RAIL STRATEGIC
RESEARCH & INNOVATION AGENDA

SRIA

ERRAC
The European Rail Research Advisory Council

This SRIA was produced by:

Christophe Chéron, SRIA Task Force leader, supported by:

M Brennan, R French, N Furio, P-E Gautier, J Goikoetxea, U Guida, D Kuzmina, M Lundgren, C Mazzariello, M Morgan, C Nash, F. Papa, Y Perreal, J.Schlaht, S Stichel, G Travaini, and D Winkler - with contributions from many others.

The task was overseen by the ERRAC Steering Committee, chaired by Alberto Parrondo and his vice-chairs Carole Desnost and Sebastian Stichel.

ERRAC
The European Rail Research Advisory Council

RAIL STRATEGIC

RESEARCH & INNOVATION AGENDA

SRIA

Glossary of terms abbreviations

	Description
AC	Alternating Current
ACS	Advanced Adaptable Communication System
ADSS	Advanced Decision Support systems
AI	Artificial Intelligence
API	Application Programming Interface
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
AR	Augmented Reality
BIM	Building Information Modelling
CBM	Condition-Based Maintenance
CCA	Cross-Cutting Activities Shift2Rail
CCS	Control Command System
CCTV	Closed-Circuit Television
CDM	Conceptual Data Model
CEF	Connecting Europe Facility
DAC	Digital Automatic Coupling
DAS	Driver Advisory System
DC	Direct Current
DRIMS	Dynamic Railway Information Management System
DRT	Demand Responsive Transport
EC	European Commission
EDP	ERTMS European Deployment Plan
EIC	European Innovation Council
EIT	European Institute of Innovation & Technology
EoT	End-of-Train
EP	European Partnership
ERA	European Union Agency for Railways
ERRAC	European Rail Research Advisory Council
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
ETML	European Traffic Management Layer
EU	European Union
EULYNX	EU initiative for linking interlocking systems
FDF	Functional Distribution Framework
FRMCS	Future Railway Mobile Communication System
GHG	Greenhouse Gas Emissions
GoA	Grade of Automation. Range from GoA1 to GoA4

GSA	European Global Navigation Satellite System Agency
HE	Horizon Europe
HMI	Human Machine Interfaces
IAMS	Intelligent Asset Management Strategies
IEC	International Electrotechnical Commission
IFC	Industry Foundation Classes
IM	Infrastructure Manager
IoT	Internet of Things
IP #	Innovation Programme #
ISO	International Organization for Standardization
I2M	Intelligent Mobility Management
KIC	Knowledge and Innovation Communities
KPI	Key Performance Indicator
LRT	Light Rail Transit
MaaS	Mobility as a Service
PRM	Persons with Reduced Mobility
PTA	Planned Time of Arrival
RCA	Reference CCS Architecture
R&I	Research, Development and Innovation
RIMMS	Railway Integrated Measuring and Monitoring System
RSI	Rail Supply Industry
RTM	RailTopoModel
SERA	Single European Rail Area
SRIA	Strategic Research and Innovation Agenda
S2R	Shift2Rail
S2R JU	Shift2Rail Joint Undertaking
TCMS	Train Control and Monitoring System
TCN	Train Communication Network
TD	Shift2Rail Technology Demonstrator
TEN-T	Trans-European Transport Network
TERS	Transforming Europe's Rail System
TMS	Traffic Management System
TP	Transforming Project
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
TSP	Transport Services Providers
VR	Virtual Reality

Foreword

Rail has already demonstrated it can safely transport goods and passengers in the most environmentally friendly manner, thanks to technology and innovation. It has also demonstrated it can simultaneously create value and industrial jobs throughout Europe, exporting goods produced in our factories, and help preserve our planet for future generations. Rail is an essential part of the European landscape, culture and way of living.

However, European rail is currently confronted with major challenges - to preserve jobs, to maintain industrial and technological leadership, and to deliver growth to European citizens, since it needs to confront the arrival of new players strongly supported by their Governments to innovate and to be more and more competitive. From a demand side, rail has to accommodate a further increase in mobility, has to become more attractive to our citizens, needs to be more flexible and interrelate more with other transport modes. In order to meet these constrains, research and innovation is the way to transform the railway system and make it more attractive, comfortable and affordable. For the benefit of the youngest, we must accelerate the arrival of digital technologies, artificial intelligence, automated and autonomous trains, and more solutions.

Rail has demonstrated it can satisfy the mobility needs of goods and passengers, can accommodate capacity growth and can deliver large transformation programmes. The sector is rich in ideas to make effective use of technology and innovation, as you will find throughout this document.

I am proud to present this Strategic Research and Innovation Agenda as a rail sector collective contribution to help prioritise the research and innovation activities for the new Rail European Partnership. I am calling on our policy makers to endorse and support this Agenda, allocating the required budget to safely deliver our targets.

Alberto Parrondo

ERRAC Chairman
Thales

Contents

Executive Summary

This Strategic Research and Innovation Agenda (SRIA) for the railway sector in Europe sets out how a new programme of technical and operational innovation can transform the railways' contribution to mobility in Europe, addressing the needs of railway users, the economy and society, and protect natural resources and the environment. The SRIA has been produced on behalf of the sector by its European Technology Platform, ERRAC[1] (European Rail Research Advisory Council).

The ERRAC Vision and Priorities

ERRAC gathers all the sector's actors, with the mission to deliver an articulated vision of the railway's future. ERRAC's Rail 2050 Vision[2], and its Priorities for 2030[3], which inspire the SRIA, state:

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

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

ERRAC also contributed to the July 2020 rail sector statement 'Transforming Europe's Rail System[4].

The Key Challenges

The challenges of climate and environmental change, increasing urbanisation, the ambition to achieve European technological leadership and strategic autonomy and ensuring a sustainable and inclusive recovery from the Covid-19 crisis require the convergence of dispersed research and innovation efforts within a shared vision of system transformation. Addressing these issues needs long-term action plans, based on the Sustainable Development Goals of the United Nations. Rail and public transport[5] are part of the solution, offering innovated services that provide mobility for passengers and delivery of goods and thereby ensuring sustainable socio-economic evolution. This can build on rail's existing credentials as the current most environmentally friendly form of mass land transport.

A new research programme dedicated to railways, including public transport, is a unique opportunity to deliver an innovative, shared, barrier-free and integrated system, with lower service production costs that can capture a large proportion of the traffic to sustainable (low-emissions, energy, space, etc.) transport modes and to raise expectations, perceptions and opinions about the relevance, attractiveness and value of public transport. The programme must have strong links with relevant stakeholders (including end users and staff) at European, national, regional and sectoral level and with European Partnerships developing relevant technologies, such as related to Hydrogen, Batteries and Digital technology, and to Cyber-Security.

1. *https://errac.org/*
2. *https://errac.org/publications/rail-2050-vision-document/*
3. *https://errac.org/publications/rail-2030-research-and-innovation-priorities-2/*
4. *https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-transforming-europes-rail-system.pdf*
5. *In the present document, unless otherwise specified, public transport means rail based public transport duly integrated and interfaced with other public transport modes.*

SRIA - The Main Orientations

The sector is committed to transforming the railway system, the key concept being to use railways in combination with other public transport, integrating aviation and shipping as needed, to become the backbone of Europe's mobility and the logistic chain. The SRIA anticipates a new paradigm for sustainable multimodal mobility, in which transport is not synonymous with individual vehicles. The research programme must help unleash rail's value to urban life. With its higher capacity, its utilisation can make cities less congested and less polluted, while maintaining a multimodal system that adequately and equally serves metropolises, conurbations and their surrounding regions. Rural areas, too, can be well linked to the economic hubs. Customer experience must be revolutionised through the creation of a seamless, affordable, multimodal mobility network with rail as its backbone and which utilises flow management to anticipate and react to consumer demand patterns. It is possible to reform cumbersome elements of public transport which act as a barrier to its use. The SRIA provides a perspective associating rail transport with freedom, flexibility and comfort. Above all, its value, as seen by the customers, must be enhanced. Railway networks must be made intelligent, to optimise existing system use and thus increase capacity and flexibility. Already shaping the design of future networks, those developments will use autonomous vehicles, the Internet of Things and artificial intelligence. This will be made possible by focusing on a new telecommunications infrastructure that makes the best use of 5G technology or modern satellite communication, being developed across the entire rail industry.

The roadmap

System transformation requires the provision, based on outputs from high quality scientific work, of new services, optimised operations and innovative assets throughout Europe. The work is to be effected through an integrated set of 'Transforming Projects' (TPs) contributing to the delivery of a common system vision. The system vision, setting the frame for what is wanted, is to be developed within the 'System Pillar' and the TPs, which deliver it, developed within the 'Innovation Pillar' of the new rail Partnership.

The System Pillar will focus on:

- Capturing and defining the general vision and target requirements for the railway system architecture while coordinating the various existing initiatives;
- Ensuring the synchronized delivery of user and interface specifications for all required parts;
- Defining a smooth transition path from the current situation towards the target;
- Preparing the operational rules adapted to this the new architecture;
- Examining the business case for the innovations and their socio-economic impact.

The Innovation Pillar will produce solutions directed at three targets, though the related TPs.

First, the railway system and stakeholders need to deliver **new services** which at the core of this transformation, place rail as the mobility engine for attractive multi-modal journeys:

- Smart Integration for Railways within Door-to-Door Mobility;
- Rail as the Backbone of a Green Freight Logistic Chain.

Second, the railway system will transform its internal processes and optimise its **operations** in order to exploit its genuine network advantages in by embracing digitalisation and automation:

- Connected and Open Rail Framework for European Mobility;
- Network Management Planning and Control;
- Environmentally Friendly and Attractive Sustainable Mobility.

Third, the railway will research and reveal innovative **assets** that have the potential to create capabilities for the railways (and beyond) that are not possible today, as high speed did in the 1970s:

- Assets for Automated and/or Autonomous and/or Remotely Piloted Operations;
- Smart Asset Management and Maintenance of the Future;
- Non-traditional and Emerging Transport Models and Systems;
- Railways Digital Twin, Simulation & Virtualisation.

Thus, the two pillars (i.e. System and Innovation) are intrinsically linked and mutually supportive, with the outputs of the Innovation Pillar providing the technical and operational means to enable the future railway envisioned by the System Pillar, which will also ensure that the overall system-level arrangements and robust delivery mechanisms are in place. Together, they maximise the opportunity for research and innovation to allow railways to play their full part in Europe's future mobility.

1. Introduction

1.1 The Strategic Research and Innovation Agenda – context and purpose

This SRIA, developed by the European Rail Research Advisory Council (ERRAC), identifies at a high level what the sector needs in terms of targeted and focused research and innovation (R&I) to deliver its ambitious vision to European citizens. It translates the ERRAC vision[6] into a long-term systemic approach to define the logic, rationales and principles governing that R&I and dealing with emerging uncertainties. Thus, it offers a framework towards operationalisation and for further decision-making on joint actions. This document can also be used by the future Rail Joint Undertaking when linking its own mission and vision with more substantial planning, in its Masterplan and multi-annual work plans for the new Rail European Partnership, to be developed from 2021 and amended as necessary thereafter.

This SRIA addresses complex and multi-faceted challenges facing the rail sector and its contributions to meeting the challenges defined in the UN Sustainable Development Goals and translated into European Union policy objectives. To do this, the proposed innovative solutions will emerge in the context of a holistic/systemic, inter-and transdisciplinary programme to support transformational change. It also recognizes the huge challenge that railways face from the Covid-19 pandemic and the responsibility of the railways to contribute not only to the economic recovery in Europe but to trigger the European industrial and technological leadership.

The ERRAC SRIA reflects the expectation expressed by the Horizon Europe programme that the co-funded rail R&I delivered via a dedicated Joint Undertaking, will be strategic and impact-oriented and contribute to the implementation of European Union policy objectives. It also expresses a strong commitment and sense of ownership from all the rail sector partners to embrace the changes proposed. It describes R&I activities that actively seek complementarities and synergies with other relevant European Partnerships and programmes at the EU and national/regional levels where these can support the transformation of the rail sector.

This SRIA is based on extensive consultation, starting with all ERRAC stakeholders, to ensure that common research and innovation needs are well understood and to ensure an open and inclusive approach to the development of the research and innovation agenda. These include the consultations made in the context of the Draft Proposal for a European Partnership under 'Horizon Europe Transforming Europe's Rail System' endorsed and published by the European Commission on 23rd July[7]. Consultations during the preparation of the SRIA have helped develop the Partnership's concrete objectives and targets, associating them with KPIs and matching resources. This drives its impact-orientation and customer focus to promote the market uptake of the R&I outputs.

As the Draft Proposal says, railway is a complex system of systems, an enabler, capable of delivering huge value to its users and to wider society, by moving large volumes of passengers and freight safely, speedily, and sustainably. It must be user-centred, organised, and engineered to deliver the highest levels of dependability, resilience, and service quality. At the core of a competitive and resource-efficient multi-modal European transport network, it can facilitate a shift from dependence on less sustainable modes and thereby help deliver the urgent decarbonisation identified as crucial in the European Green Deal. Rail is significantly more environmentally friendly and energy-efficient than other modes and will continue to be so. By developing a better understanding of the interfaces and interactions between the components of the whole railway system and its external connections - creating a functional system architecture - an integrated programme of research and innovation will be developed. Within this, Transforming Projects, underpinned by a systemic, smart and sustainable Concept of Operations, will serve the evolving needs of customers by producing new mobility and transport solutions, in collaboration with other modes. Only through forward-looking cutting edge, integrated and systemic research and innovation, it will be possible to tackle the complexities of rail and maximise the benefits of the R&I investment both within the Union and beyond.

6. *https://errac.org/wp-content/uploads/2019/03/122017_ERRAC-RAIL-2050.pdf*

7. *https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-transforming-europes-rail-system.pdf - This informal document does not reflect the final views of the Commission, nor pre-empt the formal decision-making (comitology or legislative procedure) on the establishment of European Partnerships.*

1.2 Backbone of Mobility in 2030: Challenges and rail sector's answers

The vision of the railway sector in Europe, as expressed in 'Rail Vision 2050' (ERRAC, 2017) is that railways will (again) become the backbone of Europe's sustainable mobility system - for both passengers and freight. For passengers, the objective is to offer easy, affordable and seamless access to a portfolio of sustainable door to door mobility options. For the freight customer, the 'vision is to transform rail freight into a high-performing, efficient and sustainable backbone transport system for a European multimodal logistics industry[8] . Realising that vision requires consideration of the stages between today and the future, and particularly which aspects of the vision should be delivered when, as a guide to formulating the priorities for research and innovation. The first such stage, the period to 2030, was the focus of the subsequent publication 'Rail 2030 Research and Innovation Priorities' (ERRAC, 2019).

