin is a virtual representation able to imitate the behaviour of a physical system during the spans its lifecycle*. Within the railway, digital twins will be merging the knowledge on the fundamental behaviour of systems and sub-systems along into digital simulations in predicted or operational regimes. A digital twin will enable a more efficient way to predict and control the present and future performance of assets, and therefore has the potential to transform many different aspects of the business. In particular, a digital representation of a part of the real railway system (infrastructure, vehicles and operation) will allow visualizing, simulating and predicting current and future status as well as behaviour of the system. It will improve safety, availability and lower operational costs for the complete transportation system by predicting future events and support the development and faster deployment of innovations with low impact and virtualized tests. The digital twins will cover all rail market segments and their subsystems, including urban. The overall representation of the entire railways system will emerge from an aggregation of multiple digital twins in a suitable granularity and level of detail which needs to be adopted to the intended use.

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/sub-system). As measured data maybe inconsistent or contains information gaps, mathematical tools, such as statistical analysis, shall be developed to ensure the best possible data is feedback to the digital twins. Adopting standardized statistical methods and tools as an integral part of the transversal functions will enable the different Flagships to use suitable datasets, conformed with a stable and standardized framework, to test and validate their digital twins.

The development of a framework "railway digital enabler" will cover the entire railway sector to gain on efficient implementation in the real world as a second step. Developing a digital twin within each railway/stakeholder's domain/subdomain would instead lead to possible incompatibility of assets or processes once applied together in the network and leading therefore to the need of further patches and adaptations.

The transversal topic on digitalisation will support operational processes and activities of the FAs and especially their implementation of the related use cases. It will take into account the System Pillar (SP) CONOPS (Concept of Operation) of the rail system as well as definitions of SP-architectures and SP-interfaces. Requirements, implementation and data for the digital twins are responsibility of the FA. The transversal topic on digital topics will support this by three aspects: Firstly the Digital Twins support for operational processes of the FA by composition of reusable, 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 Digital Twins Design toolbox (design-time) to model development tools for design as well as for validation, verification and test; to model registry and discovery services and to model Interoperability validation tools. Thirdly TT will provide a Federated dataspace to feed digital twins in order to ensure a common Ontology, Identity and Trust management, Federation Services, Data Assets registry and discovery services, Data Distribution Services, Data stream management, cyber security etc.

It is of upmost importance to understand that the TT-Architecture and the related interfaces needs by nature to be wider than the Architecture provided e.g. for the CCS+ to enable the digital twin environment to work properly. Hence all the results and definition of the SP will be taken into account and represented entirely.

#### *7.8.1.2 Innovation beyond state of the art, including integration of S2R results*

The work builds upon all IPX (IPX), IP1 (IP1), IP3 (IP3) and CCA (CCA) activities of S2R related to virtualisation of assets. It will use the data structure provided by FA1 and could also incorporate new elements in its model, in particular on the connection interfaces with other transport modes from the works of FA1 and FA6. Being the transversal topic, it provides the tools for simulation and prediction to all other FAs.

The recent European collaborative works carried out within the S2R programme already paved the way for the digital twin in different applications.

Such an approach should enable the development of a global and shared "railway digital enabler" with digital twins of different areas of the railway environment acting in it.

| State Of The Art | Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|---|
| Virtual testing to transfer test 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, CCA Virtual certification (PLASA (PLASA, 2016) | General approach for the virtual certification / homologation based on the aggregation of suitable digital twins (granularity and level of detail) |
| Certification approaches for rolling stock and related components based on digital models | Specific activities for the Virtual certification for S2R IP1 rolling stock (PIVOT (PIVOT, 2017) with respect to bogies, PINTA (PINTA) with respect to Traction systems) | General approach for the virtual certification / homologation of rolling stock based on the aggregation of suitable digital twins (granularity and level of detail) as well as accepted tools |
| Field measurement of noise emissions and subsequent certification | Noise auralisation and visualization (FINE1 (FINE1, 2016), FINE2 (FINE2, 2019) | General approach for the virtual certification / homologation based on the aggregation of suitable digital twins (granularity and level of detail) as well as accepted tools |
| Planning, certification and approval of planning based on expert knowledge. Certification and approval of infrastructures by field measurement. | Virtual certification for infrastructures IP3 infrastructure (In2Smart2 (IN2SMART2, 2019), In2Track (IN2TRACK, 2016), In2Track2 (IN2TRACK2, 2018), In2Track3 (IN2TRACK3, 2021) | General approach for the virtual certification / homologation of planning and implementation of infrastructures based on the aggregation of suitable digital twins (granularity and level of detail) as well as accepted tools |
| Planning, certification and approval of planning based on expert knowledge. | Virtual certification for command control and signalling systems | General approach for the virtual certification / homologation of planning and implementation of infrastructures based on the |

| State Of The Art | Shift2Rail results | Further innovation needed and covered by this FA |
|---|---|---|
| Certification and approval of infrastructures by field measurement. | | aggregation of suitable digital twins (granularity and level of detail) as well as accepted tools |
| Planning, certification and approval of planning based on expert knowledge. Certification and approval of infrastructures by field measurement. | Virtual certification for energy management systems (IN2Stempo (IN2STEMPO, 2017) | General approach for the virtual certification / homologation of planning and implementation of infrastructures based on the aggregation of suitable digital twins (granularity and level of detail) as well as accepted tools |
| Individual, but partially incompatible digital data models and ontologies tailor-made for the specific purpose or application. | The S2R IPX (IPX) LinX4Rail (LinX4Rail:, 2019) project, starting end of 2019, sets the ground for a shared vision of the railway system architecture as well as for development of a CDM. UIC projects RSM and OntoRail (Ontorail), associated to LinX4Rail (LinX4Rail:, 2019) activities, are also materially contributing to a converging sector approach for defining the railway CDM and all the necessary elements developed by major initiatives such as IFC Rail and Eulynx. Combined, they will enable different simulation or operational subsystems to run together, paving the way to build a shared and interoperable architecture. | Development of a conceptual data model for the entire railway system incl. the required data structures and functionalities. The results from L4RLinX4Rail-1 and -2 with respect to CDM will be further developed and deployed . |

*Table 48 - Overview of the innovation of this FA and the input from state-of-the-art research and Shift2Rail.*

As described before, it is a key objective to enable the fitting of individual digital twins in a joined environment, the "railway digital enabler". Consequently, there are a number of risks related to a lack of consensus, alignment, access to data and interoperability of systems. Thus, already within the EU-RAIL JU, there is the risk that consolidation with other FAs will not be reached in time or in all needed areas to a sufficient extent.

Additionally, a lack of an agreed framework on rights and obligations as well as governance associated with use of a digital twin and federated data could hinder a proper usage of the developed digital environment. In particular for the rolling stock and CCS virtual certification it shall be required at least that the models are kept open or verified by third parties.

Another risk associate to digital twin development is finding right complexity as well as granularity level. On one side, creating a simple digital twin will mainly result in a digital model that cannot accurately represent the real system. On the other side, creating a too complex digital twin will require substantial amount of work by orders of magnitude and can result on a very complex digital twin, making its almost impossible to understand, maintain and debug.

The final purpose of developing a railway digital twin is 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 digital twins. With this major opportunity comes the challenge of coordination and specification that needs to be done with the other FA. A lack of specification and coordination will mainly lead to a partially usable digital twin and therefore to inability to achieve the full potential of the served FA. Using one specific digital twin in two Areas can lead to similar functional but different complexity requirements. In order to reduce complexity, some railway-specific standards could be developed within the TT. From the model-based operational requirement, to validation of system models, a number of standards (for specifications and interfaces) would ease the building the related digital twins. This needs to be done in a moderated, transversal way in collaboration and in coordination with the FAs.

Transversality as such is a risk. Requirements and functionalities need to be collected from the FAs as well as the architecture developed in LinX4Rail (LinX4Rail:, 2019) and further developed in the System Pillar needs to be considered. In addition requirements from different stakeholders and FAs need to be accommodated and integrated. Besides the content related challenges this is an issue for project management and governance.

#### *7.8.1.3 System integration, interactions with System Pillar and with other Flagship Areas*

As the "railway digital twin" is a digital representation of all physical assets (as their digital twins) and their interactions, some processes / rules for specific cases will be inserted which lead to improved prediction of failures or possible events. Once there is a common system of system framework with easily interpretable operational rules, the complexity of use cases / processes to be inserted in the digital twin simulation framework is reduced and potentially the synergies found across sub-systems increased, also digitally, through simulation. The TT creates value only when used in the other "vertical" FA. The comprehensive and distributed TT-architecture with the ability to leverage networked digital resources will maximise the digital environment development for the overall railway system.

The separation of application logic, which is specialized to support specific use cases (addressed by the FAs), from the core digital resource management functions provided by the Digital Enablers, which are common across EU-RAIL JU FAs and may also be common across Partnerships in the Horizon Europe programme (automotive, aviation) and other Industries, is also important in the pursuit of synergies with S2R outcomes or market ready solutions as an overarching principle adopted in the development of the EU-RAIL JU MAWP.

Inherent digitalisation Use Cases requires a holistic approach that relies on the following pillars:

1. Enabling the digitalised **data sharing** across the entire supply chain to specify, tender, design, manufacture, planning, automated validation & verification (V&V) of planning, maintain, test, validate, certify, homologate, operate, refurbish, recycle and dispose rail assets with the support of digital twins, digital models as well as related services and interfaces.
2. Integrate **Virtual simulation and testing** (by using digital twins and models feed by high quality datasets) as part of the system (services, manufacturing processes, operations and assets) during the introduction of changes and innovations.
3. Using **predictions and visualization** of state of (part of) the system (services, manufacturing processes, maintenance, operations and assets) and of passenger and/or goods flow.

TT will provide the common set of core digital resource management functions to other FAs while the FAs will provide the specific Use Cases based on the description in annex 1. Generally an intensive cooperation between all FAs and TT is foreseen to identify, detail and describe the use cases. TT will help to enable the demonstrations planned in the FAs by the technical enablers developed. A strong interaction with the System Pillar is planned, too, with respect to architecture and standardisation among others.

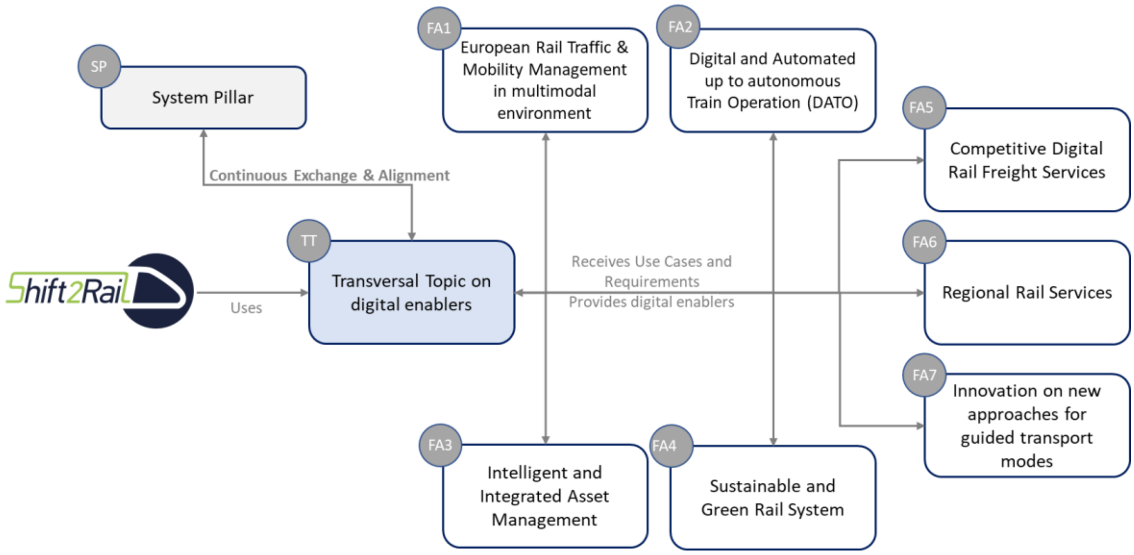


*Figure 31 - Interaction with FA and SP*

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 synchronized 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 on the granularity of the architecture and resultant specifications and associated system outputs to be delivered by the Programme.