This latter document explained that in transforming the European mobility system, the railway sector will make wider social, economic and environmental contributions by 2030. It will produce significant value to the wider economy thanks to a variety of innovative technical and operational solutions which will have been developed within that timeframe. These will contribute to the creation of new added-value, green, EU based jobs and the reduction of negative externalities such as air pollution, greenhouse gas emission and noise and vibration. The innovations will also accelerate the availability of new options to meet the expectations of society and legislators, in particular for a more sustainable society while maintaining and improving the competitiveness of European industry as a whole.

The 2030 rail system will interact with other transport modes and with local, regional, national and European economic activities in transformational societal changes and trends. Safe, reliable, comfortable and efficient rail mobility services will influence and benefit many different areas, such as lifestyle, spatial planning, citizens' everyday experience, health, sustainable flows of material goods and generate a better general standard of living.

The three key challenges for mobility are: Attractiveness and convenience; Capacity; and Sustainability and Security.

The objective is to offer end-users/citizens easy and seamless access to a portfolio of sustainable mobility options which have rail as their backbone. Delivering on this objective means significantly improving the current customer experience of transport services. Today the needs of passengers and freight shippers are covered by multiple modes of transport and different segments within each mode. These tend to operate in silos and have difficulties working together to meet the variety and complexity of their customers' overall needs in a simple, holistic and effective way. This often leaves customers dissatisfied with their daily travel experience. Young people in particular, the users of the future, perceive the railways as being behind the times and not sufficiently well connected with other modes for seamless travel, while manufacturers and shippers experience inadequacies in coordinating global supply chains when getting goods to markets.

A second key challenge for the railway, beyond the overall attractiveness of its offering, relates to its level of agility in adapting capacity to meet both short term variations and longer-term trends in demand, and to facilitate modal transfer. This is also a key consideration in the railway's ability to contribute to the third major challenge area, sustainability and security, with the reduction of carbon and greenhouse gases and delivering other aspects of the European Green Deal agenda.

Figure 1 below details these three challenges and the basis of the sector's response, based on developments in digitalisation, automation, new mobility solutions and sustainability solutions.

8. https://uic.org/freight/

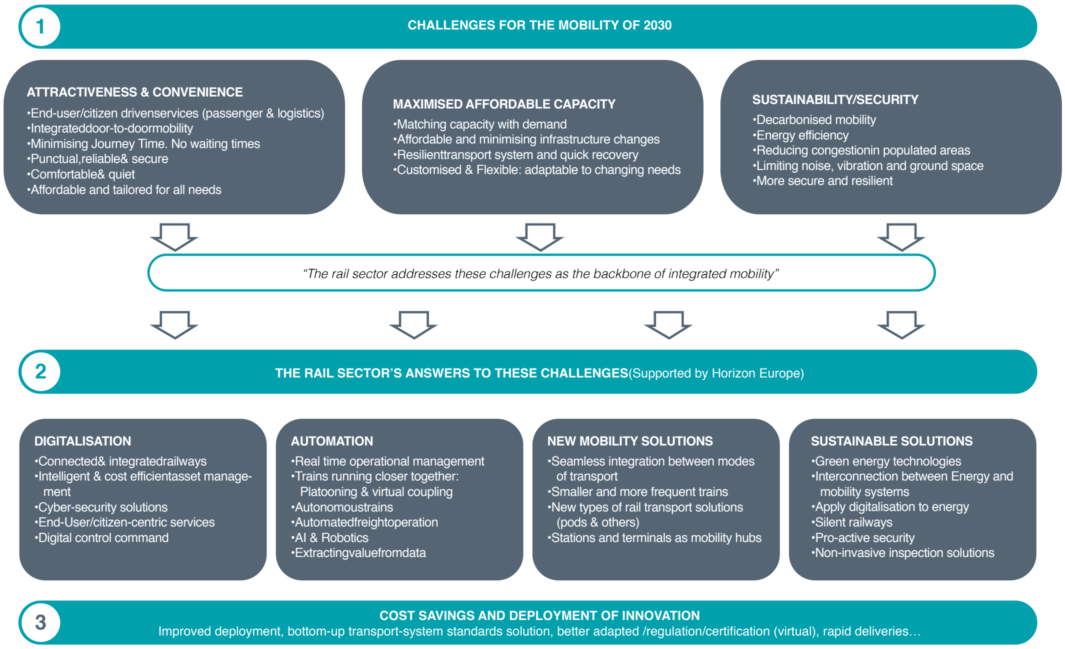


Figure 1: Mobility 2030 challenges and rail sectorial answers. Source: 'Rail 2030 Research and Innovation Priorities' (ERRAC, 2019)

The current social/business context and the on-going technological developments, particularly in digitalisation, open new opportunities to change the world of mobility, enabling the different modes and segments to work together with railways for the benefit of the end-users/citizen. Railways are well placed to play a central role in this process. The long-term vision for rail mobility as presented in the ERRAC Rail 2050 Vision has rail transport as the backbone of future mobility in a multi-modal context. The sector proposes a set of time-focused concrete plans to transform this vision into reality, based on the identification of the right questions to answer in each ten-year time period and setting meaningful milestones for delivering targeted impacts. The first set was articulated in ERRAC 'Rail 2030 Research and Innovation Priorities'.

The top targets were identified in that document as:

- **Advanced interoperable train control systems** will deliver better real-time adaptation of capacity to demand and economic competitiveness through increased flexibility in capacity and operations precisely adjusted to actual needs;
- **Advanced traffic management** can help energy optimisation, support operational resilience and flexibility while increasing infrastructure capacity;
- **Next generation of Control Command 4.0** will help to leverage the benefits of the combination of autonomous, intelligent and highly responsive vehicles able to communicate with each other through an advanced adaptable communication system (ACS) in line with the Future Railway Mobile Communication System (FRMCS) and with the intelligent infrastructure;
- **Intelligent and Autonomous Vehicles /operation**- Vehicles and (freight) train composition will have to become more intelligent in a more automated system;
- **Automation of the Logistics Chain** - Digitalisation will strengthen the end-users' communication and set up a direct link to the production process of the rail freight system and to other transport modes.

In addition to these main set of priorities identified by ERRAC, new concepts are being developed.

- **New concepts of rail/guided vehicles** that can broaden the horizon of the railway industry are to be included as a target.

This rail SRIA now provides a focused proposal for the way in which these and related innovations can be developed within the rail Partnership to deliver 'rail as a backbone' to EU citizens.

1.3 The necessity for a European Partnership

The Rail sector needs a European Partnership for research and innovation, and its form needs to be that of an Institutionalised Partnership under Article 187 TFEU (hereinafter the European Partnership or Rail European Partnership).

The sector has expressed its detailed view in the "Draft proposal for a European Partnership under Horizon Europe Transforming Europe's Rail System" (Version 1 July 2020) available here:

https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-transforming-europes-rail-system.pdf

2. Vision, impact and commitment of the Rail European Partnership

2.1 Contribution to EU Policies

The future Rail European Partnership will have both the potential and ambition to contribute directly to the objectives of the European policies notably the European Green Deal. By boosting the rail sector through research & innovation activities and bringing together key stakeholders across Europe, the Partnership will help the rail sector to fulfil the role of 'game changer' in the transport sector. The R&I Programme of the new Rail European Partnership will have to be sufficiently agile to be able to adapt to the changing environment in the entire mobility chain and will take into consideration the impact on society of the Covid-19 outbreak and, particularly, on transport and mobility. Innovative solutions on health & safety aspects will be included into the overall approach to the system design and operation.

European Green Deal [9]

The rail sector is committed to the European Green Deal ambition: firstly, by accompanying the transition towards a lower carbon footprint, across all modes of transport by offering integrated, complementary and connected services, and secondly, by enhancing the sector's commitment to a rail system based on circular economy principles. Through the new Rail European Partnership, the rail sector will lead the transition towards integrated, digital, autonomous, sustainable mobility in Europe and at the same time contributing to its global industrial competitiveness.

An economy that works for people: A New Industrial Strategy for Europe

An efficient, resilient, accessible and reliable railway system, integrated with other transport systems, provides EU citizens with access to a wide range of employment, education and leisure opportunities, as well as contributing to a vibrant market economy that supports growth and job creation. The proposed new Rail European Partnership will actively seek to promote social inclusion leveraging research, technologies, solutions, and services that strengthen the European single market that benefits society as whole. As the rail workforce is rapidly ageing, it will be essential to take advantage of the immense available rail expertise to ensure continuity of activities, while at the same time creating new opportunities and 'green' jobs for its next generation.

A Europe fit for the digital age: Shaping Europe's Digital Future

The new Rail European Partnership will function as a European platform to deliver an integrated, digital and sustainable European Rail System for the "digital age". Rail is an integrated, complex assembly of components that, at given and non-negotiable levels of safety, can maximize their collective performance when managed by a system architecture and reference implementation, taking into account "a system of systems" approach across its full life cycle.

A stronger Europe in the world

The rail sector is an important contributor to industrial growth, jobs and innovation in the EU, with the overall railway sector accounting for more than 1 million direct and 1.2 million indirect jobs in the EU. In order for Europe to maintain its leadership, research and innovation effort is crucial: *The world leadership of the European rail supply industry (RSI) is largely due to its R&I capacities. While international competition constitutes a cause for concern for the European rail suppliers, staying at the forefront of research and innovation with end-users will be a key factor to ensure that the European RSI preserves its leadership and remains able to compete successfully with foreign suppliers*[10] .To achieve this, in the new Rail European Partnership the so-called quintuple helix approach, i.e. a close cooperation between academia, rail suppliers, Infrastructure Managers (IMs), Railway Undertakings (RUs), Urban Operators, governments, civil society and the natural environment, should be applied.

9. *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en*

10. *Report of the expert group on competitiveness of the European rail supply industry: https://ec.europa.eu/docs-room/documents/37829*

2.2 The vision and ambition of a Europe's Rail Programme

Rail is a complex system of systems. Rail needs to have their potential unleashed. This requires a Common Vision, shared right across the sector, on new Concepts of Operations and Maintenance, structured in a services-focused system-of-systems architecture, delivered by new technological and operational enablers leveraging digitalization and automation opportunities. According to the draft proposal for a Partnership under Horizon Europe, titled "Europe's Rail", there is a need and willingness for collective commitment to a Common Vision, right across the sector.

Common Vision [11]

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

This will be done while respecting at the same time the specific needs and operational requirements of those representing different elements of the whole. The work will be carried out in a coherent and suitably transparent and inclusive manner and, where appropriate, coordinated with other transport modes and connected services. Europe's Rail will encompass urban rail as a core of urban mobility. In 2030, urban rail and urban nodes will be at the heart of the integrated urban mobility systems. This is the only solution to meet societal needs to move large numbers of people in and around urban and suburban areas reliably and efficiently with minimum negative externalities such as pollution, congestion, climate change and use of scarce space.

General and specific objectives of the future Rail European Partnership

Figure 2 depicts both general and specific objectives of the Partnership and puts them into context with the EU rail transport policy goals, as well as with the Union's overarching political priorities.

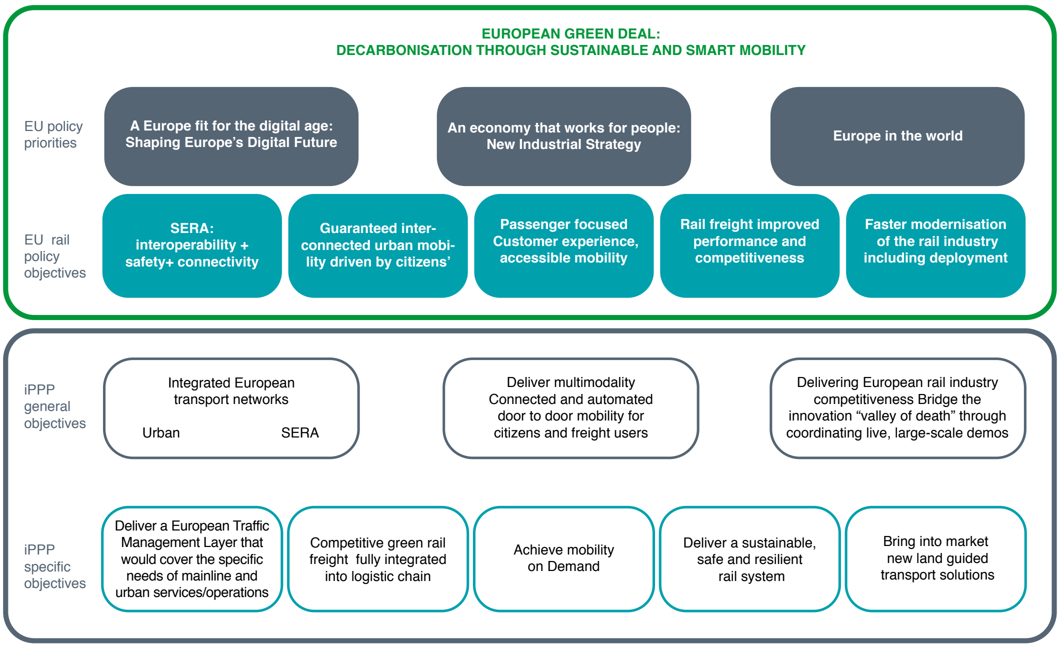


Figure 2: Objectives of the future European Rail Partnership. Source: 'Draft proposal for a European Partnership under Horizon Europe Transforming Europe's Rail System' (Version 1 July 2020)

11. Extract from https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-transforming-europes-rail-system.pdf

2.3 Impacts of a Europe's Rail Programme

The new Rail European Partnership will make wider societal, economic and environmental contributions. It will produce significant value to the wider economy thanks to a variety of innovative technical and operational solutions that will be delivered by joint research and innovation activities and will in parallel help to reduce negative externalities (directly and indirectly). It will also contribute to an overall sustainable growth and jobs creation.

The expected impacts for the proposed Rail European Partnership are notably:

- A new harmonised Concept of Operations and Maintenance for Rail, through a System of Systems service-oriented approach, that answers the needs of all the users;
- Sustainable integrated mobility via new concepts of rail operations and services across Europe (freight services, passenger services in high speed, intercity, night train, regional and urban contexts) for the benefit of the EU citizens;
- A coherent, integrated rail system delivering resilient, reliable, sustainable 24/7 available services with provision for open access as well as "public service" contracts in urban nodes, for example, for urban rail within integrated mobility;
- Availability of urban rail on most densely used corridors with priority over and in coordination with other forms of motorised mobility;
- Fast delivery of R&I results to the market through coordinating live, large-scale demonstrators, standardization documents at the European Union level, combining regional, national and other European Programmes;
- An increased capacity to "shift onto rail";
- Improved operational and planning process through advanced decision support tools developed as demonstrators and simulators connecting actors and promoting data sharing, transforming the railway system collectively as an integrated whole, solving identified problems;
- Significantly increased competitiveness of the European rail stakeholders worldwide (e.g.EU Rail Supply Industry, EU Rail operators);
- European universities and research centres that are world leaders in rail and mobility research and education;
- New opportunities and a more attractive skills ecosystem for the professional rail workforce and a challenging environment to attract new generations of engineers/experts from other industrial sectors with system knowledge/experience useful for cross-fertilisation;
- New opportunities for start-ups and industrial initiatives that will foster the European leadership of existing and future European railway ecosystem.