*Details of the exchange between the Flagship Areas and TT can be found in Annex B*

The following use cases by the FA are focus of the TT and will be used for system integration:

- Network management planning and control & Mobility Management in a multimodal environment (FA1)
    - Machine-readable ontology of an interoperable ‘connected’ TMS
    - Interfaces for data exchange with legacy TMS
    - Holistic real-time simulation platform for transport / traffic management optimization and planning
- Digital & Automated up to autonomous railway operation (FA2)
    - Artificial Intelligence training and Certification on digitalized real and emulated / simulated operational scenarios
    - Digital maps for both train localisation and environment perception systems
    - Exchange between e.g. trackside and on-board subsystems.
    - Remote control and command network (based on results from TAURO)
    - Automated planning, generation of planning and engineering, automatic V&V of planning, auto-corrections, certifiable proofs for certification
    - Virtual Certification
- Intelligent and Integrated Asset Management (FA3)
    - Machine readable Ontology of Assets Lifecycle domain
    - Cybersecure networking, (cabled, Wi-Fi, or satellite) of distributed Internet of Thing sensors and devices, mobile and stationary
    - Data collection/aggregation from networked assets, sensors and devices
    - Statistical methods and tools to support the solution of data inconsistencies
    - Providing digital twins for Predictive, prescriptive and Condition Based Maintenance
    - Construction site surveillance, inspection and project management
- A Sustainable and Green Rail System (FA4)
    - Holistic Energy Management, including monitoring and metering of energy production, recovery, distribution, consumption; monitoring and metering emissions

    - Environmental monitoring in and around the infrastructure (noise and vibration, meteorological, electrical, pollutants)
- Full Digital Green Logistics (FA5)
    - Digital capacity management
    - Digitalization of cross-border freight traffic and freight logistics chain
    - DAC as enabler for digital freight transports and upgrade for locomotives
    - Digital customer interfaces and services
    - Goods data sharing platform
    - Data harvesting and digitalization of freight operations
    - Integration of last mile services and digital shipment consolidation
- Seamless rail freight (FA5)
    - Telematics data
- Innovative Freight Assets (FA5)
    - Status supervision of freight trains
- Regional rail services / innovative rail services to revitalize low density/rural railway lines (FA6)
    - Data sharing and Integration
    - Passenger Information System
    - Virtual certification of the rolling stock
    - Virtual certification of the CCS
- New / Emerging transportation systems (FA7)
    - Defining digital interconnections & interfaces between existing offers in the field of public transport, mobility services, logistics and future MOD systems
    - Customer oriented services supporting automation and unstaffed transport by iCCTV & PIS for automatic handling of passengers and goods,
    - Development and demonstration of distributed security mechanism for enabling data and model exchange between transportation modes

#### *7.8.1.4 Who does what by stakeholder group*

The **IM's/RU's** can provide detailed understanding and relations between solutions and performed rail operations. Hence they can provide data structures and content as well as processes as e.g. certification which can be subject for digitalisation.

The **Suppliers** will develop digitalisation solutions and provide innovations based on state-of-the-art technologies in the area of digitalisation. The group of suppliers represent the core of the rail supply industry making it possible to apply digital technologies during development phase. They are mainly responsible for providing the system solution, related data and/or models of the products and tools based on the operating community requirements and specifications including the development of prototypes and necessary equipment for demonstrating the use cases.

The **Research Centres** are in charge of supporting and providing methods to both IM's / RU's and suppliers as well as any possible scientific or methodical issues that may arise during the development of digital enablers. With the support of the research centres, a new generation of technologies can be matured into market-ready solutions together with the suppliers.

#### *7.8.1.5 Interaction with other Programmes, European and/or National*

Further, the connection to sectors beyond railway needs to be established. Besides synergy-enabling activities with similar topics in the other partnerships of Horizon Europe, the initiative GAIA-X is of special interest. The TT of digital enablers focusses on a holistic integration of the digital railway ecosystem at three stages: Data, Services and Edge-Cloud infrastructure. Therefore, it is obvious, that a strong link can be drawn to other EU programmes on edge-cloud technology and information technology in principle. Thus, the GAIA-X initiative is a central point of adoption and cooperation. Within this initiative, several technologies needed in rail are already under development and can be adopted by the rail sector. Since these developments are carried out on a very abstract and generic way, the ambition is to address as much industries as possible. The technology shall be usable in finance, healthcare, industry, mobility and so on. That is why the results cannot be used directly, but need to be transferred to the rail domain. Anyhow, the principles, guidelines and concepts can be used for synergy reasons.

### *7.8.2 Results/Outcomes*

#### *7.8.2.1 Operational solutions outcome*

Rapid development of digital technologies offers numerous opportunities for creating new value-added services in the railway industry. To seize these opportunities, three levels of action are required.

First: 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 standardized data structures to form a data ecosystem that meets the requirements of the railway industry, esp. the exchange of digital twins. The requirements to exchange data are focusing on high data security, -integrity, -sovereignty, and –privacy, access, control, transparency, traceability. As an outcome, the members of the working group shall establish a blueprint architecture, which enables all railway stakeholders to participate digitally in common data space ecosystems within railway and other domains. The blueprint is primarily based on data relationships among trusted partners that are governed by a system of standards (e.g. Conceptual Data Model (CDM), GAIA-X, International Data Space Association) for secure and sovereign data exchange, certification and governance for business and industry across Europe. To ensure a smooth uptake a continuous integration of the experts form the FA and SP is essential.

Second: The need to properly process data by standardized services.

The data available is meant to be made use of by powerful tooling 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 visualization as generic data services for reuse in all applications and for all kinds of digital twins. This software might be used to handle data objects or digital twins, regardless of the respective application the digital twin is meant for. Examples of these generic functionalities are compression of digital twin data, encryption, efficient data transport or data transformation. The services shall therefore include generic platform minimum architecture (such as data dictionary and common standardized railway ontology) as well as functionalities for distributed platform architectures. Here, the blueprint architecture for any kind of digital twin is developed to link to the work of the other flagship areas, where the respective application is worked out in detail and therefore the software and services – including potential application logic – is compiled.

<u>Third: Powerful data and communication infrastructure.</u>
The above mentioned software and data assets require a digital infrastructure to exist in. Not only sensor hardware (e.g., satellite data, drone, etc.) but also backend technologies such as HPC centres as well as digital edge components (on-board systems and interfaces) have to be adopted for usage in a federated railway digital edge-cloud continuum. Also, the data transfer technology in between these infrastructure elements (e.g. connectivity as 5G, protocols for encryption, data protection, etc.) shall be adopted for usage within the railways. Most of these technologies are already available from other sectors and it is envisioned to utilize them for the railways.

They all together form a concept called the “**Railway digital enabler” or “edge-cloud continuum”** with adequate interfaces and transfer of principles.

Because of the major importance of the concept of digital twins within the railways, the figure below displays the details of the above-mentioned concept in more depth and displays the relationship between the surrounding ecosystem and the digital twins.

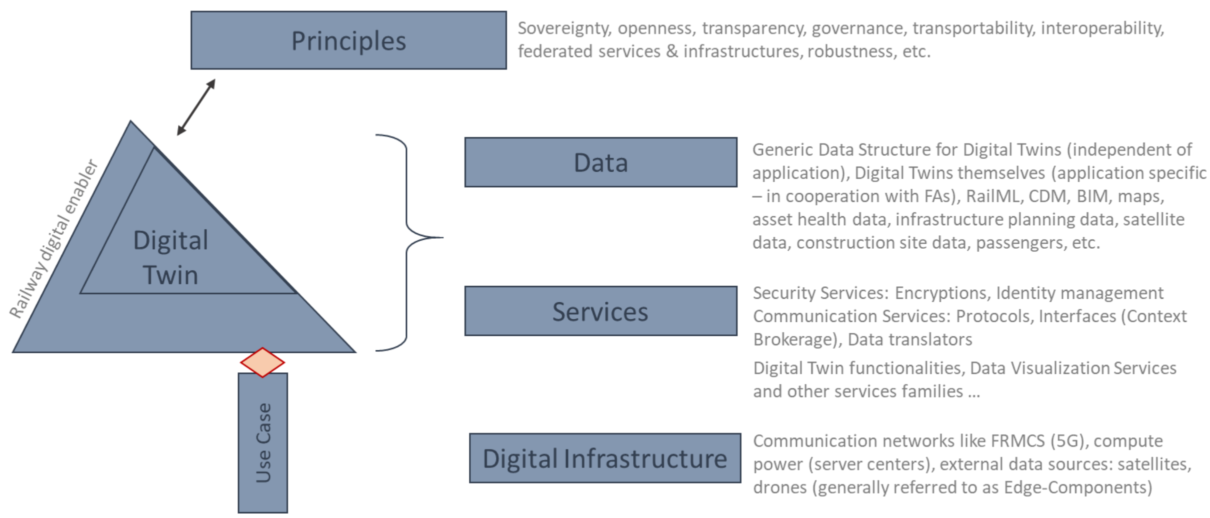



*Figure 32 - Railways digital twin ecosystem*

Here, the railway digital enabler is meant to be considered as a set of concepts, models, technologies and methods addressing the three levels of actions = data, services, digital infrastructure. It relates to the concept of the digital twin in a way that the digital twin exists within this larger digital environment of data, services and digital infrastructure while the twin itself carries its data, services methods and application logic along. The railway digital enabler is therefore an abstract object that needs to be filled with real technology and architectures in a later and more specific stage of the work programme. Some examples of possible work areas that might be addressed or adopted are listed within the picture for clarification of the concept. Related to that concept, it should be emphasized that in addition to a common standardized / well-documented data space, a common standardized / well-documented semantics and standardized / well-documented protocols are also needed and shall be worked out in detail.

Core results of the transversal topic will therefore be:

1) the above-mentioned open, trusted and sovereign data space architecture for railway digital twins and the identification of technologies needed for its implementation.
2) 2) The elaboration of principles and standards for developing generic and reusable software and services for rail applications with the overall goal of balancing the CAPEX vs OPEX.
3) 3) The definition of concepts for development and use of data infrastructures such as communication technology (e.g., 5G, FRMCS), HPC centres and other means to satisfy specific data demands.

It is of key importance for the opening of the market that access to the Rolling Stock models is kept open, in order to promote design and validation independence.

*7.8.2.2 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 organizations, and the extension of the network must be allowed to grow as the digitalization of the overall system progresses and becomes more and more interconnected with other mobility and industry sectors in the European digital economy.

There is therefore a need to build a mechanism for making all these data available to specialized digital applications in multiple domains while – at the same time – a) allowing incremental extensions and avoiding the rigidity of synchronized and centralized deployment timelines and b) providing data owners with the ability to retain control of their assets.

**Conceptual data model (CDM)**

The above mentioned importance of high quality data and its accessibility is key to the success of the next generation of railway application and services. Therefore, the data does not only need to be of high semantic quality, but also has to be formatted by a standardized high quality syntax. Here data formats come into play, whilst TT emphasises the importance to continue on the excellent work done in recent R&D activities on the conceptual data modal.

Not only shall the underlaying concepts and principles of the CDM be respected, they shall be developed further as described in section 2, to add additional value (e.g. transparency, sovereignty or governance) and to make use of it using fully interoperable digital twins in syntax and semantics.

**Digital Twin Design-time environment**

The availability of data resources in the federated data spaces allows the development of "Digital Twins", or digitally replicated versions of the rail system's real-world entities and processes, synchronized at a specified frequency and fidelity. These digital twins 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 coefficient and/or variables of the model's logico-mathematical expressions. These models may be created by composition or coupling of sub models of constituent components.

A Digital twin Design-time environment consists of a set of software tools and procedures allowing domain model experts to develop the entities' models, and to store them as compiled 'black-box' units with standard interfaces for reuse in the composition of higher level models. Developers of the compiled units retain control on the reuse of models, which can only be accessed through the standard interfaces without the need to expose the models' encapsulated knowledge. Tools that can automatically assess compliance with the standard interfaces are also part of the build time environment in order to ensure that they can interoperate when deployed on the digital twin runtime environment.

**Digital Twin run-time environment**

Compiled model units are used in simulations using instance coefficient and variables data available on the federated data space. Simulations may involve multiple independently developed units which are connected through standard interfaces between them and with the underlying data federation spaces. Mechanisms are therefore provided by the runtime environment for deploying and configuring the simulation execution, the initialization, and for executing and monitoring simulation runs. The results can be analysed in a powerful analytical visual interface for root cause analysis. Digital Twin run-time environment will have capabilities to connect real time streaming data from physical assets to enable real time operational twin assisting the operators in decision making.

An estimation of the technical readiness level of the capabilities in 2025, 2027 and 2031 is provided in Table below.

| **Capabilities enabling Operational objectives** | **TRL in 2025** | **TRL in 2027** | **TRL in 2031** | **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 focusing on one source model of X2Rail4 of TMS. Based on the alignment with FAs we need to prioritize the source models and improve the coverage. In case of more coverage of source models such as BIM, the TT needs more time. |
| Identity and Trust Services | 6 | 7 | 8 | The IAM and CyberSecurity is designed and implemented by the outsourced company. The company shall also specify how to keep the |

| Capabilities enabling Operational objectives | TRL in 2025 | TRL in 2027 | TRL in 2031 | Allocation |
|---|---|---|---|---|
| | | | | security intact for future enhancements. |
| Data Assets Registry and Discovery Services | 5 or 6 | 7 | | Specified and outsourced to IT company. Based on the initial usage and feedback from FAs, the services are improved. |
| Data Assets Distribution Services | 5 or 6 | 7 | | Specified and outsourced to IT company. Based on the initial usage and feedback from FAs, the services are improved. |
| Digital Twin Design-time Environment | 5 | 6 | 7 | The design time environment is outsourced.<br>TRL 8 due to missing features or enhancements needed based on the feedback from FAs after initial uses and enhance further to 9 on continuous basis. |
| 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 FAs and TTs. This forms the foundation library of FMUs. The development environment provides basic necessary twin models based on which FAs can 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 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.<br>Not reaching TRL 8 due to missing features or enhancements needed based on the feedback from FAs after initial uses and enhance further to 9 on continuous basis. |
| FMU deployment and Configuration | 5 | 6 or 7 | 7 | reasoning is same as FMU Twin model |
| Federated Data Spaces | 6 | 7 | 7 | The coverage of data space federation could be low at the beginning focusing on specific FA demonstrator like FA1 to simulate real time traffic just as an example. Based on the experience the TRL can be increased. |
| Federated dataspace Interface and messaging infrastructure | 6 | 7 | 7 | Specified by TT and delivered by IT company |
| Time management | 7 | 8 | 8 | Specified by TT and delivered by IT company |

| Capabilities enabling Operational objectives | TRL in 2025 | TRL in 2027 | TRL in 2031 | Allocation |
|---|---|---|---|---|
| Simulation execution monitor | 6 | 7 | 7 | Specified by TT and delivered by IT company |
| Root Cause Analysis Tool | 5 | 6 | 7 | Specified by TT and delivered by IT company |

*Table 49 - Estimation of the Technical Readiness Level of the capabilities in 2025, 2027 and 2031*

The above mentioned TRLs are to be updated after feedback of the FA with respect to the needs of their Use Case.

The operational solutions outcome requires of technical enablers to develop, implement and support the solutions described.

The edge-cloud continuum or the rail digital enabler as well as the digital twin outlined above is at first hand "just" an architectural pattern and needs to be specified in more detail. Thus, technological components or building blocks can be identified to show probable cause of a later implementation. Some of these technological enablers are listed below:

- ML/AI generic tools to:
    - aggregate and analyse data from different data lakes,
    - compare predicted behaviour of a system with its observed behaviour (possibly with a physical model), and build a statistical model in order to predict more accurately the actual behaviour of the system
    - elaborate decision support systems for real time traffic management or maintenance planning or rescheduling after incidents
- technologies to develop real time fatigue or degradation models for strategic assets ,or traffic management, the current models being more design oriented being often quite long to run , as no real time applications were needed so far
- Technologies to describe a **generic an standardized data space** for the railway domain to create and access **digital twins** of railway assets in an open, standardized, trusted and widely used data repository including machine readable ontologies. Technologies needed / enabling this activity might be IDS and/or FiWare.
    - The Ontology-based approach of the CDM from LinX4Rail should be further developed , including ontologies related to architectures
- Other technical necessary IT enablers are listed below :

    Connectors and interfaces, identity providers Individual data lakes Edge device extensions, Data transfer and encryption technologies
- From the (model-based) operational specifications, to validation of system models, a number of standards (in specifications and interfaces) would make easy the task of building a digital twin. All of that, in a transversal way and 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

#### *7.8.2.3 Implementation Approach*

For proper implementation, the work is carried out in close cooperation with the other flagship areas and with the system pillar in particular. In order to ensure the best common results the work is organized within two layers. In the first (blue) layer, the work on the digital enablers is embedded inside the flagship areas, whilst, 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 of the rail sector are explored and adapted if suitable. It is assumed that all FA projects have a dedicated WP on digitalisation which is implementing the digitalisation enablers inside the FA.

<u>Embedded implementation (blue layer)</u>

The idea behind this approach is to ensure, that the knowledge and the requirements of the respective railway application – reflected by the different flagship areas – towards the Digital Enablers inside the TT is conveyed properly. Since the flagship area experts know the best of what the digital needs are, to handle their application optimally. That is why digital enablers like specific digital twins need to be developed in very close cooperation with the respective flagship area. Here, the very details of the data and algorithms are discussed and developed, that lead to a proper implementation of the inner logic and correctness of the digital assets (e.g. a digital twin of a maintenance activity, or a network part or an algorithms logic for failure detection and similar).

<u>The traversal part (green layer)</u>

Within the green layer, the more conceptual work is being implemented to support the work in the flagship areas in a way, that it creates specifications, tools and concepts on how the above mentioned digital assets can be build, so that they are going to be interoperable to each other. This approach shall pave the way to enable cross-application use of the data, services and algorithms often referred to as “co-simulation”. This co-simulation shall enable the usage of data and knowledge within an application in railways, that usually would not have access to that information, due to barriers often found in large companies. This is the key value, that is being added by the TT, to describe how a federated ecosystem could be created and used by the different applications and railway units in an interoperable way.
The green layer therefore builds the bridge between the flagship areas, the system pillar and the generic IT specific parts of the work package.

<u>Generic IT parts (orange layer)</u>

While working on digital aspect of the railway system it is necessary to include non-railway generic IT tools and concepts. The orange painted layer deals with aspects within the TT that shall be outsourced or subcontracted to railway stakeholder interested in these topics or non-railway stakeholders and suppliers from the IT sector. Here, the partners are dealing with generic IT technology and concepts, that are used (not developed) and adopted to support a respective railway application and its needs. E.g. communication protocols (TCP/IP) , data encryption/compression, visualization, service API specification and/or cloud technology in general that might be used within the ERJU innovation programme.

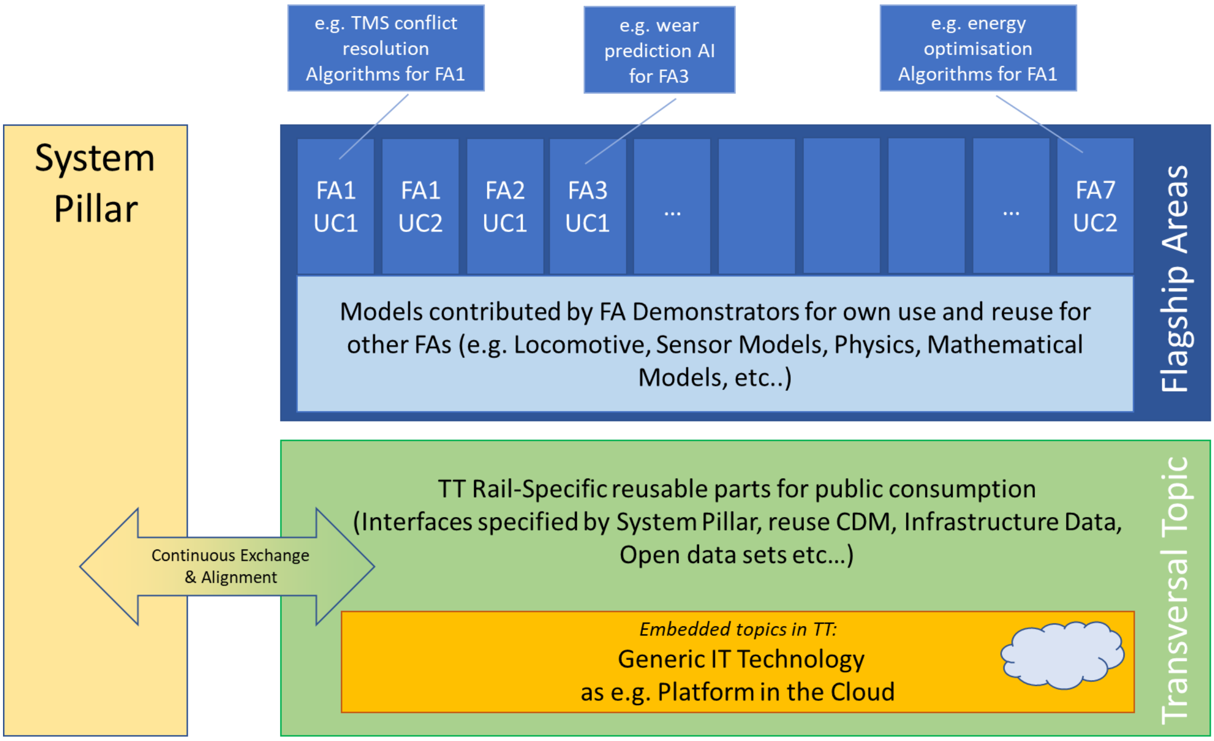



*Figure 33 - Implementation approach and interaction with the flagship areas*

The interaction between the TT and the SP is focused on the optimal outcomes of common railway architectures, since the specifications and standardisation outputs are important deliverables to the overall program.

#### *7.8.2.4 Demonstration implementations*

The blueprint of the rail digital enabler for railways' architecture has to be implemented in a way that railway specific digital value-added services can run 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' Common Mobility Data Space can be used to deploy specific use cases in the area of distributed digital twin, between all stakeholders (train operators, infrastructure managers, ECMs, train builders, suppliers of train components and systems and for infrastructure components).

In EU-RAIL JU demonstrations for the rail digital enabler and the individual digital twins in it shall fulfil the following requirements and conditions:

- Show how the system is able to analyse signalling specific communication protocols (in non-invasive and transparent mode) and identify potential cyber or physical safety or security anomalies
- Use the same data model for at least two different applications (optimally developed by two different entities) and ensure that they produce the same outcomes

- Simulation in the laboratory of specific behaviours (within asset management, traffic operations, etc.) using digital twins including the required physical models
- Virtual certification/homologation without requiring field validation.
- Use of Edge and Cloud Computing to run existing applications with the same outcomes under the new constraints and/or conditions.

#### *7.8.3 Impacts*

##### *7.8.3.1 Description of the impacts against existing rail services*

The development of a framework "railway digital enabler" will cover the entire railway sector and system to gain on efficient implementation in the real world as a second step. Consequently the digital interoperability will increase. The use of digital enablers will enhance by principle the harmonised approach to evolution and greater adaptability. A a consequence the costs for development, certification and operation are reduced which again improves the EU rail industry competitiveness.

| | |
|---|---|
| | Reduced costs<br>To allow the deployment for existing networks, the representation and detailing of digital twins will be allowed to continuously improve over time and in areas where positive effects are to be expected. The twin capability will be not just help to understand history and present situation, but also simulate scenarios with continuation and forecast alternatives for use and maintenance evolution/change. This approach will lead to huge benefits and impacts in designing significant evolution of the railway system. |
| | Harmonised approach to evolution and greater adaptability<br>Design and planning based on verified performances all along the design cycle can be achieved following the digital twin approach, rather than design based on specifications. This would ensure a quicker development cycle: in the current approach if performance is not met at the end of the development cycle, it has to be restarted from the beginning. The proposed approach would lead to a continuous check that the performances are met all along the development cycle. |
| | Improved EU rail supply industry competitiveness<br>The need of using real physical networks, data and systems for authorization processes will be significantly reduced by virtual validation and certification processes. The virtual certification resulting from this process is an important step to shorten and to make more efficient the time to market needed for railways assets e.g. the rolling stock. Some initiative have been taken for several years, some by the stakeholders, some gathered in European projects. The TT approach will consolidate them and increase their impact.<br>The digital twin will provide a much more realistic framework for virtual certification, already addressed in S2R than individual subsystem |

| | |
|---|---|
| | simulation could when strong connections with other subsystems are needed (like HIL testing philosophy). |

Table 50 - Descriptions of TT impacts related to the intended impacts in the Master Plan

#### 7.8.3.2 Quantitative KPI demonstrated in this FA

The digital twin capability in order to be full beneficial it must support the automatization of some tasks that today are still conducted on the field. Moreover, the availability of historical data about a “twin” should not only allow to assess the current status of the asset but as well as to predict the future behaviour. The first 3 KPI are oriented to monitor the improvement in the number of tasks that can be executed in the laboratory. The 4$^{th}$ KPI is oriented to monitor the improvement in the predictive capability.