In addition, the future Rail European Partnership will facilitate contribution to policy making, regulatory framework and standards' development, which will pave the way for the Member States'/Regions/Urban's investment in new railway systems.

2.4 The commitment towards a Europe's Rail Partnership

The Common vision requires:

- A seamless European research and innovation system that assures continuity builds on through fundamental and blue-sky research, applied research, development, demonstration and innovation in products and services over many years and takes a transformative, strong mission-oriented approach;
- Strong cooperation between European rail stakeholders: This will be the key factor for success to ensure that the solutions developed fully answer the needs of the users in an efficient and sustainable way;

- The integration of experts from other scientific disciplines and from academia, bringing valuable knowledge from other sectors;
- Effective cooperation with other modes of transport to provide a connected, efficient, and reliable European transport system.

Market forces alone are insufficient to provide the necessary level of investment. Since local public transport services are not commercially viable and rely on public service contracts with local competent authorities providing additional resources to the operators usually there are no profits generated that can be invested in R&I activities. Nevertheless, investment in rail infrastructure in general has strong user and external benefits and cannot be financed by the customers only. Therefore, public funding both at European and national levels remains vital.

Nevertheless, the co-funding of a significant R&I shared and common Programme by the railway sector and its extensive and active participation will demonstrate the sector firm commitment to the delivery of the vision.

The sector considers that the Programme of the future Rail European Partnership, estimated at the total value of EUR 3.3 billion matched by a funding of EUR 1.5 billion, at least, would allow achieving this focused SRIA's ambition.

The R&I activities to deliver the SRIA, addressing the specific segments' interfaces, will be structured around the following:

- **Exploratory and fundamental research (estimated funding within EUR 0.2 billion)** – this will allow to explore and generate new ideas, including breakthrough solutions for an agile market implementation or for long term deployment. It is essential to create a pipeline of innovative ideas that will allow the rail systems to evolve over time to maximize its performance for citizens and business;
- **Applied research and innovation (estimated funding within EUR 0.8 billion)** - including relevant development, will be the core of the research and innovation activities where desired market solutions, containing most of the technological and operational solutions, will be pushed to move towards market deployment and uptake or terminated because not progressing as expected;
- **R&I Large Scale Operational Demos (estimated funding within EUR 0.5 billion)** – this will be one of the major game changers in the impact to be achieved by the new Rail European Partnership. 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 9 level, and to show the benefits from the European deployment of new solutions.

This Programme will result from an integrated system vision developed jointly by the rail sector and industry focused on delivering actual impacts, deployment and market uptake of its outcomes; any arbitrary de-structuring, de-scoping or selective exclusion of any of its parts would require the sector rethinking the presented delivery commitments and will lead to an unfocused approach – rather than one oriented towards achieving the targets for all of its stakeholders.

The proposed Programme will be based on two pillars:

- A System Pillar focusing on innovated concept of operations and functional objectives, and potentially on innovated concept of railway transport;
- An Innovation Pillar focusing on Transforming Projects taking into account the work done in the System Pillar, in order to develop solutions and products, which are compliant with the System Pillar.

Nevertheless, Horizon Europe funding will need to be complemented with other European, national, or regional funding and financial instruments for the deployment of the output of the Rail R&I Partnership results. This complementarity is needed to accelerate the deployment and market uptake of its outcomes all over Europe uniformly to ensure that innovations result in a fully interoperable transformed rail system rather than in islands of non-interoperable obsolete and up-to-date systems, operational procedures and regulation provisions. The Union should start with reserving a large share of CEF funding for the deployment of new Rail technological and operational solutions, including in urban TEN-T nodes. In addition, a revision of the current CEF regulatory framework should take place to mirror the evolution of rail operations, infrastructure, etc.

2.5 Instruments

Single coordinating body

The institutional nature of the new Rail European Partnership would provide the sector with the necessary governance that would ensure the sector participating in the decision making process towards the convergence of solutions. In this respect, the European Partnership will act as **"single coordinating body"** bringing the whole sector together to develop a Concept of Operations, Functional Reference System Architecture, and associated specifications and standards, consolidating, and coordinating current initiatives. It will require:

i. A clear mandate to the Commission to oversee developments, with a central role for ERA to ensure that mainline and SERA outputs when relevant are processed into TSIs efficiently and ensuring safety and interoperability;

ii. Broad representation from the sector, with the presence of technical bodies and associations and end-users' representatives from across Europe, with a voice in decisions taken;

iii. Inclusive governance – a guarantee that decisions will be taken objectively and impartially;

iv. Sufficient resources and decision-making capacity within the future Partnership.

The objective of this structure is to facilitate the process of bringing R&I technological and operational solutions to the market, providing solid and sector shared input for harmonization processes such as TSIs, standards. The model requires further refinement, not least to ensure appropriate engagement with Member States as also with members of the scientific community.

The proposed structure aims to provide a strategic, ambitious, and efficient approach by having a single coordinated process to define the operational concept and functional system architecture (under the policy guidance of the EC) and by defining requirements in cooperation with the sector and industry. By coordinating initiatives under a single umbrella, it should be possible to make the best use of scarce resources, both from the Union and others, financial and human and targeting linked R&I. The clarification of roles should assist with the systematic, fast, and timely development of products, standards, and specifications.

The governance structures within the future JU would be aligned with the expected outputs through establishing two pillars, a System Pillar designed to best serve the development of the overall Concept of Operations and Functional Reference System Architecture, and an Innovation Pillar to deliver user focussed research, innovation, and demonstrations, including project deliverables as well-defined inputs to the System Pillar.

The multi-annual approach will allow efficient Programme implementation, through the use of "instalments" as established in the European Union General Financial Regulation. The overall implementation of the new Rail European Partnership Programme will result from the combination of funding and governance to deliver the ambitious content described in this SRIA.

Openness and Transparency

Effective R&I efforts that deliver new technologies that also enable geographical and technical integration of rail systems require integration of the full value chain of such technologies, ensuring a coherent approach from conception and design to funding of deployment in the operating environment. Openness will be achieved by attracting and providing a wide opportunity for participation to entities that are ready to commit to the shared programme, contributing with their expertise and breakthrough technologies.

Openness will also be achieved by cooperating with research centres and academia. The objectives of such cooperation beneficial to the rail sector as a whole, are:

- Encourage sharing of knowledge, ideas and skills across academia and industry;
- Cultivate the development of future professionals by creating opportunities;
- Promote scientific excellence in rail research by increasing the amount of high-quality peer reviewed scientific papers in prestigious journals;
- Generate open science in a transparent and accessible manner that is shared and developed through collaborative networks, being therefore in line with one of the goals of the research and innovation policy of the EC;
- Provide equal opportunities in research, recognising diversity and inclusivity as key to the competitiveness of the industry;
- Showcase and promote industrial solutions.

In particular, the new rail European Partnership must provide possibilities for encouraging research across disciplines on the most promising ideas and concepts with help of for example dedicated workshops and summer schools. Furthermore, the development of incentives such as young scientists' awards, internships and PhD opportunities will be essential to attract young students and researchers and increase attractiveness of the rail sector for young professionals.

To provide coherence and equal opportunities for researchers and perspective students across the Union, these events must be coordinated at a European level, thus providing strong collaborations between universities and research centres and the next Rail Partnership.

To ensure openness and transparency in the course of implementation of the activities, the Master Plan will be translated in a Multi-Annual Work Plan that will be refined considering the evolution of the needs of the users and Union's policies.

2.6 Synergies

To bring the relevant technologies to the rail, to contribute to the overall transformation of the mobility, collaboration with relevant stakeholders and interested actors (including end users and staff) at European, national, regional and sectorial level is essential.

As priority, connections should be considered with the existing and planned European Partnerships (EP) and initiatives, energy and fuels with EP Clean Hydrogen, European industrial battery value chain, EP for Key Digital Technologies, EP on Artificial Intelligence, Data & Robotics, EP for High Performance Computing, EP for Integrated Air Traffic Management (multimodal integrated approach, traffic and network management), EP for Clean Aviation (new materials, alternative fuels, etc.), space technologies as satellite communication and positioning (collaboration with GSA), EP for Smart Networks and Services successor of 5G PPP.

In addition:

- Opportunities for collaboration may come from the EP on Connected and Automated Driving (e.g. sharing urban space with urban rail, level crossings, network concepts);
- Regarding the medium and long term view, the cooperation with the European Technology Platforms in the transport and mobility domain (ACARE, ALICE, ECTP, ERTRAC, Waterborne) could be necessary to align views, identify synergies for further roadmaps alignments;
- At the forefront of cutting edge technologies and innovation, synergies and cooperation with the European Innovation Council (EIC) could be established, especially to ensure the potential involvement of start-ups;
- EIT Knowledge and Innovation Communities are dynamic and creative partnerships that harness European innovation and entrepreneurship to find solutions to major societal challenges in areas with high innovation potential – and create quality jobs and growth. Connections to the KICs Urban Mobility and InnoEnergy could offer acceleration from research to the market;
- European research and innovation missions aim to deliver solutions to some of the greatest challenges facing our world. Synergies and cooperation should be looked for with the following missions proposed, 100 Climate-Neutral Cities by 2030 - by and for the citizens and Accelerating the transition to a climate prepared and resilient Europe;
- At European level, collaboration/integration with TEN-T related activities and with the Rail Freight Corridors would be instrumental for the achievement of the EU policy ambitions. Potential large scale demonstration activities in the rail Partnership aim at facilitating the deployment of successful results in strategic European corridors, financed through CEF and possibly other instruments;
- At National and Regional level (especially with National Rail Technology Platforms), cooperation is paramount, on the one hand, to ensure effective coordination of rail programmes and avoid duplications and, on the other hand, to accelerate the market uptake of the technological and operational solutions for faster and bigger impact;
- The cooperation with local authorities and local operators (urban rail and public transport services), even though not easy given their fragmentation, would be of great interest to agree on common shared priorities for urban mobility and further EU-wide commonly agreed harmonized specifications;
- Additionally, improving the European Rail System, investigating new operations, services and their connection with other transport modes will decrease the overall transport impact on climate change and create new business/collaboration opportunities across sectors.

3. A coherent Research Programme implementation

To efficiently address the challenges for mobility of 2030 that the sector identified (see Figure 1), and at the same time to respond to the EU policy priorities (see Figure 2) the new rail research and innovation programme, building upon an innovated concept of operations and functional objectives (System Pillar), will deliver innovative operational and technological solutions demonstrated at pre-deployment stage (Innovation Pillar) resulting in:

- European rail concept(s) of operations and functional system architecture shared and adopted at sector level, including the necessary interfaces, for example to connect with overall urban mobility, but also with ports and airports;
- Automated/autonomous/remote operations to be deployed on high speed, main, regional, suburban and urban lines and trains for passenger and freight convoys, adapted to meet socio-economic and business needs;
- Intelligent trains operating on the European network towards zero signalling infrastructure, building upon digital positioning, computing capacity and communications, with centralized European supervision to maximize network performance, accommodating all convoys in an agile and flexible manner;
- Non-stop border crossing and zero-barrier European freight train operation and full integration in the logistic value chain;
- Towards zero-impact system and operations, such as hybrid trains for continuity of operations in different environmental conditions, noise and other pollutant residue (e.g. from brakes) mitigating systems, passenger and staff protection system against injuries, building upon circular economy concepts by design;
- New land guided systems for hyper speed, on demand services, flexible network;
- "Workshop of the future" building upon data and robotics with remote controls for new maintenance concepts on vehicles and infrastructure;
- A globally leading industrial rail sector, recognized for the new excellence in product and services;
- Rethinking of business models-based performance scheme for revenue charges.

The rail sector, building upon its staff know-how and together with the representatives of passengers and freight needs, commits to this ambitious research and innovation agenda with the necessary European funding and conditions, to be complemented by national and regional resources, and to meet the Union policy objectives framed in President von der Leyen' "Union that strives for more". The capacity to engage with European and national regulators and all other rail and transport initiatives will be paramount to deliver tangible transformation.

The outputs are enabled by a series of interconnected Research and Innovation activities (Transforming Projects) reaching high TRL which are part of the Innovation Pillar delivered by its Members together with other stakeholders. At the same time the expected system transformation implies **working on delivering new services, optimised operations and innovative assets all around Europe.** Therefore, for the first time in the history of the journey to create a Single European Rail Area, the entire sector will be collaborating to ensure effective R&I outcomes and the implementation of interoperable solutions in the System Pillar, under the strategic supervision the European Commission within the new Partnership.

As referred to in previous sections, a holistic and collaborative approach is needed in the research programme to maximize the delivered benefits relative to the invested effort. This also implies a top down approach, with customer needs becoming the driver for R&I activities. The solutions proposed should be European interoperable solutions that can be implemented throughout the entire Union and be anchored in a commonly agreed system of system architecture. A system perspective needs to be adopted (cf. Section 3.1), taking into account how the delivered R&I and operational decisions by sector stakeholders can transform the European Rail system and the relations among its actors.

The implementation of the Innovation Pillar is based on the concept of nine Transforming Projects which are described in detail in a dedicated section of this SRIA (see Section 4 to 6) and are presented as necessary activities to meet the new Partnership objectives in Section 3.2.

The R&I solutions, providing new services, optimised operations and innovative assets that together will constitute the railway system of the future, also need to have sustainable socio-economic business cases. A specific challenge that needs to be tackled is the business models at system level that may imply a different distribution of costs and benefits and possibly requiring support from the legislator and regulator to ensure that the social function of rail transportation in connecting people, regions and countries is cared for. Therefore, clear business cases will be derived so that they can guide the programme management addressing with the right model the optimal operational implementation of the R&I activities and at the same time guide them toward reaching outcomes that are economically and socially viable. These socio-economic aspects are described in Section 3.3.

To monitor the success of the Programme a set of Key Performance Indicators (KPI) are introduced in Section 3.5.

Finally, recent unfortunate pandemic health events that impacted the worldwide population and its mobility calls for additional measures whereby R&I can also contribute to make sure that future technical and processes solutions are by design integrating mitigating and insofar as possible preventive measures. Ad-hoc R&I activities (not being Transforming Projects) may arise and some are described as preliminary ideas in the section 3.4, although the majority of the solutions would imply a broader system approach that the future Partnership can provide with the Transforming Projects of the Innovation Pillar and the sectorial implementation approaches defined within the System Pillar.