The KPIs 5 & 6 are useful to identify which are the most critical data types to be considered for modelling as well as to check for the harmonization of the process.
Another important aspect is the Data Readness for FA application based on FA requirements, any data must meet the data quality requirement for a specific application. The KPIs 7 & 8 monitor the improvement of the consistency and completeness of the data as well as the quality level expected for the specific FA application.

The adoption of digital infrastructures based on edge-cloud continuum poses new challenges to manage cybersecurity vulnerabilities and data transfers. The KPIs 9 and 10 are oriented to monitor the improvement in the time to respond and time to complete a data transfer.

| KPI description | Improvement |
|---|---|
| ***Digital Twin Capability*** | |
| 1. Number of infrastructure inspections that can be conducted in laboratory without requiring field inspection. | % increase in lab |
| 2. Number of rolling stock inspections that can be conducted in laboratory without requiring field inspection. | % increase in lab |
| 3. Number of virtual certification tasks that can be conducted in a laboratory | % increase in lab |
| 4. Number of predicted future behaviours thanks to the digital twin use | % increase in predictions |
| ***Data Modelling*** | |
| 5. Number of times the same data type is managed in isolated manner in a process using an independent system. | No. of use |
| 6. Number or share of data entities that have been homogenized. | No. of use |
| ***Data Quality*** | |
| 7. % of coverage physical asset with related digital twins (completeness) | % increase in coverage |
| 8. % of errors present in the digital twins list (inconsistency) | % reduction against 2022 baseline |
| ***Cybersecurity*** | |
| 9. Data Security – Role based security of data in DT environment measured by passing of white hack test | Increase in no. of survived tests |
| 10. Time to respond and resolve a vulnerability | Reduced time |
| ***Connectivity*** | |
| 11. Time to complete a data transfer task from the Edge to the Cloud. | Reduced time |

Table 51 - Overview over the TT KPI improvements

KPIs need to be discussed, adjusted and agreed with the FAs with respect to their specific Use Cases and the resulting need for improvement.

#### *7.8.3.3 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 digitalized railway system. To make an efficient switch to this future reality, the TT results must support a deployment of the 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, the 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.

## 7.9 Exploratory Research and other activities

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

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

- Study on upcoming enabling technologies and general/breakthrough innovations coming also from other sectors as well, that can be applicable to the rail system and sub-systems.
- Disrupting the innovation cycle itself by applying game changing methodologies with the goal of significantly shortening time to market and significantly reducing costs of the innovation process itself and the resulting solutions.
- Socio-economic and market influencing factors analysis, including user-acceptance studies (reflecting changes in demand), taking various geographic settings into account (regional, intercity, urban, etc.).

- Research on emerging technologies or their critical subsystems, including mag-lev/magrail/aerodynamic propulsion and vacuum tube technologies, such as HyperloopTM solutions.
- Research on business, innovation and transport models.
- Research on emerging safety, security and certification issues.
- Personalised rail infrastructure/vehicle concepts moving over different transport modes infrastructures.
- Multimodal, customer-centric and sustainable, shared-mobility solutions including full integration with other modes of transport, including in an urban environment.
- Studies of ultra-high speed (beyond 500 km/h) trains and synergies with non-conventional and/or emerging new modes of transport (e.g. hyperloop).
- Impact of innovation on operations and human factors.
- Setting up networks bringing together different rail communities, such as in relation to regional hydrogen rail, rail research centre around specific concepts, etc.
- Programmes for PhDs on EU-Rail related activities.

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

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 the future rail research and innovation solutions, as well as to support their deployment.

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

The work performed in the System Pillar ensures the convergence of the sector on the future concept of operations and underpinning system architecture that will transform the performance of the European rail system and contribute to eliminating physical and digital barriers; the Innovation Pillar will deliver the operational and technological solutions which provide the necessary capabilities to transform the European rail system. Only via a coordinated and integrated deployment of system integrated solutions can rail reap the benefits of the investments made, accelerate its transformation and deliver new services to its clients. Notwithstanding these uncontested targets, the relevant adaptations in the legal framework must not be forgotten; be it at the level of EU and / or national legislation, be it at the level of standards. They must be developed in a well-coordinated manner to support a swift deployment of the solutions, where the transition phase is of utmost importance.

In the past years, the deployment of innovative solutions has too often resulted in a patchwork system, where the intrinsic benefits of investments were lost and even resulted in additional costs as, in many cases, such solutions have been deployed as additional layers on existing systems or a patchwork. This resulted in doubling the maintenance costs, in additional complexities, in a lack of trust in the new solutions and, de facto, has anchored Europe rail systems to their legacy, missing the opportunity for a major transformation. How quickly these obligations were implemented, very often depended on the state of the legacy system, national transport policy priorities and the available financial power of the relevant stakeholders. Therefore, the baselines among MS may vary considerably and need to be taken into account when setting up a specific transition regime and an investment plan. Without the full support of the concerned stakeholder groups, a swift deployment will not take place and 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 shape also the execution of the future EU-RAIL projects and a different approach: where the introduction of innovative solutions has a clear impact on rail in its systemic nature, deployment shall be coordinated and consistent to accelerate the return on investment and phase out legacy products. This new way of working shall be based on more flexibility and adaptability to user needs, creating solutions much more focused on prototyping and large scale demonstrations, and increased collaboration integrating new entrants, leading to a shorter innovation cycle and delivering impactful results.

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

- Examine and provide recommendations on alternative scenarios for the rollout of innovative solutions.
- A roadmap for the coordinated and integrated deployment of the relevant rail research and innovation results, (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 consideration on the necessary accompanying funding and financial measures.
- Use of a performance scheme that would contribute to accelerating deployment and/or any other relevant measures.
- Any other relevant matter that would contribute to reducing the innovation lifecycle and increase the performance of rail, maintaining the same level of safety or increasing it.

The 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 TRL9, in order to allow phasing in deployment as from 2025.

# 9 Financial Resources of EU-Rail

The Union financial contribution from the Horizon Europe Programme to EU-Rail, including EFTA appropriations, to cover administrative costs and operational costs, shall be up to EUR 600 000 000:

- R&I Programme: EUR 576 000 000, of which
  - System Pillar, at least EUR 50 000 000
  - Innovation Pillar, EUR 526 000 000, of which
    - Industrial Research , EUR 462 500 000
    - Exploratory Research and Other, EUR 63 500 000
- Running costs 24 000 000

This amount could be later complemented with additional Union financial contributions coming from other programmes; it may be increased with contributions from third countries associated to Horizon Europe in line with Article 16(5) of the Horizon Europe Regulation and provided that the total amount by which the Union contribution is increased is at least matched by the contribution of members other than the Union, or their constituent or affiliated entities.

The total value of the Programme is estimated at EUR 1 266 796 000:

- R&I Programme: EUR 1 218 796 000
  - System Pillar: EUR 58 824 000, funded up to EUR 50 000 000
  - Innovation Pillar: EUR 1 159 972 000
    - Industrial Research, EUR 1 069 258 000, of which EUR 22 731 000 of Additional Activities (Article 2(9) SBA) and funded up to EUR 462 500 000
    - Exploratory Research and Other, EUR 90 714 000, funded up to EUR 63 500 000
- Running costs: EUR 48 000 000.

The Innovation Pillar – Industrial Research in terms of Total Value of the Programme, amounts to EUR 1 046 527 000 excluding the Additional Activities (Article 2(9) SBA) and is split indicatively in the following areas of priority and large-scale demonstrations:

| | EUR |
|---|---|
| Flagship Area 1: Network management planning and control & Mobility Management in a multimodal environment | 133 849 000 |
| Flagship Area 2: Digital & Automated up to Autonomous Train Operations | 251 865 000 |
| Flagship Area 3: Intelligent & Integrated asset management | 217 414 000 |
| Flagship Area 4: A sustainable and green rail system | 169 193 000 |
| Flagship Area 5: Sustainable Competitive Digital Green Rail Freight Services | 136 328 000 |
| Flagship Area 6: Regional rail services / Innovative rail services to revitalise capillary lines | 82 286 000 |
| Flagship Area 7: Innovation on new approaches for guided transport modes | 15 687 000 |
| Transversal Topic: Digital Enablers | 39 905 000 |

# 10 Multi-Annual 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 research and innovation indirect actions, selected following open, transparent and competitive calls except in duly justified cases specified in its annual work programme in order to set additional conditions requiring the participation of Members of the JU.

EU-Rail has opted to make use of Lump Sum Grants, complemented as needed by procurement procedures or any other instrument foreseen in its Financial Rules.

The Programme is implemented via multi-annuality by instalments, allowing EU-Rail to launch calls and sign grant agreements beyond the annual budget appropriations availability, in order to strengthen and integrate the scientific, innovation and technological capacities and facilitate collaborative links across the Union to support the creation and diffusion of high-quality new knowledge and skills, in particular with a view to delivering on global challenges, securing and enhancing Union competitiveness, European added value, resilience and sustainability.

In this respect, on indicative basis, EU-Rail Programme is expected to be implemented as it follows:

***With regard to the System Pillar activities***

Considering

- the need to ensure that the functional system architecture and concept of operations are ready in their initial elements before the start of the other research and innovation activities,
- the type of expertise required to perform such activities,
- to benefit from large flexibility in the 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 implementation via one or more framework contracts (procurement) appears to be the most appropriate approach. The first call for tenders is expected to be launched by the end of the first quarter 2022.

***With regard to the Innovation Pillar activities***

This constitutes the core of the Programme, where the Other Members are expected to provide their contribution up to EUR 576 million.

In accordance with the SBA, as already mentioned, EU-Rail shall provide financial support, mainly in the form of grants, to research and innovation indirect actions, selected following open, transparent and competitive calls except in duly justified cases specified in their work programme in order to set additional conditions requiring the participation of members of the joint undertaking or their constituent or affiliated entities.

In order to ensure a smooth rump up phase of the Programme and especially

- securing sustainability-driven global leadership and resilience of Union value chains in key technologies and industries in line with the relevant Union policies;
- developing and accelerating the uptake of innovative solutions throughout the Union addressing climate, environmental, digital and other global challenges contributing to Union strategic priorities, accelerating the economic growth of the Union 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, as it follows:

- Call 2022, planned for Q1 2022 and expected to cover up to 50% of the research and innovation activities value to be performed between end 2022 and mid 2027, to reach overall TRL5, and in some cases, building upon the results of S2R also higher,
- Call 2025/2026, planned for Q1 2025/2026 and expected to cover around 30% of the research and innovation activities value to be performed between mid/end 2026 and

2029, largely to run demonstrations at large scale on mature enough solutions while ensuring a continuous pipeline of research at lower TRL,
- Call 2027, planned for Q4 2027 and expected to cover the remaining part of the activities to be performed until 2031, to ensure that EU-Rail technological and operational solutions are ready to enter industrialization and future deployment.

The overall objective is to ensure a virtuous cycle of research and innovation that would allow the transformation of the rail system with a modular and scalable approach.

In addition, during the period 2022 – 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 research and innovation 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 answers the evolving needs from the policy, technology or society perspective, a mid-term review will be performed in 2025 as well as a second one most probably towards 2028.

***With regard to the Deployment Group activities***

These activities will accompany the process that would bridge research and innovation to the future coordinated deployment and they will be defined in line with the evolution of the Programme.

# 11 Other operational activities and outreach

## 11.1 Stakeholder engagement

**Institutional Stakeholders**

EU-RAIL shall ensure the necessary relations with its key institutional stakeholders such as the European Commission, the European Parliament, and the European Council, to ensure that its activities are aligned with and take into account the policy evolution. It will also establish appropriate cooperation and coordination with the following organisations, including through formal cooperative arrangements as appropriate:

**European Agency for Railways (ERA)** - to secure close collaboration with 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, authorization, etc. and ultimately accelerating market uptake of EU-RAIL innovative solutions. Also, EU-RAIL will ensure to meet ERA needs in specific rail research and innovation activities, to maintain an integrated approach and maximize resources. EU-RAIL will also support ERA in European and international activities that relate to securing the necessary safety, security, interoperability and regulatory arrangements.