3.1 System Pillar

➔ Motivation: hard railway system transformations

In order to further enhance **capacity** and **reliability** while also delivering **better and new services to customers,** transformations of the European railway system have to be managed. There is today a need and opportunity to be more ambitious in **harmonising the overall railway system** in the EU to improve the **business case** based on an **efficient operation** and **cost-effective technical solutions.**

Over the past years, extensive European policy and standards have been developed, notably to support a harmonised approach to safety and interoperability. Specific attention is now paid to Control Command and Signalling systems (CCS) that are crucial for overall system performance but still rely on a large number of national solutions, which are a significant cost driver and a major contributor to the lack of interoperability of the European railway system. The migration path is long and costly and the value horizon of Railway policies and R&I activities for operators and suppliers is most of the time very distant and uncertain.

➔ Purpose: a dynamic European railway sector

Without pre-empting the evolution of the System Pillar and jeopardising the resources that will be dedicated to it, it is clear that the starting point will be the mainline European rail network and in particular CCS harmonisation at European level. Work needs to be focussed on:

- An operational concept and the development of a functional system architecture based on radio-based ERTMS-alone networks
- Service-driven operations within one functional system architecture

Such work is necessary to provide a framework for the evolution of the system and the associated research and innovation. The future JU should act as the single coordinating body to bring the whole sector together to develop operational concepts, functional system architecture, and associated specifications and standards, consolidating and coordinating current initiatives (RCA, SmartRail 4.0, EuLynx, OCORA, FRMCS).

In order to perform this role, certain conditions are required, in particular:

- A clear mandate from the Commission and the willingness of the sector to deliver it
- Broad representation from the sector, with a voice in decisions taken
- Inclusive governance – a guarantee that decisions will be taken based on objectivity and impartiality
- Sufficient resources and decision making capacity within the future JU
- Centrality of Commission role to oversee developments, to ensure that outputs when relevant are processed into TSIs or standards efficiently and ensuring safety and interoperability.

The target for CCS technology **convergence harmonisation (for services, operations and assets)** can only be achieved if **embedded** into a **complete system approach** supported by the development of a modular European Rail System architecture framework, taking into account the diversity of sector business needs. All European railway actors together should coordinate in order to make sure that **operational concept, system architecture and technical specifications** have reached a **sufficient** level of **maturity** and can be effectively **implemented** on an EU scale. The challenge is to find a collective path for a rapid transformation of processes railway services, operations and assets involved in the railway system.

A System Pillar for the European rail sector helps to coordinate new technology developments, migration plans, industrialisation and deployment. It contributes to a more efficient collaboration and better use of scarce resources. A System Pillar drives an accelerated market uptake of innovation and the integration or development/deployment of new technologies. It is the opportunity for the railway stakeholders, to develop a **dynamic and resilient industrial policy** for **advanced solutions** supporting **enhanced European railway operations** and a **global competitiveness of the European railway industry.**

The interaction between the System Pillar and the Innovation Pillar within the new rail European Partnership will result from the capacity of the sector and those more directly involved in the R&I activities to contribute to each other. The Innovation Pillar should create the enablers which would deliver the renewed concept of operations and functional system architecture but at the same time challenge concepts and ideas offering opportunity to reap the benefits of the most advanced technological solutions.

The pillars will not work in isolation – and there would be iteration between them.

➔ Implementation: rapid and valuable migrations

There must be a forum bringing together and involving all EU railway stakeholders in order **to facilitate industrialisation, migration and deployment and early values from R&I activities** carried out in the sector (public and private financing). It should allow stakeholders to **capitalise, acknowledge and promote** any **R&I result** that can help support **rapid EU wide migrations.**

The System Pillar should look at the maturity of the market on the supply and demand side, in particular to identify the parts of the railway system that require enhancement in terms of functions, new technology and operational rules and harmonisation of services, operations and assets. Further, this work should include a clear business case analysis, to provide the initial necessary input for regulation, standardisation or the development of the R&I activities to be added in future revisions of the railway SRIA. Therefore, this type of socio-economic consideration will be an integral part of the management of the Partnership. The socio-economic research activities foreseen are described in Section 3.3.

In order to support convergence, coordination and efficiency, the System Pillar should set up a joint European Rail System framework supporting collaboration on a sector scale for R&I performed in the TPs but also for possible development activities carried on in the System Pillar. This framework should address methods and tools allowing to move, in a harmonised or interoperable way, towards model- based systems engineering. It is a key enabler for sharing and reusing specifications and solutions between projects activities on a sector scale. A model based approach will help requirements quality, modularity and interoperability. While engineering method and tools will always be a matter for R&I activities, there is the need and opportunity, with the System Pillar, to define a minimum agreed framework supporting sector collaboration and efficiency.

The System Pillar will interact with the Innovation Pillar through regular exchanges with TP3 'Connected and Open Rail Framework for European Mobility', which will provide guidance, when relevant, for TPs1,2,4,5,6,7,8&9 and collect feedbacks/information from these TPs that could impact the definition of the European rail architecture system. TP 3 will manage the two-way communication between the Transforming Projects and the System Pillar.

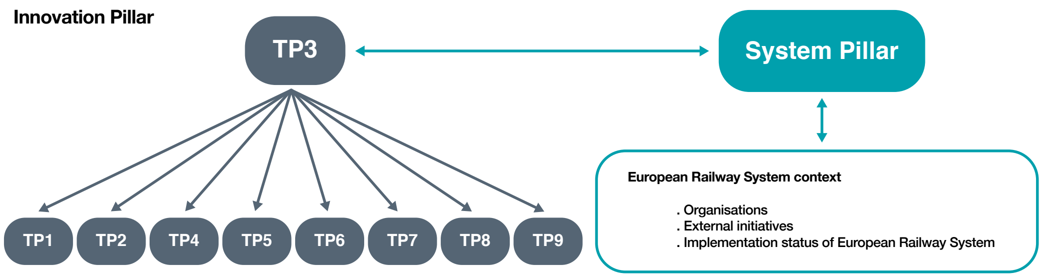


Figure 3: Relations between the System Pillar and the Innovation Pillar

3.2 Innovation Pillar: Transforming Projects to deliver new services, optimised operations and innovative assets

The Innovation Pillar within the new rail European Partnership will be the engine to deliver the technological and operational solutions to meet the expectations of the European rail sector matching a systemic transformation. Ensuring successful R&I outcomes of the set of Transforming Projects defined in Section 4 to 6 is the core of the Programme. Those Transforming Projects should focus on pre-deployment deliverables resulting from integrated and cost efficient research and innovation activities: they shall embed all the needed technical, operational and process-oriented work. As a deliberate choice, at this stage, it is proposed to focus on a limited number of nine Transforming Projects, covering the full range of technology readiness levels and in particular able to reach Large Scale Demonstrations (at TRL 9) for pre-deployment deliverables that would bridge the gap of the 'valley of death' between research and innovative solutions successfully applied in the market.

This approach will allow for a better return on investment from public and private funding as it will provide sufficiently developed and proven R&I results upon which the sector could build and transform the rail system, in a sectorial coordination within the System Pillar (see Section 3.1). Nevertheless, research and innovation is also prone to failure and recognizing to have failed to start on new basis shall be embedded in such wide Programme: the next rail R&I activities shall be a combination of exploration of new concepts and ideas, evolution of progress achieved so far and delivery-oriented activities for pre-deployment targets.

The work of new rail European Partnership will focus on providing:

- ✓ Greater value for the final users (passengers or freight forwarders), as they will be able to benefit from new interoperable and harmonised services and be involved in pre-commercial solutions (through Large Scale Demonstrations) to shape with the members of the Partnership the way how on-demand services are moving people and goods within and between cities, how in a multi-modal context rail is best interfaced with other transport modes and other services and how they can enjoy a seamless, worry-free experience;

- ✓ An agile, interoperable and open environment, in which companies can optimise their operations within integrated European mobility networks and interact with other businesses to deliver a sustainable and efficient mobility for Europe;

- ✓ European rail industry competitiveness, through innovative assets which will enhance the capabilities of transporting and reliably servicing people and goods, mainly leveraging technological breakthroughs. Also at global level: it will create the opportunity to export business models enabled by forefront technological and operational solutions, for European socio-economic growth.

Figure 4 below presents the way the nine Transforming Projects build upon each other to deliver the new Partnership objectives with new services, optimised operations and innovative assets. Further details on functional and technical interdependencies as well as the proposed R&I content are provided in Section 4 to 6

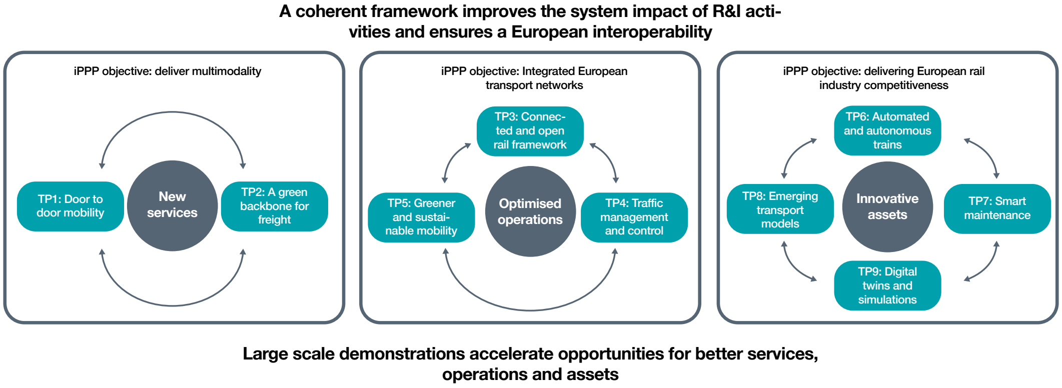


Figure 4: The Transforming Projects delivering new services, optimised operations and innovative assets

3.3 Socio-economic assessment

The main aims of the socio economic research should be to forecast the future circumstances in the transport market that will give rise to a need for innovation, to suggest the nature of the innovations needed and to establish the costs and benefits of the innovations produced by Shift2Rail and the new rail European Partnership. This requires establishment of the concept of operations, the business models to be used and the use of KPIs to measure the progress. (For the description of the KPIs see Section 3.5). Innovations such as automation, virtual coupling or completely new technologies may lead to radically different operating models in terms of frequency, train length, the role of wagonload services and the sharing of tracks between different types of traffic, and it is necessary to identify the best operating model before judgement can be made on the value of the innovation. It is clear that the fundamental aim of the programme is to contribute to the European Green Deal by strongly influencing mode split in favour of rail, and the achievement of this should be an ultimate measure of success.

The KPIs produced by the individual Shift2Rail activities and the new proposed Transforming Projects will feed into this process. It is essential that these forecast the projects' impact on the cost, quality and impact on society of rail transport in a consistent manner, with common assumptions for instance on discount rates, and that these are integrated with externally determined changes in order to produce forecasts of the impact on modal split. The business case will rest on the traffic and revenue that can be gained by rail, the costs of carrying it, the user benefits, the impacts on third parties such as net reduced externalities (pollution, greenhouse gases, accidents, congestion) and the wider economic impacts (such as changes in the location of economic activity and in productivity) of changes in the quality and cost of rail services. A methodology for valuing these externalities is given in the EC Handbook on the external cost of transport.

The forecasting may most effectively be made taking into consideration European, national and regional strategic deployment-oriented case studies, reflecting the full diversity of European conditions, including Central and Eastern Europe. Allowance must be made for changes within the rail sector, for instance in demand and revenues, costs and supply, and for external changes, for instance in population, employment, land use and lifestyles, and developments in other modes, including automated cars, heavy goods vehicle platooning and electrification of road transport. For this, either existing models for freight and passenger transport must be adapted or new ones developed. New research on the implications of such developments for rail traffic is needed. Obviously, this involves enormous uncertainties, and due to this the work should model a set of alternative scenarios rather than producing a single forecast, covering a range of policy and exogenous factors such as economics, demographics, technology, and also the long term impact of Covid-19 (see section 3.4). For many of the innovations, such as big improvements in real time multimodal information and ticketing, new research is needed to identify the impact these will have on mode choice. In terms of modelling costs, the Universal Cost Model (UCM), being developed and enhanced as part of the Shift2Rail NEXTGEAR and PIVOT-2 projects should provide important new modelling capability and could be expanded to other assets (such as electrification assets) that also deteriorate with traffic.

Reduced externalities and elements of wider economic impacts have been extensively studied for individual rail projects but less so for the overall cost, quality of rail services and wider impact on society. This needs to be related to expected future developments in land use, such as the growth of cities, and the nature of employment, and to include the impact of alternative policies to influence these in the direction of decarbonisation and environmental protection. The impact of radical improvements in rail services on land use patterns and economic growth need to be taken into account. Rail service improvements tend to encourage the growth of cities and of the benefits of agglomeration. Further, intercity passenger and freight investments improving connections for example between southern and northern Europe have the potential to change the economic structure of regions, promoting trade and specialisation. Resulting 'localisation' agglomeration impacts are an under-researched area and there is scope here for development of methodologies and supporting ex-post empirical evidence such as from large scale TEN-T projects. The uncertainties introduced by the Covid 19 epidemic also need to be considered.

Innovations will only contribute to the future of rail if they are implemented. Research is needed on incentives and mechanisms to promote innovation and quickly overcome barriers.

In summary, we see the need for a set of cross cutting socio economic projects covering:

- Development of the outline business case for the S2R innovations (including coordination of KPIs, determination of key parameters driving costs, utilizing statistical methods and building on the UCM)
- Forecasting demand and mode split (a series of passenger and freight case studies concentrating on different geographical areas and on different issues in terms of technological developments on rail and other modes)
- Examining the benefits and costs of improved and innovative rail services, including environmental benefits and wider economic and social impacts
- Reasons for non-implementation of past innovations and incentives for implementation of the innovations of this programme.

These projects aim to support a delivery oriented programme.

3.4 Safe, secure and healthy rail mobility and transport

The Covid-19 outbreak in 2020 is an unprecedented black swan of the XXI century[12] and has hit the transport sector exceptionally. Due to imposed personal mobility restrictions, the passenger transportation was almost entirely shut down during the spring of 2020 leading to unprecedented minimum transport volumes.

In freight transportation the volumes also suffered enormous decays due to drop of demand but also because of national border closures and imposed quarantines to drivers. In this context, rail freight proved to be more competitive than other transport modes and was even able to play a significant role in markets such as the transportation of consumables and refrigerated goods where it normally does not perform largely. Freight trains proved to be able to play a significant role in ensuring that, despite a Union-wide emergency, supply chains remain up and running also in areas typically covered by road transport such as the fast delivery mode of break bulk products. In this instance, rail reassured the manufacturer that its products could be delivered. Rail also provided the retailer with the ability to respond flexibly to supply bottlenecks and allowed consumers to maintain their shopping habits.

However, the crisis had a severe impact on the attitude of end-users towards public transport in general and rail in particular. Rail has been stigmatised as dangerous and precarious, while private mobility has been portrayed as safe and secure.

12. The term is from "The Black Swan: The Impact of the Highly Improbable" by Nassim Nicholas Taleb, 2007

This is not the first unprecedented event that rail sector has encountered, in previous it faced with terrorist attacks and natural disasters, but now the necessity to develop a roadmap for railway became even more obvious in order to sail in these unchartered waters and help the rail sector to become more resilient and ready to mitigate future unpredictable events at a sustainable cost.

In light of the railway performance under the stress induced by the Covid-19 crisis and by vulnerability of public transport to terrorist attacks, additional research and innovation activities should be carried out not only to address short-term problems and improve the sector position on the global market, but also to study and propose mitigating measures for both the Single European Rail Area and urban rail services in the long-term perspective. The EU will have to ensure high levels of efficient mobility for future crises and unprecedented events, and the railway sector will be able to contribute to this goal if equipped with valuable policy tools.

The Covid-19 crisis especially highlighted the importance of efficient infrastructure in the context of emergencies. It is therefore necessary to push forward digital and physical infrastructures to support the mobility of citizens and goods, both at national and European level, with a focus on efficiency and respect for the environment. As such, it will be necessary to investigate the effects of different regulatory frameworks on infrastructure development, to identify the most effective governance practices in ensuring a high level of resilience. Study on how regulatory framework can cope with externalities, such as health crisis or terrorist attacks, must be conducted.

The rail sector must be able to provide seamless experience to be the passengers' first choice in mobility modes at all time. On the one hand, challenges of COVID-19 requested immediate response to the situation, and some of these measures appeared to be ineffective and intrusive acting as limitations in the context of public transport and reduce the natural advantages of rail as a seamless barrier-free experience and thus push end-users back to individual mobility. This attitude must, of course, include extreme health and safety measures in the peak of the emergency. The same approach was used after emergency situations caused by terrorist attacks or natural disasters. Undeniable, these measures were contingent and necessary in order to allow public transportation to run efficiently during the emergency and can't be considered as measures to alter the level of services, but rail should be ready in more efficient way to future challenges. Thus, on the other hand, long-term measures should be developed to deal with issues concerning health, safety and security. The rail sector should aim for both satisfying economic and social needs by providing safe, secure and environmentally efficient public transport and providing benefits of individual transport at the same time.

Rethinking public transport and mass mobility, including rail, should consider two perspectives: from the evolution of the whole public transport environment and from emphasising a place of rail in relation to other modes of transport, improving integrated mobility.

Based on the observations of the railway sector response to the 2020 pandemic, this initial roadmap identifies the following steps as a guideline to approach future large-scale disruptions[13]:

- Resilience, to integrate business continuity with emergency recovery and disaster preparedness initiatives.
- Return, to restore the business back to scale as quickly as possible. It also includes restoration of customer trust and changing passengers' wrong perception of public transport.
- Reimagination, to adapt to the "new normal" after the crisis with targeted research activities.
- Reform, to enhance the role of railways in crisis prevention and management by including participation of European universities and research centres.
- Research, to produce an organized, integrated research output that will avoid duplicities and waste of resources.

13. based on the 5R approach in "Covid-19 impact in transport", EURNEX 2020.

➔ Scope / Actions

To provide safe, secure and healthy mass transportation services, the scope of research activities must focus on three components: increased safety & security on networks, crisis management & recovery planning strategies, and cleaner and healthier networks,

1.Increased Safety & Security on Networks and Assets

Within the second component, research must focus on the main aspects such as threat and risk analysis, resilient and secure design, contingency management from demand management and operations planning, to automation in operations and new technologies for maintenance.

Threat and risk analysis have the objective to identify and prevent the situation that would produce crisis and emergency situation in the system creating heavy disruptions in the service. That requires an integrated and multidisciplinary approach, being tightly linked to external activities and actors like intelligence services and Health organisations.

A resilient and secure design should be approach from a holistic manner, touching upon stations, vehicles and operations so that the rail system will capable to work at load capacity in emergency situations. Its design would imply a close link with the System Pillar as well as with the TP3 “Connected and Open Rail Framework for European Mobility”.

The focus on demand management and operations planning must lead to the development of novel technologies to monitor and manage demand. The work is linked to TP1 “Smart Integration for Railways within Door-to-Door Mobility” and TP4 “Network Management Planning and Control”.

While phasing in automation at different levels, the aspect of safe working conditions should also be taken into consideration. Smooth network operation is only possible when staff are safe and secure, not only those in the maintenance workshops but also drivers and train crew/conductors on trains. Correct practices in this context can avert the risk of local lockdowns and/or full stop of operations. In the link with other Transforming Projects of the SRIA, such as TP6 “Assets for Automated and/or Autonomous and/or remotely piloted Operations” and TP7 “Smart Asset Management and Maintenance of the Future” developments significantly contribute to safety and health of rail transport. Higher grade of automation in operations, together with the inclusion of predictive maintenance and robotic measures with respect to resilient infrastructure, and also the use of a remote control system of the robots for the identification and repair of faults, will enable the rail sector to be more robust against pandemics and similar threats in the long term.

Last but not least, unconventional rail transport technologies (i.e. fully automated Multi-Modal Mobility-Systems for passengers and goods) or new rail transport concepts which allow seamless and safe & secure door-to-door transport can bring new ideas in the sector (linked to TP1 and TP8).

2. Crisis management & recovery planning strategies

The third component focuses on the ability of a system to automatically recover from crisis situations when human intervention is not possible anymore. Any solution would need to operate within a defined system and for this the outputs of the System Pillar and TP3 “Connected and Open Rail Framework for European Mobility” are essential. Specific decision management tool, pushing the use of AI to its limit and provide the necessary checks and balances, may be part of dedicated research activities alongside the work of TP4 “Network Management Planning and Control”, TP2 “Rail as the Backbone of a Green Freight Logistic Chain”, TP1 “Smart Integration for Railways within Door-to-Door Mobility”, TP7 “Smart Asset Management and Maintenance of the Future” and TP6 “Assets for Automated and/or Autonomous and/or remotely piloted Operations” tested in a simulated environment of the real rail system provided by TP9 “Railways Digital Twin, Simulation & Virtualisation”.

3. Cleaner & Healthier networks

The relevance of novel research under this pillar originates from the need to understand how to adapt railway networks to higher standards of sanitation and increased attention towards public health standards. Research activities can cover the application in the rail system of new technological solutions for automated cleaning and disinfection, as well as virus entrapment system which can be easily deployed. The acceleration of the deployment of European IT solutions for passenger information and flow management touched in S2R IP4 and IP3 and in the TP1 “Smart Integration for Railways within Door-to-Door Mobility” would also provide indirect benefits. In addition, TP5 “Environmentally Friendly and Attractive Sustainable Mobility” will provide better interior designs including with safe and environmentally friendly technologies.

In order to join forces with other modes of transport, these R&I activities should include collaboration activities with other European Technology Platforms: ACARE, ALICE, ERTRAC and WATERBORNE to develop a common approach towards health and safe transport. Additionally, in the framework of this pillar the link with SRIA of European Partnership for Health Innovation, as well as with EU4Health 2021-2027 that is EU’s response to Covid-19, should be created.

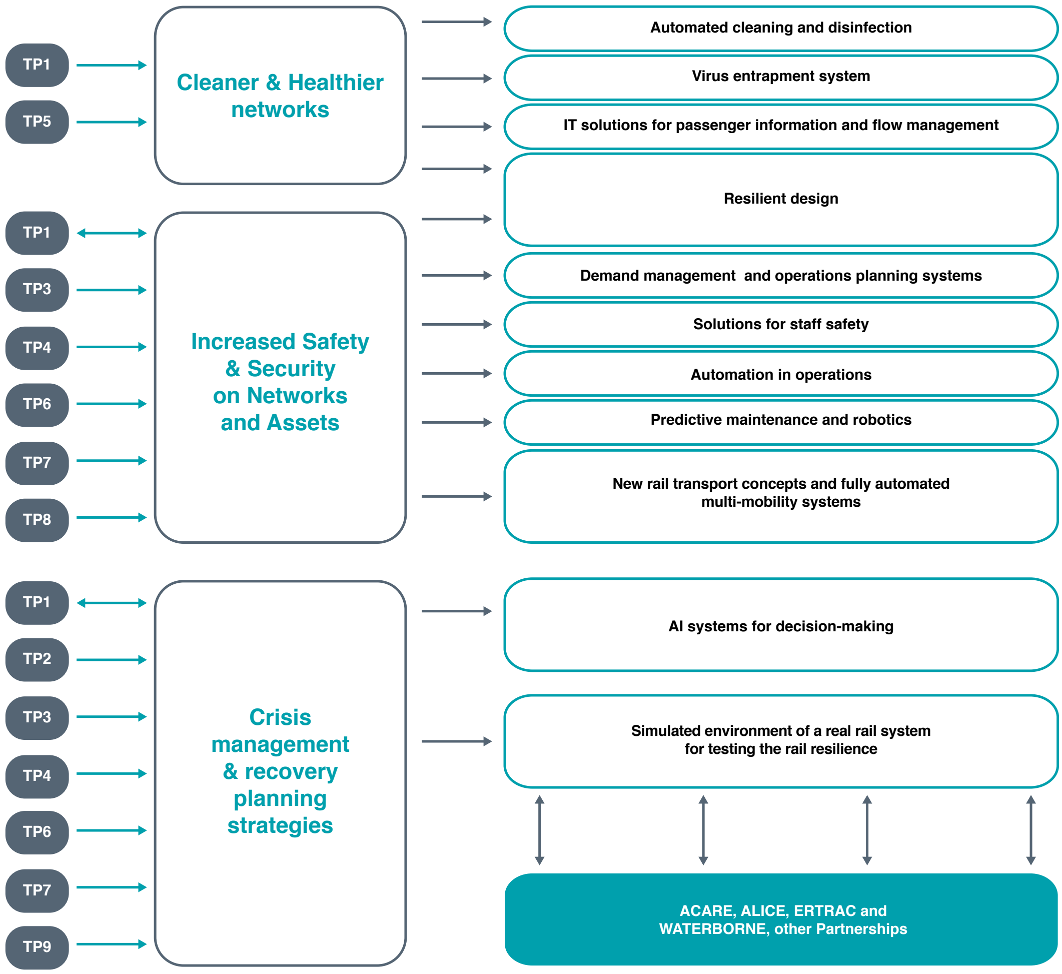


Figure 5: Contribution of the TPs to provide safe, secure and healthy mass transportation services

3.5 Key Performance Indicators

The fundamental aim of the research programme is to achieve a radical increase in the rail share of the transport market. It should be noted that the KPIs will need to be estimated in advance of the implementation of the innovations produced by the research. Thus it will be necessary to forecast them.

Thus the high level KPIs should be forecast rail passenger and freight mode share for specific years (e.g. 2030 and 2050). These, and KPIs reflecting the determinants of mode share, need to be broken down by the main market segments e.g. high speed rail, regional and urban passenger and bulk and general merchandise freight.

But beneath this it is necessary to examine the contribution of the research to improving a number of factors that determine rail market share. One key KPI in terms of ability to raise rail market share will be the reduction in forecast life cycle costs. A further important factor is the attractiveness of passenger and freight rail services. Mode split forecasting models mostly work in terms of a single measure of the attractiveness of rail services such as generalised time or cost. At the basic level, this adds the fare or freight rate to the journey time multiplied by the value of time. It may be extended to value other aspects of quality. For freight, the key factor is reliability. For passenger, this is also important, but they are many other important aspects of quality of service, including walking and waiting time, comfort, quality of interchange, ease of ticketing and information. The disutility of all these aspects of quality may be measured relative to journey time or fare using revealed or stated preference methods. In many cases adequate evidence exists for such valuations, but in some (especially for aspects of ticketing and information) new research will be needed.

This will in turn require forecasting of the impact of innovations on factors such capacity, lateness, frequency and availability of through services. Automation and virtual coupling may lead to significant improvements in these aspects of rail service quality.

A further objective of the research is to reduce the external costs of rail transport, including carbon emissions, noise and air pollution.

A preliminary set of KPIs may therefore be forecast percentage changes in the following, for each market segment:

➔ **High level**

- Rail market share
- Life cycle cost
- Rail attractiveness

➔ **Components of rail attractiveness**

- Delays
- Cancellations
- Walking
- Waiting
- Interchange
- Comfort
- Station quality
- Ease of ticketing
- Quality of information

➔ **Externalities**

- Carbon
- Noise
- Other pollutants (e.g. NOx, PM10)

It should be noted that these KPIs will in turn provide the information necessary to assess the business case for the various innovations and the contribution of the programme to the European Green Deal.

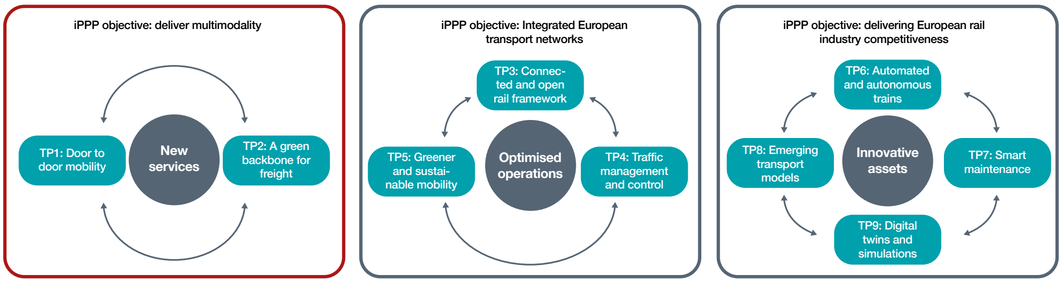
It is understood that there may be many other KPIs calculated in examining the success of individual projects at a more detailed level.

These more detailed KPIs will be selected in the light of the content of the individual projects.

In addition, there will need to be KPIs for research programme management performance.

4. R&I for delivering new rail services integrated in a mobility and logistic ecosystem

By providing door to door mobility to passengers and freight, rail being at the core, by moving goods all over Europe, the rail network being a green backbone, the rail mode will regenerate its services to its customers as described in the following TPs.