**European Union Agency for the Space Programme (EUSPA)** – to ensure coordination in relation to the role of EGNOS and Galileo in the next generation of rail operations.

**Industry stakeholders**

EU-RAIL will foster collaboration with key European stakeholders, including in particular the following:

**ERRAC** – EU-RAIL will participate in the advisory council as needed to ensure the necessary coherence and consistency of the activities and to secure the link with the ERRAC 2050 vision.

**ALICE** – EU-RAIL will liaise with the platform to ensure that rail research and innovation solutions with regard to rail cargo in particular meet the expectations of the logistic value chain.

**CEN-CENELEC-ETSI** - The participation of EU-RAIL in the standardization activities is essential to ensure a faster uptake of innovative solutions. This includes a close collaboration also by the Members of the JU with the standardization bodies. Alignment of priorities, coordination of work plans will be also considered.

**Professional staff organisations**. EU-RAIL will maintain the necessary relation with different professional staff associations to provide the necessary knowledge on the transformation expected to be introduced in the rail system.

**Passengers' associations** – EU-RAIL will ensure that the needs of the passengers as well as of PRMs are duly take into accounts in its research and innovation works. A continuous and open dialogue will be maintained.

**New entrants** – EU-RAIL will liaise with different new entrants representatives in rail as well as in the land guided systems that will be part of its activities. The JU will promote integration and inclusiveness.

Relations established with sector associations will continue building upon the progress achieved in S2R JU.

The JU will also consider how to integrate the aforementioned relations in specific works to be undertaken by industry stakeholders in supporting to deliver the Programme.

## 11.2 Synergies

EU-RAIL JU will put in place measures to maximise its impact using synergies with other European, national and regional programmes and activities. Beyond the involvement in the overall coordination of Horizon Europe, the EU-RAIL will in particular focus on capturing synergies across the following:

**Synergies within 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 multi-modal transport, automation in vehicles and other assets, decarbonisation, use of alternative fuels, etc. In particular, a specific coordination with the European Partnership for Clean Hydrogen, as well as with the Battery co-programmed partnership appear of key relevance.

**Synergies with the "Digital, Industry and Space" cluster:** Considering the key expectations coming from the digital transformation of rail, there are major expectations on how this cluster would be contributing with rail-critical applications. Artificial intelligence, cyber-security and high-performance computing are cross sectorial issues that require deep coordination especially for the development of use cases and the application of European standards. In addition, European space policy appears of key relevance, considering the ambition to introduce more and more satellite-based solutions for localization or data transmission. Here also synergies with EUSPA will be continued building upon the past experience.

**Synergies with the Co-Programmed Partnership** on AI, Data and Robotics, which could support access to such 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 4 priority areas defined under the robotics PPP, so there is knowledge to build on, notably project RIMA, the network of Digital Innovation Hubs for I&M. In addition, EU-Rail will ensure the collaboration with the ongoing 5Grail Project in relation to FRMCS, which constitutes one of the enabler of rail digitalization and automation.

**Synergies with EU Missions**: EU-Rail will explore joint activities with the Climate-Neutral and Smart Cities Mission contributing to comprehensive climate-neutral and smart urban mobility solutions. Single ticketing and smart transport hubs integrating sub-urban and long-distance passenger rail traffic with urban mobility are possible areas of collaboration.

**Coherence and synergies in relation to major national (sectorial) policies, programmes and activities:** it is estimated that around 15% of the EU stimulus package called Recovery and Resilience Facility -RRF- will be invested in different areas of rail national systems. There is a need to ensure maximum levels of complementarity and impact, including focusing on future-proof investments. This will require to leverage local, regional and national investments to complement the research and innovation activities performed at EU-RAIL level and viceversa. In this respect, the SRG is expected to play a key role.

## 11.3 Cooperation with Third Countries and other organizations

In accordance with Article 83(3), 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 research and innovation, in line with the 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 global level.

EU-RAIL will continue the cooperation set up by the S2R JU with a number of key international partners, such as FRA, APTA, FTA in the US, CUTRIC (CA), Gulf Countries, India and in the near future Australia.

In line with the policy priority of the Commission in terms of rail international relations as well as keeping in mind the aforementioned objectives, it is expected that exchanges will take place with Australia, ASEAN, Japan, South Korea and Mexico.

The collaboration with the EU neighbouring countries, in particular Western Balkans, will continue and enhances, 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 Joint Undertaking will respect the principle of sound financial management. EU-Rail shall also comply with the provisions of the Model Financial Regulation applicable to the Joint Undertaking. Any departure from this Model Financial Regulation, required for the purpose of the Joint Undertaking's specific needs, shall be subject to the Commission's prior consent. Monitoring arrangements, including through the Union representation in the Governing Board, as well as reporting arrangements will ensure that the 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 lifetime 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;
- scientific evaluation of project results

Various measures shall be established to mitigate the inherent risk of conflict of interest within the 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 Governing Board to adopt rules for the prevention, avoidance and management of conflicts of interest in the Joint Undertaking in accordance with the financial rules of the Joint Undertaking 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 Joint Undertaking, and will be monitored by the Commission. The Executive Director, as Authorising Officer, will be required to introduce a cost-effective system of internal control and management. He/she 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, as well as by following the results of ex post audits on the recipients of EU funds from 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 the control burden required and avoid lowering the attractiveness of the Union's Research programme.

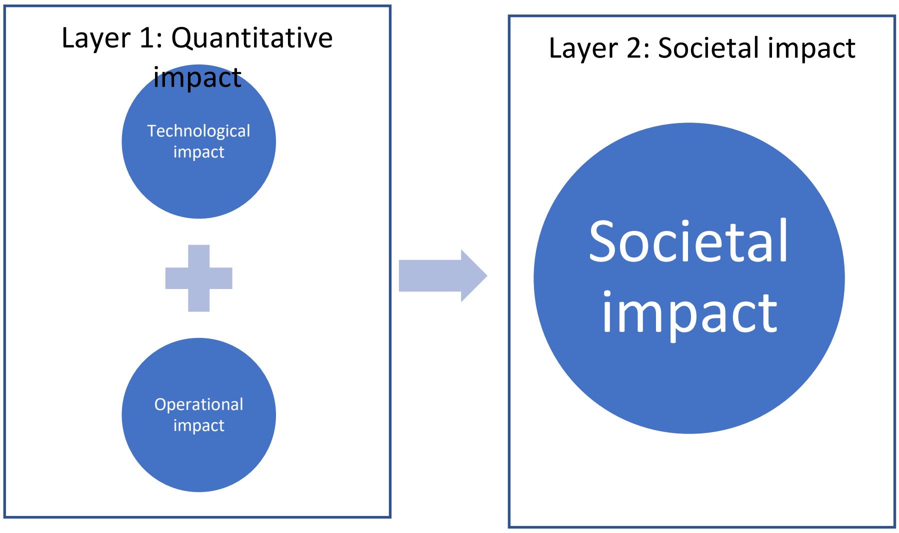
On the basis of the above, EU-Rail will implement its activities in accordance with the provisions of the SBA, its Financial Rules and other GB and ED Decisions that will provide assurance on the sound management of the resources available. In this respect, the JU, as Union body, is subject to internal and external assurance processes, as well as it has established agreements with regard to the protection of the financial interest of the Union, including with OLAF and in the future with EPPO.

## 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 KPI 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 advances generated by the research and innovation 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.




The targets and achievements of the Shift2Rail Joint undertaking are currently revised in view of the definition of impact KPIs capable to assess the performance of the innovative solutions when 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 are provided that contribute to the JU's overall KPIs.

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

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

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

## 12.3 Risk Management

EU-Rail has an established Risk Management that has been implemented within the S2R JU for the last 5 years. It is a continuous process involving 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 is willing to accept (risk appetite). The Executive Director approves the policy and set the tone, staff at the different levels implement the policy. The Governing Board 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 for the requirements for the System Pillar and Innovation Pillar to inform the development of the EU-RAIL Multi Annual Work Programme. The deliverables may change through the ongoing EU-RAIL preparatory work, but should be taken as a guide of the type of outputs required from the System Pillar and Innovation Pillar in EU-RAIL, and resource planned accordingly. This document will be finalised as a basis for the work to be carried out within EU-RAIL.*

The EU-RAIL, through the System Pillar (SP) will aim to have a coherent approach to the evolution of the European rail system through a system architecture approach.

The SP has a discrete work scope to set the system architecture of the rail system (Task 1), and in particular the CCS+ architecture (Task 2), as well as coordinating the standardisation and TSI outputs of the EU-RAIL. While the main focus will be on these two Tasks, the System Pillar will have to integrate and duly considered other key subsystems, such as digital automatic coupling as enabler of future much 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), aiming at no variation compared to present.

The Innovation Pillar (IP) will deliver, through research and innovation, advances in, *inter alia*, advanced traffic management, digital and automated train operations, and rail freight.

A structured and continuous interaction between SP and IP will be necessary to achieve the overall objectives of EU-RAIL, as well as how the system work performed within the IP would integrate and remain 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 system pillar report, as well as the current proposals received from the IP Flagship areas.

When there is existing available TSI regulations or standards for these topics, the works both from the SP and the IP will be based on them and updates or modifications would be proposed instead of new drafting proposals.

As further definitional work on the system approach is carried out, there will be additional system-led requirements which may impact the work of the IP, and outputs from the IP that will influence the system architecture. It is therefore necessary to allow flexibility in definition of IP and SP outputs through 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 Flagship Area interacting with the SP and vice versa. In addition, the necessary Supervision and Change Management will be anticipated including organisation of regular review meetings.

According to the System Pillar Report SP and IP have different roles

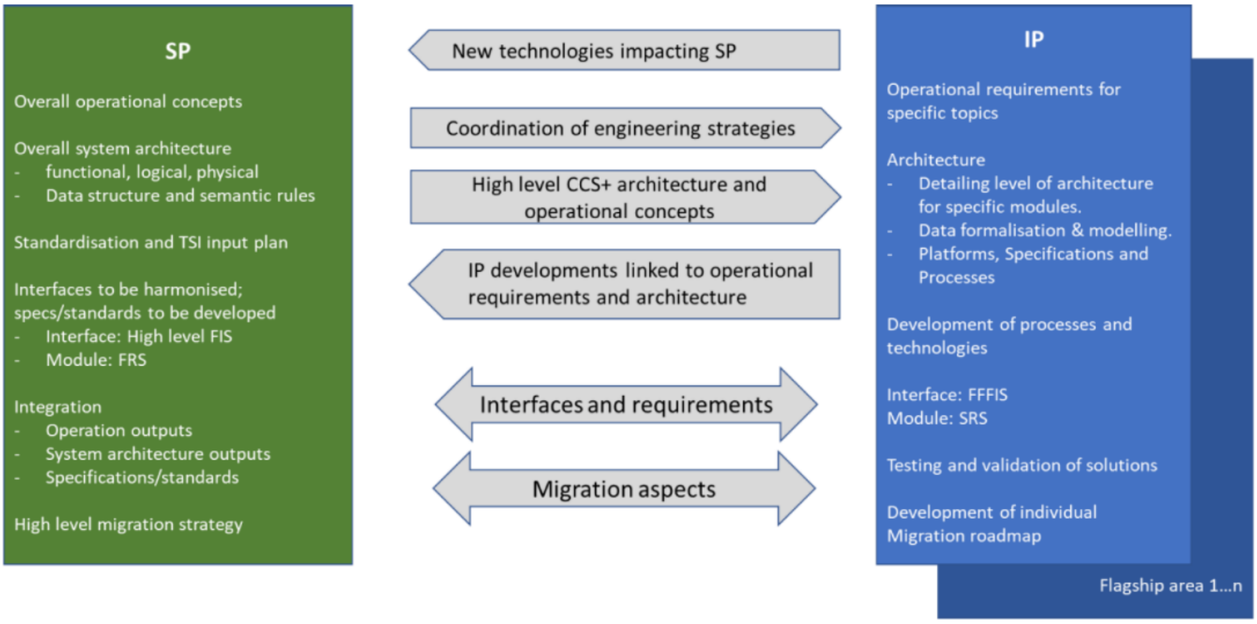



*Figure 34 - Relationship between the Innovation Pillar and the System Pillar*

The following descriptions set out for the Innovation Pillar Flagship Areas the expected split of roles between the Innovation Pillar and System Pillar.