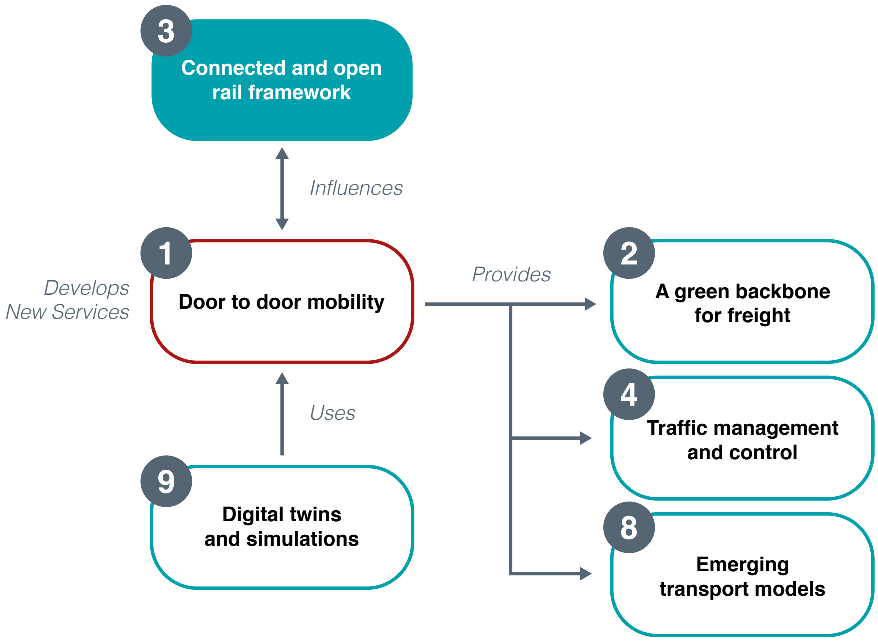
4.1 TP n°1: Smart Integration for Railways within Door-to-Door Mobility

➔ Vision & Challenges

Rail is a pillar of the European decarbonised mobility offers: it therefore needs to be seamlessly integrated into the European mobility ecosystem in order to provide easy and/or timely access to door to door mobility for both people and goods. This transforming project will enable a transition to decarbonised end-to-end mobility for people and goods operating across all transport modes. To achieve this, it will develop three essential capabilities:

- **Adjust the available mobility supply to mobility demand,** by monitoring flows of "anonymised" people & goods moving within and between cities and regions, and developing services offerings enabling a better adaptation of the multimodal offer to the actual demand, taking into account the characteristics of each mode.
- **Improve the integration of rail into the European mobility ecosystem,** developing further interfaces with the other modes, both physically in passenger stations and multimodal freight hubs and digitally to enhance multi-modal coordination and real time monitoring.
- **Provide end-users seamless access to all services associated with their multi-modal journey or logistics chain,** pushing for coordination with similar initiatives from other sectors to foster alignment and market uptake. This aspect can be seen as a technical and organisational enabler of the Mobility as a Service (MaaS) paradigm.

This transforming project builds upon Shift2Rail IP4 outcomes and has its main design collaboration with TP3 - Connected and Open Rail Framework for European Mobility. Additionally, it makes use of the simulation environment offered by TP9 – Railways Digital Twin, Simulation and Virtualisation, rely on and complement TP4 – Network Management, Planning and Control activities, and provides tools for TP8 – Non-Traditional and Emerging Transport Models and Systems, TP2 – Rail as the Backbone of a Green Freight Logistic Chain.



➔ Challenges of the Transforming Project

The challenge is to strengthen the integration of rail into the digitalised, decarbonised mobility offer supply, so that it becomes a truly compelling player in the market for people & goods mobility:

Improve operations for an integrated multimodal public transport offering:

- *Physical and digital integration of rail into a multi-modal offer.* The rail station and logistics hubs design and layout, hosting the other modes of transport, require specific attention with smart, efficient and flexible interchanges. Digital integration requires a distributed computing model across the shared transport modes (incl. standards, API, ontologies…), implemented as a platform that monitors and provides a digital abstraction of all mobility resources and allows the development of new coordination capabilities, making use of the tools developed with TP9 and complementing on-going sector initiatives.
- *Multimodal Traffic Event Management,* giving the ability to forecast, adjust and react to actual conditions of traffic dynamics in real time, including when disruptions or crises occur, providing additional tools to TP8.
- *Accurately match mobility demand to available mobility supply.* With real time knowledge of the flow of passengers and goods obtained through the fusion of outputs from various sensors, the challenge is to dynamically adapt the different mobility offers taking into account the specificities of each mode (flexibility, capacity, fixed or on-demand routes…) in order to achieve the best matching between offer and demand.

Provide the best multi-modal offer tailored to individual needs with the rail mode as backbone:

- *Shared and unified mobility token,* to overcome the current situation with different payment schemes (e.g. post-payment, pre-payment, account based) and a large number of ticketing, payment and validation systems across operators and transport modes.
- *Distributed General Ledger and Automatic Contract execution.* To provide MaaS providers with a decentralized solution to the issues they currently face in the enforcement of contracts, in accounting and revenue collection and in financial settlement with multiple mobility service suppliers.
- *Inclusive multi-modal journeys for specific requirements.* PRM but also logistics operators must be able to configure easily service bundles to adjust mobility offers to their own specific requirements.

A necessary post condition for successful deployment of the TP1 outcomes is the definition of a clear framework specifying rights and obligations on data sharing and service interactions across people and goods mobility operators that can leverage this transforming project.

➔ Status

Shift2Rail IP4 has already developed a large amount of the innovations needed to achieve the end-user perspective:

- The Interoperability Framework developed in Shift2Rrail IP4 is the founding layer for further development to achieve smart integration with other transport modes and ensure interoperability between these modes for the end-user point of view (TD4.1).
- The Travel Companion is used to manage traveller information, to define ID and preferences, trip information, to store entitlements, and is preventing the users to provide this personal information each time they interact with a different service provider (TD4.5).
- Providing a "one-stop shop", giving visibility to all accessible mobility offers for all modes including shared and personal transport (TD4.2).
- Issuing a secured entitlement, electronically stored, and containing the tokens needed for the complete door-to-door journey validation (TD 4.3).
- Complex event processing to collect and process traffic flow as well as disturbances that may hinder the multimodal transportation system (TD4.4).
- Handling new forms of travel experiences and providing navigation assistance and other additional services (TD 4.4 and TD4.5).

Some achievements have been delivered in the TD future stations in IP3 (TD3.11), using the layout of the stations to propose guidance to the passengers.

However, solutions to properly address the adaptation of the various public transport offers in a multi-modal context to match the mobility demand in real time are not widespread and commonly used.

➔ Proposed areas for support (classified by TRLs)

Derived from what has been described in the Vision & Challenges section above, the following main areas shall be improved, enriched or developed:

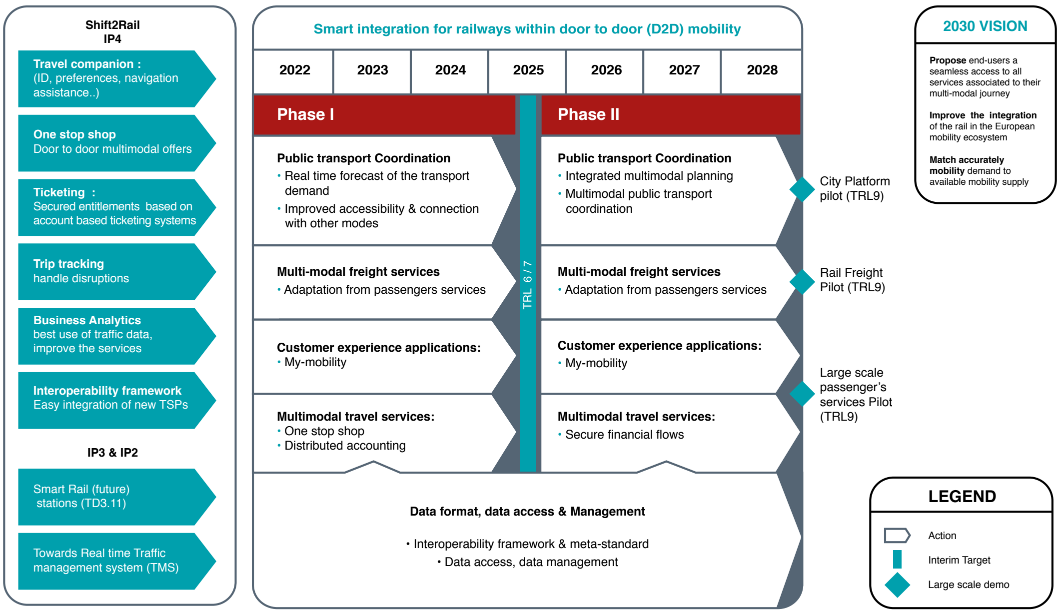
- **Public transport coordination:**
  (leveraging TP4 – Network Management, Planning and Control, and TP9 – Digital Twin)
  - *Real time forecast of the transport demand:* Framework or applications to allow the fusion and processing of the information provided by multiple sensors, video, ticketing, smartphone geo-localisation, to monitor the flow of passengers/goods (TRL2 to TRL9).
  - *Business Analytics for improvement of transport offer:* Monitoring the transport demand is bringing information on the usages (preferences), on how the capacities are consumed and the benefits of each mode and can be used to adjust the transport offer in a multi-modal context (TRL3 to TRL9).
  - *Integrated multimodal planning:* Using the flow of passengers and goods in all transport modes, propose design of optimal schedules (or capacity planning combined with on-demand dispatching) (TRL3 to TRL9).
  - *Improved Accessibility & connection with other modes:* Deliver a better service to impaired people, not only in terms of guidance but by ensuring a seamless and effective connection of services. (TRL3 to TRL9).

- *Multimodal Public transport coordination and Event Management:* Real time traffic management (see TP4) is giving to the rail the capacity to optimise train operations and reconfigured in case of disturbing events. In a multimodal context, even if each public transport mode is still optimized on its own, overarching coordination is needed to develop optimal mobility offers. It requires the integration in a city platform of mechanisms to enforce specific priorities (e.g. mode choices to promote or incentivize the use of frugal modes) or to propose coherent plans to face disruptions, and to optimize the global mobility offers to match the transport demand (TRL3 to TRL9). The rail system architecture to include urban rail interfaces within the TP3 is vital.

- **Multi-modal logistics services:**
  - Rail freight services are key for decarbonized logistics, and strongly contribute to a green environment, but must be complemented for the last mile to maximise their potential. Challenges similar to those faced by the provision of mobility-as-a-service offerings for people must be addressed for goods, and freight must continue to explore the convergence and the adaptation of solutions developed for passengers to decarbonized logistics together with the relevant actors (e.g. shippers, forwarders, other industries, etc.) (TRL3 to TRL9).
- **Customer experience application:**
  - *My Mobility*: Better understand travellers' behaviours and habits; Enhance trip tracker with GPS/Galileo and sensor based personal tracking; Machine learning to deliver services more tailored on the users' needs; Deliver an all-encompassing service to the customer integrating non-transport activities (TRL2 to TRL9).
- **Multimodal travel services:**
  - *One-stop-shop:* Enrich the Shift2Rail eco-system by including more Transport services providers (TSP) and new modes and enhancing orchestrators (TRL5 to TRL9). Improve Park&Ride integration (urban/suburban) including micro mobility and associated services such as charging stations (TRL4 to TRL9).
  - *Distributed accounting and financial settlement*: Handle issues in the Inter-modality scheme, shifting to a contract-based mobility-as-a-service scheme, leveraging the entitlement concept and expanding the ecosystem: from pre-paid to post-paid, account-based up to no manual interaction (Be-IN, Be-OUT, BiBo…) (TRL5 to TRL7).
  - *Secure financial flows*: Delivery of integrated mobility services provided by multiple actors leads to complex financial exchanges which have to be secured using a block-chain based Distributed General Ledger and Automatic Contract execution network (TRL3 to TRL9). Global transportation systems require a unified fraud management framework in order to control fare evasion and sharing data on offenders and fare dodgers (TRL3 to TRL9)
- **Data format, data access & management:**
  - *Interoperability framework and Meta-standard:* Translate IP4 Shift2Rail developments into a common reference architecture, connected with TP3 - Connected and Open Rail Framework for European Mobility, providing seamless interoperability through the "Interoperability framework". It requires the support of all stakeholders within the System Pillar and beyond, potential standardisation activities, and a strong coordination with other initiatives for market uptake. (TRL4 to TRL9).
  - *Data access, data management:* Based on the TP1 outcomes, develop a Multitenant framework for distributed computing across mobility providers, public authorities, financial institution, in order to enforce data and services ownership and responsibilities with adequate access control (TRL5 to TRL9), and develop robust anonymization for end-User data (TRL4 to TRL9).
- **Deployment and market uptake:**
  - *Development of Pilot for a city/region platform:* This pilot will demonstrate public transport coordination, with different use cases: assessment of the demand, city and region priorities, disruptions, global transport offer optimization (TRL9).

- *Development of Pilot for freight services:* This pilot will demonstrate how the developed services can be applied in the freight domain to improve the logistics chain (TRL9).
- *Development of Pilot for integration of passenger's services:* Create a specific program to aggregate the developments of end-user centric activities and to organize a large scale demonstration combined with initiatives coming from other sectors. (TRL9).

➔ Visual Roadmap



4.2 TP n°2: Rail as the Backbone of a Green Freight Logistic Chain

➔ Vision & Challenges

European freight transport is an important economic sector with high importance and massive impact on environment and society. Today, road transport accounts for almost 75% of inland freight transport with all well-known consequences to be addressed as indicated in the **European Green Deal**'s Commission Communication. Until 2030 the overall European transport volume is expected to increase by another 30%, which will have a significant effect on the whole sector since the growth cannot and should not be predominantly borne by road transport. Consequently, the European Green Deal sets the target of shifting a substantial part of today's freight volume towards rail and water ways to accelerate the shift towards a **climate-neutral continent.**

Due to the specific energy consumption for rail, which is six times lower [14] than for road due to physical advantages such as lower rolling and air resistance, rail is the best solution to cope with the upcoming transport growth in a safe and environmentally friendly way. Nevertheless, European rail freight performance is undermined by technological, operational, economic, obstacles that shall be overcome in order to **enable** both the **transport growth and the modal shift** at the same time.

14. RFF Whitepaper, 30 by 2030 Rail Freight strategy to boost modal shift

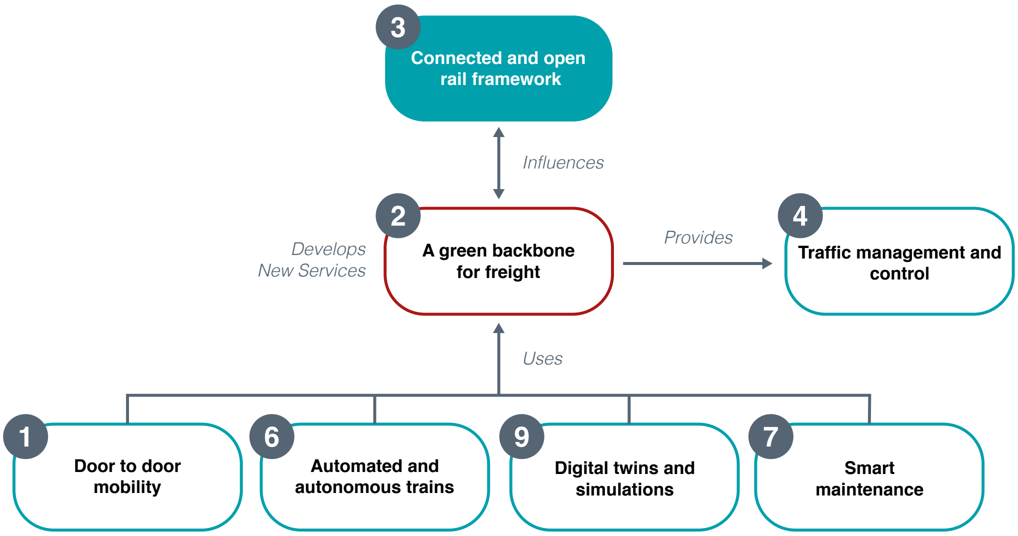
Shift2Rail has already shown that, with new rail freight technologies, punctuality and reliability can be increased by more than 70 % while LCC can be reduced by more than 30% [15]. This could lead to additional market share, as it opens the rail market for goods which today are carried by road[16]. Furthermore, recent studies show that customers require improved flexibility, accessibility and reliability in order to shift towards rail, but also the elimination of a series of unjustified operational barriers.