<u>FA1</u>

Includes outcomes to improve strategic and tactical planning of rail network (planning), develop 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<br>• Functional and non-functional requirements for network disturbance resolution<br>• Functional requirements for on demand traffic management | • Specifications for planning tools and interfaces for:<br>   ○ Rolling planning and TTR<br>   ○ Decision support for short term planning;<br>   ○ Optimization methods for capacity efficiency and energy saving;<br>   ○ feedback loops from operations<br>• Technical specifications and functional/non-functional requirements for operation tools and interfaces (including with the control and command layer) for:<br>   ○ Automation and decision support; |

| | |
|---|---|
| | <ul><li>Improved real-time connection of the networks;</li><li>Real-time convergence between planning & ope.</li><li>Dispatching and I Incident management</li><li>Disruption management</li><li>Conflict detection & resolution</li><li>Speed regulation and dynamic timetables;</li><li>Real-time crew / rolling stock dispatching</li></ul> |

It is to be highlighted that this is the main layer that has been included within the CCS+ extended scope so it is expected that the outcome of the works in this topic from EU-RAIL will 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 services TSI.

| SP | IP |
|---|---|
| <ul><li>Traffic management cross-border operational principles</li><li>Operational and architecture concept for an European TM including operational requirements and CCS principles</li></ul> | <ul><li>System requirements for Cross boarder scheduling, traffic flow optimisation and deviation management</li><li>Interface specifications and data set for interoperable connected TMS</li><li>Interface specifications and data set to integrate rail traffic within door-to-door mobility</li></ul> |

<u>FA1+FA2</u>

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 related also between the traffic management layer and the control trains layer. It is understood that there will be a coordination between these FA on these topics.

In terms of ERTMS, FA 1 & 2 shall design a CCS trackside and CCS onboard functionality as a simplified technical environment for an efficient ERTMS rollout in Europe based on the harmonized operational concept provided by SP. This includes the simplification of the trackside architecture and its migration as well as the higher grade of automation for the toolchain needed for CCS system planning, configuration engineering, monitoring, etc. It may require reconsidering the distribution of the “intelligence” between onboard, track-side and European central oversight as designed in FA1. The effort for rolling out ERTMS shall be strongly reduced by designing functionality without needs for high expert skills, configuration workload or detailed special safety cases per installation. Upgrades for trackside and vehicle ERTMS functions shall be simplified by operational, architectural and functional optimisation of the technical ERTMS environment or its components.

<table>
<tr><th>SP</th><th>IP</th></tr>
<tr><td>
<ul>
<li>Functional requirements and operational concept for the interface between Operate railway system and Control & command railway system layers</li>
<li>high level signalling principles including the list of potential types of routes and what are the rules for locking, monitoring, releasing and blocking the routes</li>
<li>Users requirements and physical and logical architecture to identify the correct level of modularity required for the related modules</li>
<li>Harmonized operational concept and requirements for a homogeneous, economic and simplified use, rollout, or change of radio-based ERTMS applications</li>
</ul>
</td><td>
<ul>
<li>Technical specifications for planning tools and interfaces (including with the control and command layer) for:
<ul>
<li>Integration ATO/TMS to improve capacity;</li>
<li>ATO journey profiles for timetabling</li>
</ul></li>
<li>Technical specifications for operation tools and interfaces between control command and signalling and traffic management for automated and digital train operation</li>
<li>system requirement specifications for the systems that will define the routes and control the train movements in consequence.</li>
<li>interface specification of the system
<ul>
<li>harmonised expected input from the timetables functions</li>
<li>harmonised expected outputs towards the trackside function that allows to control trains</li>
<li>logical and physical interfaces based on SP architecture</li>
</ul></li>
</ul>
</td></tr>
</table>

Also, strong collaboration is expected between FA1 and FA2 as regards the function to Manage railway stations & depots. Higher standardisation and harmonisation in the operations for stations & depots will increase performance of the railway system in its interface with the customer. 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 data set interfaces for the connection TMS & CTC, and automated yards<br>• FA1. Data set and interfaces for the Integration with yard and station management<br>• FA2 Engineering rules for terminals<br>• FA2 Operational rules for movements in terminals |

FA2

Includes outputs for an overarching automation process and ATP evolution & optimisation. ATP and DATO are to be designed and evolved building on the same supporting functions and infrastructure, such as high-precision localization, digital topology information, safe computing platforms, on-board communication networks, train-to-train and train-to-ground communication. In addition, combination of ETCS hybrid Level 3 or full moving block and DATO will be key to increase 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. Following the principles included in the system pillar report the following deliverables would be expected:

| SP | IP |
| --- | --- |
| • Operational concept for digital automatic train operation both for nominal and degraded operations<br>• Further detailing in the architecting (concluding for example if there is or how a direct link between TMS and ATO) | • Updated specifications for GoA3/4:<br>  ○ System requirements<br>  ○ Requirements for the communication channel<br>  ○ Requirements for diagnose<br>  ○ Communication layers<br>  ○ Interfaces ATO-ETCS + ATO-TCMS + ATO-trackside<br>• Unique set of engineering rules to deploy the different stages for DATO (see the demonstrators in FA2) |

In particular, for the outcome related to harmonised supporting functions for localization, FA2 includes an outcome such as safe absolute near real-time train positioning techniques

| SP | IP |
|---|---|
| • Architecture that implements the flexible combination of a mix of trackside sensor and onboard localisation systems.<br>• Collection of the set inputs from the CCS TSI 2022 work (e.g. from the TWG architecture)<br>• performance requirement targets for the next evolution of localization systems | • develop solutions that would allow for high-precision localization, digital topology information and safe absolute near real-time train positioning techniques.<br>• FFFIS odometry platform (enhanced train localisation interface between technology independent sensors and the EVC) |

FA 2 also highlights that for the expected output, safe unattended operation must be ensured by comprehensive, modular, and scalable perception systems (onboard and trackside) for both outdoor & indoor environments. Including also for the onboard side new generation of brake systems and new methods for qualification of brake performance under degraded adhesion. This relates in the draft CCS+ architecture to the functions of control signalling devices and manage train interfaces which are key in some of the central interfaces of the CCS+ system of interest and the related systems. Hence, modularity and interface standardisation is expected within this scope.

| SP | IP |
|---|---|
| • Operational model and requirements<br>• Functional, logical and physical architecture identifying the list of signalling devices that the CCS+ layer will control<br>• Operational concept for the signalling devices (signalling principles)<br>• Open points from topical working group architecture for CCS TSI 2022:<br>  ○ Including functional allocation between control command train and offer rollingstock (e.g odometry, TDC, shared data services, cyber, DAC interface) | • Specifications for the interfaces of the trackside CCS system to the TMS, train, trackside assets and trackworker safety systems<br>• FFFIS for signalling devices<br>• (updated) system requirements for braking<br>• Revised FIS/FFFIS of the train architecture based on the innovative solutions developed in EU-RAIL |

<u>FA3</u>

Task 2 linked: 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 & renew functional module included in the operate railway system layer is the responsibility of FA3 (to be confirmed).

| SP | IP |
|---|---|
| • Maintenance & renew principles (for HW and SW assets)<br>• Identification of functionalities within this module part of the CCS+<br>• Functional requirement for interface between function manage traffic and function execute maintenance & renew<br>• Functional requirement for interface between function Control & Command trains (infrastructure & trains) and function execute maintenance & renew | • FA3 System Requirements for the CCS+ functionalities of the intelligent asset management system – linked to maintenance and renew functional module.<br>• FA1+FA3 Interface specifications between the intelligent asset management system and the Operation and traffic management system<br>• Interface specifications between the intelligent asset management system and the TR CCS (ATP Trackside, ATO, Object Controllers)<br>• Interface specifications between the intelligent asset management system and the OB-CCS |

FA3 foresees an operational outcome related to the Information sharing 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 FA 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<br>• Overall operational concept | • description of the specific developments <u>linked to the operational requirements or system architecture</u> 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<br>• economic assessments for some of these developments<br>• global simulation results for some of the developments or some specific results of the foreseen demonstrators |

FA4

Task 2 linked: FA4 Includes outputs and results relevant for the related systems to the CCS+ identified within the SP system architecture proposed. This mainly involves the energy management considerations for the functions manage traffic and control trains. However, the expected inputs from the IP to the SP can be found both in FA1 and FA4 to be detailed in which FA the work will be done or if it will be a combined taskforce.

| SP | IP |
|---|---|
| • Energy savings principles and targets for traffic management<br>• Decisions on level of requirement and modularity necessary for any input to the standardisation and TSI input plan as regards the energy savings functionalities | • Specifications for planning tools and interfaces for:<br>  ○ Optimization methods for capacity efficiency and energy saving; [FA1/FA4]<br>  ○ feedback loops from operations [FA1/FA4] for the part related to energy<br>• Technical specifications for operation tools and interfaces (including with the control and command layer) for:<br>  ○ FA1<br>    ▪ Automation and decision support;<br>    ▪ Dispatching and i Incident management<br>    ▪ Disruption management<br>    ▪ Conflict detection & resolution<br>  ○ FA4 |

| | |
|---|---|
| | ▪ Energy savings module specifications and interfaces to these functions including for a real time timetabling |

The outputs related to advanced environmental data management foreseen 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.

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<br>• Overall operational concept | • description of the specific developments linked to the operational requirements or system architecture including alternative energy solutions for RS, energy management of the stations, alternative fuels for railways, systems improvement for low consumption emissions noise and vibrations, or systems for a healthier railways<br>• economic assessments for these developments<br>• global simulation results of the developments or the results of the foreseen demonstrators |

FA5

Task 2 linked: Previous sections in this document include the expectations on FA1 and FA2 as regards the function to Manage railway stations & depots. Higher standardisation and harmonisation in the operations for stations & depots will increase performance of the railway system in its interface with the customer. Outcomes included in FA5 will collaborate to this objective

| SP | IP |
|---|---|

| | |
|---|---|
| • CCS principles, operational concept, functional architecture and requirements for specialized railway areas like shunting yards, shunting zones in stations, depots, terminals and connected industry areas | • FA1. System requirements and data set interfaces for the connection TMS & CTC, and automated yards<br>• FA1. Data set and interfaces for the Integration with yard and station management<br>• FA2 Engineering rules for terminals<br>• FA2 Operational rules for movements in terminals<br>• FA5 system requirements for automation components such as automated/automatic brake test system or automated parking brake system.<br>• FA 5 system requirements and data set interfaces for the Wagon identity system and Yard automation equipment and tools |

Task 1 linked: FA5 includes a main objective to improve the seamless Rail freight which has several outcomes relevant for the CCS+ system of interest in its layer or interface to the traffic management. The expectations between SP and IP are therefore built on the table included previously for FA1.

| SP | IP |
|---|---|
| • Operational and architecture concept for an European TM including operational requirements and CCS principles | • FA1 System requirements for Cross boarder scheduling<br>• FA1 Interface specifications and data set for interoperable connected TMS<br>• FA1 Interface specifications and data set to integrate rail traffic within door-to-door mobility<br>• FA5 system requirements for freight automatic cross-border slot finding<br>• FA5 freight requirements for seamless traffic management planning and operation |

Migration towards the target system foreseen in the EU-RAIL for freight sector is included as a challenge in the FA5 document. SP expects to deliver a Railway system architecture migration roadmap and to achieve this, it is expected from FA5 a specific migration roadmap for the target system in specific for freight.

The outputs related to freight data foreseen 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.

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<br>• Overall operational concept | • description of the specific developments <u>linked to the operational requirements or system architecture</u> including DAC type 4&5 and hybrid, new telematic solutions, Checkpoints at borders or other operational stop points, rostering concepts<br>• economic assessments for these developments<br>• global simulation results of the developments or the results of the foreseen demonstrators |

FA6

Task 2 linked: As mentioned by the FA6, the survival of regional lines and fleet depends on their economic viability. From the SP is therefore expected that this is evaluated at a rail system level including both the infrastructure and the vehicles. Hence the initial expectations from the SP to this FA focuses on the identification of the architecture elements and operational principles that would allow to achieve this economic viability.