Therefore, the vision is to **transform rail freight into a high performing, efficient and sustainable backbone transport service** for a European multi-modal logistics industry. The full integration of rail freight and adaptation to the multimodal logistics chain ensures green, sustainable door to door logistics services. There are **three key areas** to increase productivity, capacity and reliability: (1) Digital **Customer Interaction and Services,** (2) **Multimodal Integration & Rail Freight Network and (3) Digitized and Automated Rail Freight Operations.** Also, smart rail freight services for high as well as for low density areas will be provided – this may include city fulfilment via tram or metro.

Boosting **competitiveness, performance, reliability and profitability** are the key challenges for rail freight. Taking this into account, the following strategic objectives can be derived to support the aspired modal shift:

- RUs offer innovative products to seamlessly integrate into the value chain of customers
- IMs provide capacity and service that makes running trains "as easy as running trucks"
- Authorities provide a level playing field for rail
- Dissemination of (intermediate) results[17]

This transforming project builds upon Shift2Rail IP5 outcomes and has its main design collaboration with TP3 - Connected and Open Rail Framework for European Mobility. Additionally, it makes use of outputs from TP1 - Smart Integration for Railways within Door-to-Door Mobility, TP6 - Assets for Automated and/or Autonomous and/or remotely piloted Operations, TP9 – Railways Digital Twin, Simulation and Virtualisation, TP7 - Smart Asset Management and Maintenance of the Future and provides input to TP4 – Network Management, Planning and Control activities.



15. Shift2Rail IMPACT-2, Deliverable 4.4

16. Shift2Rail FR8RAIL, Deliverable 1.1 - Confidential

17. RFF Whitepaper, 30 by 2030 Rail Freight strategy to boost modal shift

➔ Status

Shift2Rail lays the foundation to start the transformation process to a digitized and automated rail freight system. The Innovation Programme (IP) 5 "Technologies for Sustainable & Attractive European Rail Freight" covers five areas of developments:

- Fleet Digitalisation and Automation: Condition-based maintenance (CBM), DAC, Automated freight train /ATO and DAS
- Digital Transport Management: Improved methods for timetable planning, real-time yard management & single wagon load system, real-time network management and intelligent video gate
- Smart Freight Wagon Concepts: running gear, core market wagon, extended market wagon and telematics and electrification
- New Freight Propulsion Concepts: last mile propulsion systems, long trains up to 1500m, freight locomotive of the future and hybridization of legacy shunters
- Business analytics & implementation strategies: identification of market segments, development of specifications and KPIs and migration plan.

Developing obstacle detection systems and running a freight train demonstrator based on an ATO over ETCS GoA2 module (developed in IP2's X2Rail-1 and X2Rail-3) is the first major step of automated rail freight operations. Additionally, S2R offered a sectorial platform for correct delivery of a European Digital Automatic Coupling whereby all actors can support its market implementation and further support the automation of the freight operations.

The need of highest flexibility as well as independence, improved energy efficiency, increased capacity and lowered LCC are tackled by new propulsion technologies, including hybrid systems, last mile propulsion and the use of large Li-Ion batteries for catenary free operation, automation of various activities and functions as well as the development of environment sensing system for yard automation and technology for radio controlled distributed power for long trains (1500m).

The smart freight wagon concepts, fleet digitisation and automatic couplers bring sensor technology, energy and intelligence to the freight wagons. This paves the way to move from an intelligent freight wagon to an intelligent rail freight train. This will enable to increase effectivity of the single wagon services too. With CBM data collection and data transfers including the locomotive and wagon conditions are accomplished and the first algorithms are developed. The next step towards predictive maintenance could be started. Also, completely equipped assets with telematics and sensors for the digitalisation of the fleet provide real-time information on the status of the rolling stock components and cargo.

➔ Proposed areas for support (classified by TRLs)

To overcome the aforementioned challenges and to implement the vision of rail freight becoming the backbone of a green logistics chain with on demand services, a broad spectrum of R&I activities has to be initiated in the three above mentioned focus areas. Further activities are covered by other TPs which are also mentioned below.

1) Digitized Customer Interaction and Services (TRL 7-9)

Reliable **digital customer platforms** are required to offer new services to the customers. Such platforms should be designed as an open ecosystem to enhance innovation. Such an ecosystem allows real-time management throughout the whole process (i.e. along the logistics chain). Also, setting up a framework to attract third parties (e.g. start-ups) to drive innovation utilizing these data delivers additional value.

This approach would also support the development of **new business models** and to rethink the current ones to include on-demand services and to enable more freight volume to be shifted to rail. This is linked to TP1 "Smart Integration for Railways within Door-to-Door Mobility" as it includes the development of multi-modal freight services.

In general, new and innovative concepts of services must be developed and tested (e.g. capacity and yield management, multimodality with predictive Planned Time of Arrival (PTA), load and empty flows equilibrium, augmented reality/ virtual reality (AR/VR) for loading facilities and simulations, etc.). Simulations may also be possible with the use of the Digital Twins framework and tools developed by TP9. These concepts shall consider all transport modes in order to support a modern, multimodal and integrated logistics network that discharges road transport.

2) Multimodal Integration & Rail Freight Network (TRL 3-9)

It is important to identify solutions to i**mprove multimodality,** in doing so terminals in and close to ports are highly relevant with reference to volume of cargo. The latter is increasing while at the same time containerisation is advancing and both should boost multimodality. Overall, automation and digitalisation of freight train operations, yards and intermodal terminals based on real time data are areas which require further R&I developments.

The above-mentioned ecosystem should thus not only ease the process for costumers but also map the whole logistics chain and its access points. This way multi-modal services can be planned, managed and controlled and door-to-door freight transport and logistics services will be enabled, also with contribution of urban rail freight services interfaced for last-mile delivery services. Here, open digital data sharing **infrastructure and communication standards** for smooth, safe and sustainable freight transport and logistics in Europe needs to be developed.

However, stronger cross-links and digital connections of various transport modes, with special consideration of transport demand, cannot only be achieved by automation and digitalisation. For automated multimodal hubs **new terminal designs** must be developed – especially for longer trains (up to 1,500m) most terminals need new concepts. The same holds for multi-modal concepts and business models.

Most importantly, **rail freight network access** for customers must be simplified and transparent. This must be secured from the rail freight perspective in close collaboration with TP4 "Network Management Planning and Control".[18]

3) Digitalised and Automated Rail Freight Operations (TRL 7-9)

Data exchange platforms (or the creation of a rail carrier digital ecosystem) are needed to uncover the true value of the multitude of available operational data. They enable a seamless operational data exchange between all players in the rail freight sector to optimise the transport service for the customer. Here, it can be built on the rail carrier digital ecosystem which is currently being developed by the Rail Freight Forward initiative.

Digital Assistants based on new machine learning and AI methods are required to support the digital value chain in rail freight. The planning and dispatching of trains and the resources must be digitally supported by intelligent systems in order to increase actual capacity to manage the volatile business environment in rail more efficiently and tackle the expected growth for the sector as a whole.

Reliable, accurate **train and asset monitoring and positioning** supported by appropriate sensors are a prerequisite to increase the availability and efficiency of rail freight assets and can be achieved by developing an intelligent freight train. Freight wagons and locomotives, automatically coupled into **intelligent freight trains,** will communicate over the next generation of communication system and interact with their surroundings such as infrastructure and asset management sensors and systems. The European migration of the **Digital Automatic Coupler** (DAC) will lay the foundation for an intelligent freight train. With the deployment of the chosen DAC technology, which is covered in the DAC delivery program, handling times are minimized for maximized throughput of yards, supported by automation. With the DAC (type 4/5) wagons will communicate with each other and with the locomotives, in order to accelerate the train composition procedure (initialization, brake test) and to improve operational performance e.g. synchronous brake apply-release, automatic coupling un-coupling management from locomotives or remotely from marshalling yards. In general, the DAC and sensors will support automated wagon inspection, On-board monitoring (and prognostics) systems.

The **Distributed Power** (DP) concept is also vital for train integrity when it comes to trains with a length of up to

18. In general, European rail (freight) network must be linked, whatever the rail track gauges, to provide an access to all the EU countries.

1,500m and with an unmanned second push-pull locomotive. Also, a train with a length of 1,500m replacing two standard 750m trains reduces the capacity needed per ton by 40%. This may be progressively reached by the introduction of the DAC which enables to increase the length and weight at an extremely reduced cost.

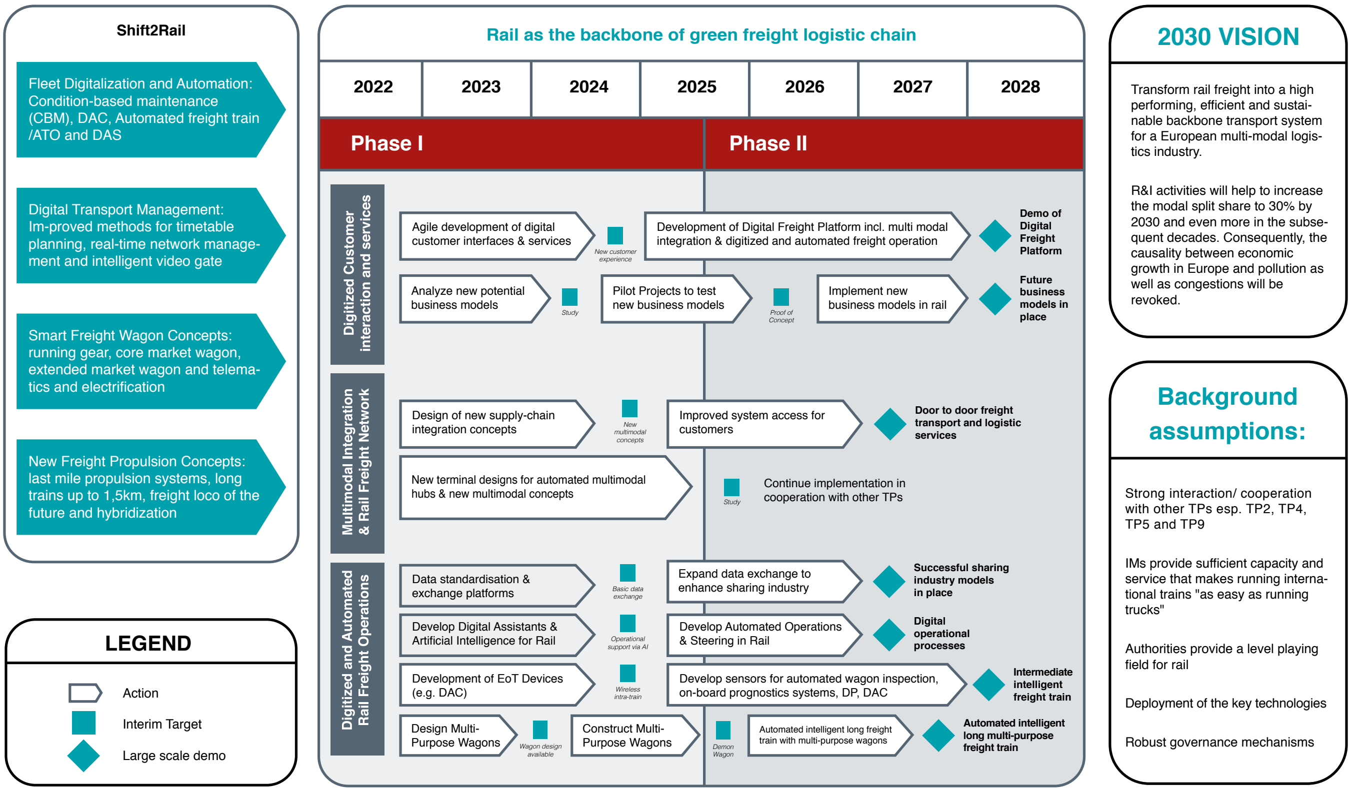
With the above there will be an improvement and increase in capacity and flexibility of rail freight operations. This will be further boosted with **new generation of wagons** such as multi-purpose wagon with improved aerodynamics which will help to reduce the number of empty wagon transports significantly.

There is a strong link to TP6 “Assets for Automated and/or Autonomous and/or remotely piloted Operations” as well as TP7 “Smart Asset Management and Maintenance of the Future” and TP3 “Connected and Open Rail Framework for European Mobility”.

In addition, there is the need for zero-barrier European freight train operations in order to eliminate the time spent at borders. This requires both, close collaboration with regulatory and safety authorities as well as an overall close alignment with all other Transforming Projects.

➔ Visual Roadmap

Looking at the content and scope, the overall goal is an integration of all developments in a fully equipped train demonstrator. Put differently, the majority of the activities should be demonstrated by building a digital freight system, also to verify the benefit the developments. After this deployment is key in order to reach the above-mentioned objectives.



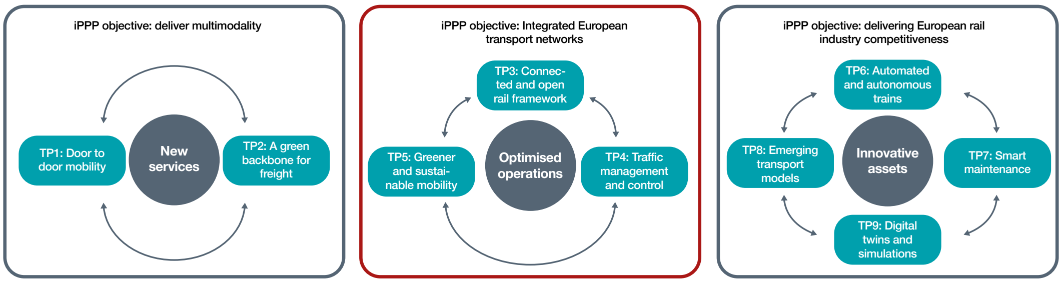
5. R&I for delivering Optimised rail and urban Operations

A connected and open rail framework will make the system smarter, easing technological evolution and transformation.