<table>
<tr><th>SP</th><th>IP</th></tr>
<tr><td>
<ul>
<li>Functional, logical and physical architecture including the list of signalling devices that the CCS+ layer will control and the different CCS+ modules onboard
<ul><li>(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</li></ul></li>
<li>Architecture migration roadmap</li>
<li>Operational concept</li>
</ul>
</td><td>
<ul>
<li>economic assessments for optimising economic viability with the SP architecture in the regional lines
<ul><li>Criteria to define the minimum functions, modules, interfaces and constituents that will optimise economic viability for regional services</li></ul></li>
<li>Asset-lifecycle, production process and device designs (incl. simplified configuration onboard and trackside) compliant to the architecture interfaces and principles of FA1 and 2 that fulfil the economic requirements</li>
<li>As-is analysis of the current systems on regional lines for the traffic management and CCS layers. Including their characteristics description that will allow for the next steps of migration towards the digital identified target regional system
<ul><li>Including for example interface with the existing interlocking and the issues of migration for these towards the target regional CCS+ architecture</li></ul></li>
</ul>
</td></tr>
</table>

Transversal to all FA and applicable to TT

**Conceptual data model. Process and architecture models**

Building of a conceptual data model for the railway system is within the scope of the EU-RAIL. As regards CCS+, within the draft functional architecture there are several interfaces between the different functions corresponding to the system of interest yellow boxes and also between the functions in the system of interest and the related systems shaded yellow boxes. These would be the priorities for the 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 the related systems<br>• Functional, logical and physical architecture<br>• Standard framework for process specification and modelling for a centralized model integration (including assurance)<br>• Principles and method for master data management, data flows and registries (e.g. functional track network topology) | • all the FA to contribute with detailed set of data flow and structures necessary<br>• 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 assures the model integrity.<br>• Centralized ontology register and change management/governance process<br>• Centralized modelling platform (also as a extranet service)<br>• TT solutions supporting the data gathering, transmitting, storage and managing that main IM and RU are doing (including where possible automatic acquisition of the data)<br>• Specification and demonstrator for the digital register (important basis for digital twins)<br>• Standard framework as regards Digital Twins for process specification and modelling for a centralized model integration (including assurance) |

**Continuous integration of results into a simulated architecture: model checking**

In addition to the data model that will include at least the interoperable data, a digital model (or partly also simulations or implementations) which is a virtual representation able to imitate the behaviour of the railway system during the spans its lifecycle is expected from TT. This should enable continuous integration, maturity assessments, virtual certification and validation of systems or specifications. Requirements and results for these are also expected by 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 System Pillar and continuously simulated in TT that allows top-down and bottom-up integration of FA and SP results in parallel.

This continuous integration process shall allow the fast development of single functionalities as single isolated models or prototypes (based on a standard TT framework), but also shall assure their later integration into a testable model simulating the overall CCS+ or railway system architecture. The depth and functional completeness of the model shall correlate to the integration validation needs defined by the System Pillar. The model shall be designed as a continuous laboratory that also supports the change request evaluation.

The centralized architecture model service a necessary instrument for continuous integration have a high importance for achieving the System Pillar targets and the end-to-end quality of the architecture. Because of this the interaction process of SP and TT shall be close and shall base on an agile workflow management.

| SP | IP |
|---|---|
| • Defines integration and validation needs and depth for the implementation of the digital twin<br>• Monitors the continuous integration process incl. the maturity of integration | • TT defines a standardized framework for the development of prototypes that can be integrated into a full-system digital twin based on a continuous integration process.<br>• TT provides a centralized digital twin laboratory (at least for CCS+) for integration validation of prototypes, that may developd as isolated solution at first. Out of systematic test-driven development of the digital twin the lab generates reports about integration problems. The test definitions are delivered by FA1-6. |

<u>Additional considerations</u>

These expectations from SP and IP are related to the expected deliverables from the technical scope of the system. However, there are other aspects that are expected both from the SP and IP and that are critical to achieve the objectives set out in the EU-RAIL. The following are the ones that are common for the different technical scopes within the CCS+:

- Regarding migration, SP will deliver target system(s) together with the stable intermediate steps to reach there. For this, it would be expected to receive from the IP in some cases the details of the technical solutions as they are now. Also, the revision of the stable intermediate steps will be reviewed by the IP to align with the roadmap of their innovative solutions

- Maturity records or pilots for different innovative solutions are to be monitored by the system pillar. The design of such pilots should be aligned with the operational concept and functional architecture of the system pillar, so iteration between pillars should be expected. In addition, and as part of the results of these pilots, it is expected from the IP to develop the testing and validating requirements necessary to evaluate the success of the demonstrator but also to test and validate the innovative solutions once they are included in the regulations or standards. This would include the testing requirements for the new developed functions but also if necessary, the update testing requirements for any development of existing functionality (e.g. with ETCS)

- SP will define principles about data exchange, communication methods, function and service design and interface design for all interfaces that are standardized.

- Regarding requirements, SP will derive top-level requirements from the operational concepts and the identified pain-points or opportunities and will break them down to process and architectural requirements. IP will design compatible system requirements that fulfil them. As a part of the validation process the correctness of this requirement deduction 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 and no logical or physical agreed architecture approach for CCS+. Hence when we are referring to an FFFIS, this does not only mean that a physical interface is expected but this can also result in a SW interface for example. The concept of the modular safety platform for several uses is also foreseen to be further analysed. The level of detail on the interfaces and modularity needs to be discussed and agreed, including a consideration of the business and economic impact.

Once the deliverables proposed in this technical note are discussed and agreed, they will be the first input to the standardisation and TSI input plan that the system pillar 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 System Pillar as ‘generic system integrator’ for the EU-RAIL.

## *Annex B: Flagship Areas and Transversal Topic Activities interdependencies*

The table below shows the expected interdependencies between the FAs and is subject to the further changes in accordance with the output of the respective FA.

| Capability that need input/output from other FA | FA | before 2025 | currently written in 2025 | before 2027 | currently written in 2027 | before 2031 | currently written in 2031 |
|---|---|---|---|---|---|---|---|
| **DAC based digital applications on CBM** | **FA5** | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8/9** | | |
| | **FA3** | Development CBM methodologies and algorithms to be potentially exploited by the DAC based digital applications on CBM | use FA5 data outputs | Development CBM methodologies and algorithms to be potentially exploited by the DAC based digital applications on CBM | use FA5 data outputs | | |
| **DAC based digital applications for safety related applications** | **FA5** | | **Demonstration TRL7** | | **Demonstration TRL8/9** | | |
| | **FA1/2** | | use FA5 data outputs | | use FA5 data outputs | | use FA5 data outputs |
| **DAC based train operation on Train Integrity and length** | **FA5** | Requirements/feedback / adjustments that may become necessary for the use of the DAC | **Demonstration TRL7** | Requirements/feedback / adjustments that may become necessary for the use of the DAC | **Demonstration TRL8** | Requirements/feedback / adjustments that may become necessary for the use of the DAC | **Demonstration TRL8/9** |
| | **FA2** | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | |

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| **DAC based train operation on efficient driving and energy management** | **FA5** | Requirements/feedback | **Demonstration TRL6/7** | Requirements/feedback | **Demonstration TRL7/8** | Requirements/feedback | **Demonstration TRL8** |
| | **FA1** | | **TRL6** : Decision support and optimization: Optimization methods for capacity efficiency and energy saving | | **TRL7** : Decision support and optimization: Optimization methods for capacity efficiency and energy saving | | **TRL8** : Decision support and optimization: Optimization methods for capacity efficiency and energy saving |
| | **FA1** | | **TRL7:** Integration of energy management (Electric Traction System) | | **TRL8:** Integration of energy management (Electric Traction System) | | **TRL8/9:** Integration of energy management (Electric Traction System) |

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| **DAC based Yard Operation : Fully automated shunting loco movements (GoA4)** | **FA5** | Requirements/feedback / special functions for the automatic and autonomous shunting operation / train protection system for shunting as well as reaction system (push/pull functions) | | Requirements/feedback / special functions for the automatic and autonomous shunting operation / train protection system for shunting as well as reaction system (push/pull functions) | **Demonstration TRL7/8** | Requirements/feedback / special functions for the automatic and autonomous shunting operation / train protection system for shunting as well as reaction system (push/pull functions) | **Demonstration TRL8/9** |
| | **FA2** | | **development TRL 5/6 :** 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 | | **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 | | **development TRL 8 :** 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 |

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| | **FA2** | | | | **TRL 6/7:** Full supervision (cab signalling) continuously in all normal modes, also for freight stabling, or for yellow fleet movements. | | **TRL 8:** Full supervision (cab signalling) continuously in all normal modes, also for freight stabling, or for yellow fleet movements. |

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| **DAC based Yard Operation : Yard digitalization for full automated train composition and dispatching (Automated Shunting Operations)** | **FA5** | DAC based automation functions: shunting operation specific function in FA5 and ensure interconnectivity with main line systems. (ATP, positioning, object detection etc.) This especially includes DAC-based automation functions such as automatic uncoupling. | **Demonstration TRL8/9** | DAC based automation functions: shunting operation specific function in FA5 and ensure 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 and ensure 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 7 :** Automating functions, such as train preparation for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness | | **TRL 8 :** Automating functions, such as train preparation for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness |

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| **DAC based Yard Operation : yard automation equipment** | **FA5** | yard automation equipment | **Development TRL 5/6** | yard automation equipment | **Demonstration TRL7/8** | yard automation equipment | **Demonstration TRL8/9** |
| | **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 7 :** Automating functions, such as train preparation for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness | | **TRL 8 :** Automating functions, such as train preparation for both passenger and freight trains. Incident handling, vehicle self-healing and self-managing, cooperative awareness |

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| **Seamless planning of rail freight service**<br><br>**· Integrated cross-border timetable planning, management and path ordering systems covering finally all planning horizons (Digital Capacity Management) and especially the specific needs of short-term path requests for (international) freight services** | **FA5** | Requirements/feedback | **Demonstration TRL6/7** | Requirements/feedback | **Demonstration TRL7/8** | Requirements/feedback | **Demonstration TRL8** |
| | **FA1** | | **TRL7:** Cross border Planning:<br>Towards European cross-border scheduling Improved capacity allocation using Rolling planning and TTR | | **TRL8:** Cross border Planning:<br>Towards European cross-border scheduling Improved capacity allocation using Rolling planning and TTR | | **TRL8-9:** Cross border Planning:<br>Towards European cross-border scheduling Improved capacity allocation using Rolling planning and TTR |
| | **FA1** | | **TRL 6 :** Decision support for short term planning | | **TRL 7 :** Decision support for short term planning | | **TRL 8/9 :** Decision support for short term planning |

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| **Seamless planning of rail freight services**<br><br>**· Integrating and connecting the last mile (accession lines/shunting/yards/ terminals) slot planning directly or via interfaces** | **FA5** | Requirements/feedback | **TRL6** specific freight developments | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |
| | **FA1** | | **TRL 6 :** Integration with yard capacity planning | | **TRL 7 :** Integration with yard capacity planning | | **TRL 8/9 :** Integration with yard capacity planning |

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| **Dynamic dispatching tools including last mile operations**<br><br>**· Harmonised real-time interfaces between TMS and e.g. yard/terminal management systems and agreed data structure/quality** | **FA5** | Requirements/feedback | **Demonstration TRL6/8** | Requirements/feedback | **Demonstration TRL7/8** | Requirements/feedback | **Demonstration TRL8/9** |
| | **FA1** | | **TRL 6 :** Integration with yard capacity planning | | **TRL 7 :** Integration with yard capacity planning | | **TRL 8/9 :** Integration with yard capacity planning |

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|---|---|---|---|---|---|---|---|
| **Dynamic dispatching tools including last mile operations**<br><br>**· Dynamic yard/terminal management systems upgrade with optimization functions using and providing real-time information from/to the dynamic TMS systems (developed in FA1).** | **FA5** | Requirements/feedback | **Demonstration TRL6** | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL7/8** |
| | **FA1** | | **TRL 6 :** Integration with yard capacity planning | | **TRL 7 :** Integration with yard capacity planning | | **TRL 8/9 :** Integration with yard capacity planning |

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| **Dynamic dispatching tools including last mile operations**<br><br>**· Dynamic freight specific real time functions for the interaction of** | **FA5** | Requirements/feedback | **Demonstration TRL4-5** | Requirements/feedback | **Demonstration TRL6-7** | Requirements/feedback | **Demonstration TRL7-8** |

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|---|---|---|---|---|---|---|---|---|
| **various TMS (FA1) and with other management systems** | **FA1** | | **TRL 6:** Cross border operation:<br>Real-time connection of the networks<br>Improved modelling for cross-border | | **TRL 7:** Cross border operation:<br>Real-time connection of the networks<br>Improved modelling for cross-border | | **TRL 8/9:** Cross border operation:<br>Real-time connection of the networks<br>Improved modelling for cross-border |
| | **FA1** | | **TRL7:** Improved integration:<br>Connection TMS & CTC, and automated yards;<br>Integration with yard management<br>Integration of station management | | **TRL8:** Improved integration:<br>Connection TMS & CTC, and automated yards<br>Integration with yard management<br>Integration of station management | | **TRL8/9:** Improved integration:<br>Connection TMS & CTC, and automated yards<br>Integration with yard management<br>Integration of station management |

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| **ATO over ETCS adapted to regional operations**<br><br>**Progressive evaluation and implementation of driver advisory systems / radio-based, all-weather ATO over ETCS up to GoA3/4 applicable and adapted to regional operations, including an obstacle detection systems. Aspects to be considered include energy savings, optimization of driving schedule and remotely controlled trains, especially, albeit not only, in shunting areas or last mile movements.** | **FA6** | Requirements/feedback | engineering support for FA2 | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |
| | **FA2** | | **development TRL 5/6**:<br>**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**:<br>**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 8**:<br>**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 |

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|---|---|---|---|---|---|---|---|
| | FA2 | | **Safe environment perception TRL 5/6**, including signal reading and obstacle detection, supporting cooperative awareness, supported by virtual certification | | **Safe environment perception TRL 6/7**, including signal reading and obstacle detection, supporting cooperative awareness, supported by virtual certification | | **Safe environment perception TRL 7/8**, including signal reading and obstacle detection, supporting cooperative awareness, supported by virtual certification |
| | FA2 | | **Remote driving and command solutions TRL 6**, for depots, for lines with low traffic, and for fall-back operations as well as for shunting | | **Remote driving and command solutions TRL 7**, for depots, for lines with low traffic, and for fall-back operations as well as for shunting | | **Remote driving and command solutions TRL 8**, for depots, for lines with low traffic, and for fall-back operations as well as for shunting |

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|---|---|---|---|---|---|---|---|
| **Regional Hybrid L3, moving block and relative braking distance** | **FA6** | Requirements/feedback | engineering support for FA2 | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |
| | **FA2** | | **TRL 5/6:** Mixed Level 2, Hybrid L3, moving block and relative braking distance | | **TRL 7:** Mixed Level 2, Hybrid L3, moving block and relative braking distance | | **TRL 8:** Mixed Level 2, Hybrid L3, moving block and relative braking distance |

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| **Regional Cost-effective communications**<br><br>**Cost-effective use of dedicated railway mobile networks or communication infrastructures owned by a third party (e.g. 4G,5G, satellite comms and IoT communications) for the innovative ways to exchange of the information between the regional railway subsystems (e.g. Train to Train, Train to Trackside – wayside assets, Trackside to Trackside). Special attention will be provided to aspects of multibearer platforms and their use (building on Shift2Rail results on ACS and FRMCS), transmission of vital CCS data over public networks, new communication service features and their application in regional railways and to cyber security aspects. The objective is to provide 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 for connecting rolling stock and wayside elements.** | **FA6** | Requirements/feedback on dedicated railway mobile networks in the remit of FA2+ investigation on use of public networks in FA6 | **Demonstration TRL7** | Requirements/feedback on dedicated railway mobile networks in the remit of FA2+ investigation on use of public networks in FA6 | **Demonstration TRL8** | Requirements/feedback on dedicated railway mobile networks in the remit of FA2+ investigation on use of public networks in FA6 | **Demonstration TRL8/9** |
| | **FA2** | | **TRL 7:** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements) | | **TRL 8:** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements) | | **TRL 8/9:** Connectivity, including FRMCS, V2X, 5G (also taking into account FA6 cost-effectiveness requirements) |

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| | **FA6** | Requirements/feedback | **Demonstration TRL6** | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |

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| **Traffic Management Systems and C-ITS for regional lines**<br><br>**Traffic Management Systems for regional lines improving resilience of a connected rail network, optimising train operations including disturbing events. Multimodal Timetables integration e.g. tactical planning through simulation and optimization with other transport modes to ensure multimodality via integrated management of rail and other services (buses, trams, metro, taxi, carsharing, bicycles, P+R) from a single command post with the link of C-ITS services. Managing real-time on-demand optimized timetable, re-scheduling and route setting.** | **FA1** | | **TRL 6 :** Decision support for short term planning | | **TRL 7 :** Decision support for short term planning | | **TRL 8/9 :** Decision support for short term planning |
| | **FA1** | | **TRL 5 :** Decision support and optimization (operation): Increased automation in decision support, Real-time conflict detection & resolution (for regional and main line and optimisation, different from S2R) | | **TRL 7 :** Decision support and optimization: Increased automation in decision support, Real-time conflict detection & resolution (for regional and main line and optimisation, different from S2R) | | **TRL 8 :** Decision support and optimization: Increased automation in decision support, Real-time conflict detection & resolution (for regional and main line and optimisation, different from S2R) |
| | **FA1** | | **TRL 5-7:** Anticipate demand leading to improved resource utilisation:<br>Short term demand forecast calculation<br>Long term demand forecast calculation<br>Integrate demand forecast in digital twin to optimize offer<br>Manage/inform disruptions across modes<br>Optimize rail capacity to better match the demand | | **TRL 7-8:** Anticipate demand leading to improved resource utilisation:<br>Short term demand forecast calculation<br>Long term demand forecast calculation<br>Integrate demand forecast in digital twin to optimize offer<br>Manage/inform disruptions across modes<br>Optimize rail capacity to better match the demand | | **TRL 8:** Anticipate demand leading to improved resource utilisation:<br>Short term demand forecast calculation<br>Long term demand forecast calculation<br>Integrate demand forecast in digital twin to optimize offer<br>Manage/inform disruptions across modes<br>Optimize rail capacity to better match the demand |

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| | **FA6** | Requirements/feedback | **Demonstration TRL6** | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |

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| **Regional Cost-effective fail-safe highly accurate train positioning**<br><br>**Cost-effective, interoperable, fail-safe, highly accurate train positioning based on among others hybrid, multi sensor (including GNSS) technologies, digital maps onboard database, as a mean to reduce balise installations, increase operational efficiency and decrease TCO in the context of regional lines.** | **FA2** | Requirements/feedback | **TRL 5/6:** Absolute safe train positioning, highly accurate and safe, incorporating new sensors | Requirements/feedback | **TRL 7:** Absolute safe train positioning, highly accurate and safe, incorporating new sensors | Requirements/feedback | **TRL 8:** Absolute safe train positioning, highly accurate and safe, incorporating new sensors |
| | **FA2** | | **TRL 6: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO | | **TRL 6: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO | | **TRL 7: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO |
| | **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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| **Regional Cost-effective fail safe on Board Train integrity**<br><br>**Cost-effective, fail safe on board train integrity to verify the completeness of train while train is in operation.**<br><br>**Cost-effective, fail-safe train length detection to determine the beginning and end of the train and detect its length.** | **FA6** | Requirements/feedback | **Demonstration TRL6/7** | Requirements/feedback | **Demonstration TRL7/8** | Requirements/feedback | **Demonstration TRL8/9** |
| | **FA2** | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | **TRL 5/6:** Mixed Level 2, Hybrid L3, moving block and relative braking distance | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | **TRL 7:** Mixed Level 2, Hybrid L3, moving block and relative braking distance | TIMS to match the ETCS EVC (TSI CCS) (class 3, which is currently state of the art) | **TRL 8/9:** Mixed Level 2, Hybrid L3, moving block and relative braking distance |

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| **Digital platforms for CCS validation & TSI certification in the regional line domain.**<br><br>**Technology infrastructures available to the actors involved in regional line APIS (Authorization for placing into service) processes will provide integral solutions to speed up related activities and reduce associated costs, with special focus on the application of digital certification in this line typology.**<br><br>**Inspired on Zero on Site Testing EC strategy these platforms aim bringing to a digital twin a range of CCS tasks in fields like design, testing, inspection, or maintenance tasks and processes…, including working conditions traditionally performed on-site at different life cycle phases. This will allow advancing potential integration issues at early stages of a project** | **FA6** | Requirements/feedback | **Demonstration TRL6** | Requirements/feedback | **Demonstration TRL7** | Requirements/feedback | **Demonstration TRL8** |
| | **FA2** | | **TRL 5/6:** Testing, validation and (virtual) certification platforms and facilities | | **TRL 7:** Testing, validation and (virtual) certification platforms and facilities | | **TRL 8:** Testing, validation and (virtual) certification platforms and facilities |
| | **FA2** | | **TRL 6: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO | | **TRL 6: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO | | **TRL 7: Digital Register**, acting as a central data source for, e.g., safe train positioning, ATP, TMS and DATO |
| | **TT** | | Support by TT available w.r.t. digital twin and virtual certification | | Support by TT available w.r.t. digital twin and virtual certification | | Support by TT available w.r.t. digital twin and virtual certification |

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| | **FA6** | Requirements/feedback | - | Requirements/feedback | - | Requirements/feedback | **Demonstration TRL7/8** |

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| **Regional New propulsion train refuelling /recharging station.**<br><br>**Alternative fuelling solutions for regional railways such as hydrogen, e-fuels, battery fuelling (dynamic and static charging). Activities should aim at developing solutions for road/rail fuelling/charging stations along regional lines.** | **FA4** | | **TRL 5/6:** Railway strategic Hydrogen demonstrator Application of solutions for the production, storage and refuelling of hydrogen for railway vehicles on the example of a prototype refuelling station. Development of a standard refuelling interface using algorithms to ensure optimum time and safety of the process. Provide scalability and future growth of the refuelling station depending on the demand for hydrogen. | | **TRL 6/7:** Railway strategic Hydrogen demonstrator Application of solutions for the production, storage and refuelling of hydrogen for railway vehicles on the example of a prototype refuelling station. Development of a standard refuelling interface using algorithms to ensure optimum time and safety of the process. Provide scalability and future growth of the refuelling station depending on the demand for hydrogen. | | **TRL 7/8:** Railway strategic Hydrogen demonstrator Application of solutions for the production, storage and refuelling of hydrogen for railway vehicles on the example of a prototype refuelling station. Development of a standard refuelling interface using algorithms to ensure optimum time and safety of the process. Provide scalability and future growth of the refuelling station depending on the demand for hydrogen. |

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| **Virtual coupling incl. self-driving freight wagons, supporting cooperative awareness** | **FA2** | | development TRL 4/5 | | development TRL 5/6 | | - |
| | **FA5** | Requirements/feedback | | Requirements/feedback | | - | |

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| **Operational feedback for planning: Planning using feedback loops from operations**<br><br>**Integration of feedback loop with** | **FA1** | | development TRL6 | | **Demonstration TRL7** | | **Demonstration TRL8-9** |
| | **FA2** | provide parameters for planning and simulation tools to calculate the capacity benefits | | Requirements/feedback | | Requirements/feedback | |

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| **ATO/TMS for higher capacity**<br><br>**Using ATO journey profiles for timetabling** | **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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| **Optimization methods for capacity efficiency and energy saving** | **FA1** | | development TRL6 | | **Demonstration TRL7** | | **Demonstration TRL8-9** |
| | **FA4** | DAS/C-DAS and energy management experts input | **TRL 5/6/7** - 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 6/7/8** - 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). | 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). |
| | **FA2** | | **TRL 5/6: 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 | | **TRL7: : 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 | | **TRL8: : 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 | |

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| **Real-time convergence between planning & operations**<br><br>**Cooperative planning multi-actors**<br><br>**Dispatching, incident management and customer information**<br><br>**Disruption management**<br><br>**Speed regulation, precise routes and target times for ATO and dynamic timetables** | **FA1** | | developments TRL5 | | **Demonstration TRL 7** | | **Demonstration TRL 8** |
| | **FA3** | | **TRL6:** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation, etc.) and to enable high performance computing with the data | | **TRL7:** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation, etc.) and to enable high performance computing with the data | | **TRL8:** Scalable information platform to integrate and exchange information (e.g. asset health, maintenance planning, fleet operation, etc.) and to enable high performance computing with the data |
| | **FA2** | | **TRL5/6**: Automated maintenance and inspection solutions | | **TRL7**: Automated maintenance and inspection solutions | | **TRL8**: Automated maintenance and inspection solutions |
| | **FA7** | | **TRL2/3**: Specific capabilities of the innovative systems (e.g. Operational Characteristics) based on operational concept | | **TRL3/4**: Specific capabilities of the innovative systems (e.g. Operational Characteristics) based on transport coordination system | | **TRL5/6**: Specific capabilities of the innovative systems (e.g. Operational Characteristics= based on prototype |
| | **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 |