An agile traffic management, adapting in real time the rail operations, will provide a more reliable service to our customers.

Rail the greenest mode? It can be still greener for a more sustainable mobility.

The TPs described in this chapter are proposed to generate a continuous optimisation of the rail operations for better services.



5.1 TP n°3: Connected and Open Rail Framework for European Mobility

➔ Vision & Challenges

The creation of a barrier-less (operational, technological and legal) European railway network will build upon the concept of operations and the functional system architecture to be developed and delivered by the System Pillar. This will be an essential step for the rest of the research and innovation activities and it will be upon the work achieved in the Linx4Rail Projects performed within the S2R JU and additional current initiatives (RCA, EULYNX, OCORA).

In a long-term view, based on the main collaboration with the Transforming Projects 1 and 2 as well as with the integration of the results from TP4 and TP5, the implementation of a ETML (European Traffic Management Layer for railways) based on a high-performance digital rail system architecture for the secure exchange of information between the key actors of the rail systems and other sectors could be envisaged, creating the basis for the European rail traffic management for railways with integrated mobility solutions and services associated to tailor made governance.

The European Rail Functional System Architecture, as defined in the System Pillar, will interface with Urban Rail, which requires the Urban Rail System Architecture to be fully designed as new system of the Rail system-of systems and as part of the Urban Mobility Architecture. This requires additional R&I work, which will be carried out in this TP3.

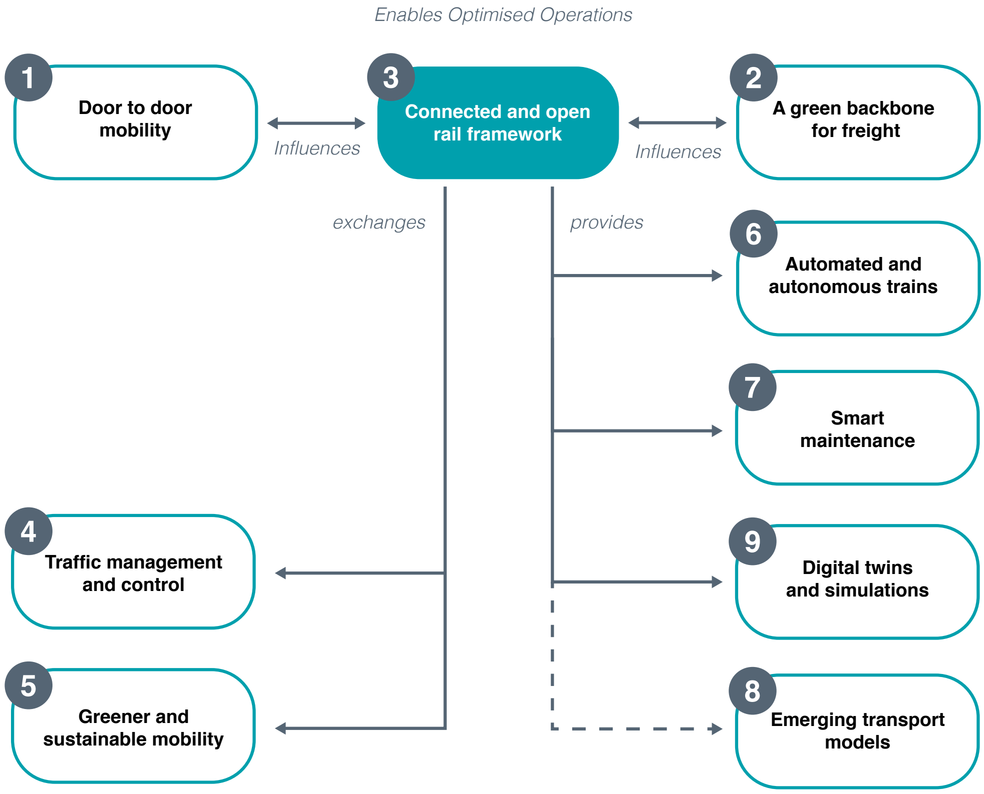
Depending on the initial focus of the System Pillar, the work should be mainly focused on research and innovation for mid to long term applications.

The research and innovation work of this TP will focus on delivering the element to operationalise the concept of operations and the functional system architecture in terms of establishing a European Railway System building upon the national infrastructure managers information systems and exploit on any future evolution considering computing capacity, communications, etc.

Data modelling and formalized processing will boost standardisation more in processes than solutions, thus fostering better quality, guaranteed safety and reduced cost and time-to-market whilst supporting project specific configurations and quick and easy adaptions strictly following and fully satisfying customer needs.

This transforming project builds upon Shift2Rail IPX and additional current initiatives (RCA, EULYNX, OCORA) outcomes and has its main collaboration with TP1 - Smart Integration for Railways within Door-to-Door Mobility and

TP2 – Rail as the Backbone of a Green Freight Logistic Chain. The collaboration with TP4 – Network Management, Planning and Control activities as well as TP5 – Environmentally Friendly and Attractive Sustainable Mobility will allow optimized European operations. Notwithstanding that, this TP ensures the integrity and coherence of the System Pillar functional architecture for all the other TPs dealing with innovative assets, but keeping open the possibility for a direct exchange of the System Pillar with individual TPs. It is of particular relevance the dependency of TP6 - Assets for Automated and/or Autonomous and/or remotely piloted Operations and TP7 - Smart Asset Management and Maintenance of the Future. It also provides the data structure that will be used by TP9 – Railways Digital Twin, Simulation and Virtualisation.



➔ Challenges

The S2R IPX activities, in particular with the LinX4Rail projects, paved the way for the Rail Functional System Architecture, currently under definition with the following characteristics:

- to be designed to offer a framework for a concrete realization, in terms of R&I programs and later implementation, of the vision, derived from the business ambitions of the railway sector,
- to be flexible enough to adapt, throughout the coming years, the vision to business, scientific and technological evolutions, whilst ensuring coherence and continuity for the railway system operation all along these evolutions,
- to be referenced to the current state of play and legacy of the railway sector, in order to enable the management of the transitions and possibly ruptures and leaps needed for the business evolution of the railway sector,
- to guarantee openness and transparency to all stakeholders by creating open and inclusive standards for all players in the sector, managing the stakeholders' IP where needed and being safe with respect to cyber security as the state of the art and its evolutions.
- to be adaptable to deal with the interfaces with other modes of transport, such as urban multimodal integrated mobility

This work will now be integrated, at large, in the System Pillar; nevertheless, the following elements will require research and innovation activities

- Fostering digital continuity by providing an open and interoperable data modelling and seamless data processes that include formal specification, development and proof for the sake of unambiguous and automated safety demonstration and authorization
- Analysing upcoming and successful innovations from inside and outside the rail sector for best uptake and exploitation to further develop the rail system architecture and its integration into a future mobility vision with full digital continuity
- Identifying conflicts and threats to the technical coherence as provided by the System Pillar output and Transforming Projects deliverables
- Ensuring the management of the interdependencies at Programme level and recommending to the Innovation Pillar the way forward in case of incompatibility of System Pillar output with and between Transforming Projects deliverables
- Analysing, modelling, designing and demonstrate innovative solutions to deliver the European Rail System.

This work has to expand at higher level and is going to touch the core of future operations - not change or harmonize the current ones - but ensure that future operations will be shared by the 27 Member States and no obstacles are created at national level.

On the other hand, this work shall expand (as already mentioned) towards interdependencies and interfaces complementing, integrating and supporting the System Pillar activities as needed.

➔ Status

Several architecture initiatives of various scopes, ambitions and purposes have already started, within S2R (e.g. ATO, TCMS, Integrated Mobility Management – I2M, Predictive infrastructure maintenance – DRIMS, RIMMS, IAMS, Multimodal Passenger Information System – IP4, etc.) or outside (BIM, OCORA, RCA, EULYNX, RailTopoModel/Rail System Model, etc.). LinX4Rail is a project within S2R created to be the coordinating platform inside Shift2Rail for the architecture, harmonizing and making coherent the development of these initiatives. Hence the development combines both a top down approach to define the main principles and development guidelines, but also a bottom up coordination and convergence of the on-going sector initiatives aiming at combining their developments towards a common approach and framework.

The architecture development takes into account legacy systems and thus enables an easier migration to digitized, data driven or breakthrough systems.

➔ Proposed areas for support (classified by TRLs)

Activities from TRL 1-4 to TRL 5-9

The area of support should focus on the following activities, taking into account the above-mentioned orientations and continuous exchanges with the System Pillar, considering System Architecture description and decisions of System Pillar as baseline:

- Manage evolution of the Architecture having in view the target system and its potential evolutions, taking advantage of the evolution of Complex System Modelling science and technologies towards a Common Data Model (CDM)
- Evaluate amendments of System Architecture Description based on input from all TPs
- Consolidate amendments of System Architecture Description and provide it to System Pillar
- Provide Architecture guidance for all TPs
- Develop amendments of System Architecture Description concerning scope of TPx
- Analyse interfaces to the external non-rail modes of transport as required by the TPs or by the evolution of positioning the Railway system in the global transport environment and provide recommendations to the System Pillar for consideration in the Architecture.
- From the Architecture and target system, develop the concept of an integrated European Traffic Management Layer
- Develop Urban Rail System Architecture as the system of railway systems following the LinX4Rail approach where applicable and provide recommendations to the System Pillar for integration or interface with the System Architecture following the system of systems approach, with the objective to realise full door-to-door mobility.

In particular, different scientific approaches should be combined in the development and implementation of the Rail system architecture: ontologies, system of systems modelling science as well as more specific scientific developments specifically adapted to complex systems with critical security and safety requirements and systems in which the human factor is still important (e.g. legacy part of the railway system, assisting management of degraded situations) with a continuous benchmark and inspiration from other sectors which have similar basic characteristics (defence, air traffic management, energy, automation etc.).

Further to the preliminary developments, the industrialisation of the development of the architecture will have to be carried out, jointly with the prefiguration of transformation of the railway system enabled by the Rail System Architecture Framework as well as further exploration of innovative solutions on a component or system scale.

This proposed transforming project does not, therefore, replace any of the other activities proposed by this strategic agenda: it rather offers a coherent and complementary framework, environment and ecosystem to develop and manage interactions, both with other transforming projects, but also within each project, managing the coherent development of each of their segments. A technical framework and environment for the development and implementation of these segments for all the involved functional or technical subsystems (rolling stock, infrastructure, energy, TMS and CCS systems,) and their internal and external (e.g. road vehicles) interactions is also provided. It will pave the way for easier certification and homologation through the connections of digital simulation systems that will help anticipating the performance obtained throughout the development cycle.

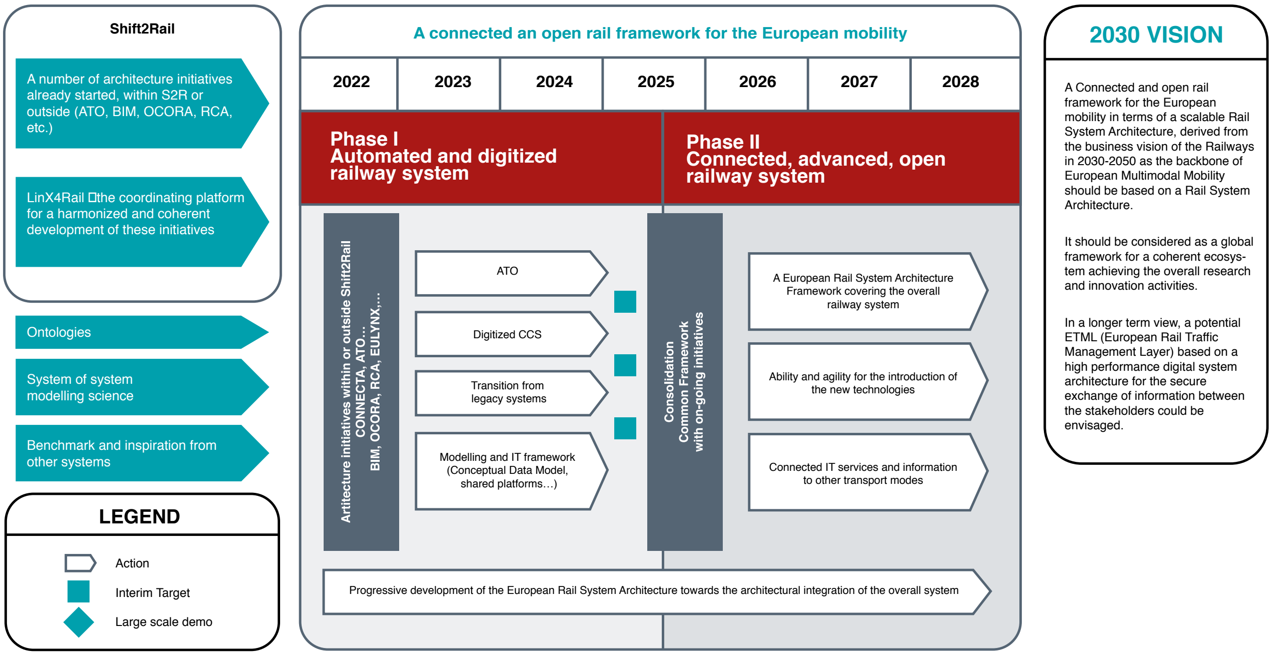
Since the railway system is conceived as the backbone of the multimodal mobility chain, the Railway System Architecture should provide connected ICT services and information to other transport modes to provide customers (both Passenger and Freight segments) with continuity of information, at both the commercial and technical levels, to ensure this seamless continuous mobility services, taking in particular into account the last mile delivery solutions. Therefore, Urban Rail Architecture, integrated in the overall Urban Mobility, should be fully designed as a new system of the Rail system-of systems, coherently with the Linx4Rail approach. As a result, clear interfaces should be defined in collaboration with the other urban mobility solutions and services: on such base, solutions can be jointly developed that contribute to integrated urban mobility.

The Rail System Architecture is indeed not a unique single and frozen concept, but an evolving and scalable collection of views involving various existing models.

Expected delivery from this TP will include:

- modelling/scientific research on system of systems and benchmarks ongoing activities (as a continuation of S2R1 activities),
- full rail ontologies finalization (as a continuation of S2R1 activities),
- sub-systems integrations in the system of systems architecture design finalised
- tools for legacy seamless migration/interactions,
- demonstrations for specific use cases,
- Urban Rail Architecture, integrated in the overall Urban Mobility, designed as new system of the Rail system-of systems
- integration and interface of external systems and services to rail,
- evaluation of impact on/redesign of operations manuals and rules,
- conformity to regulation (TSI) and full system integration tests and demos for large scale ETML or similar, targeting as far as possible TRL 7

➔ Visual Roadmap



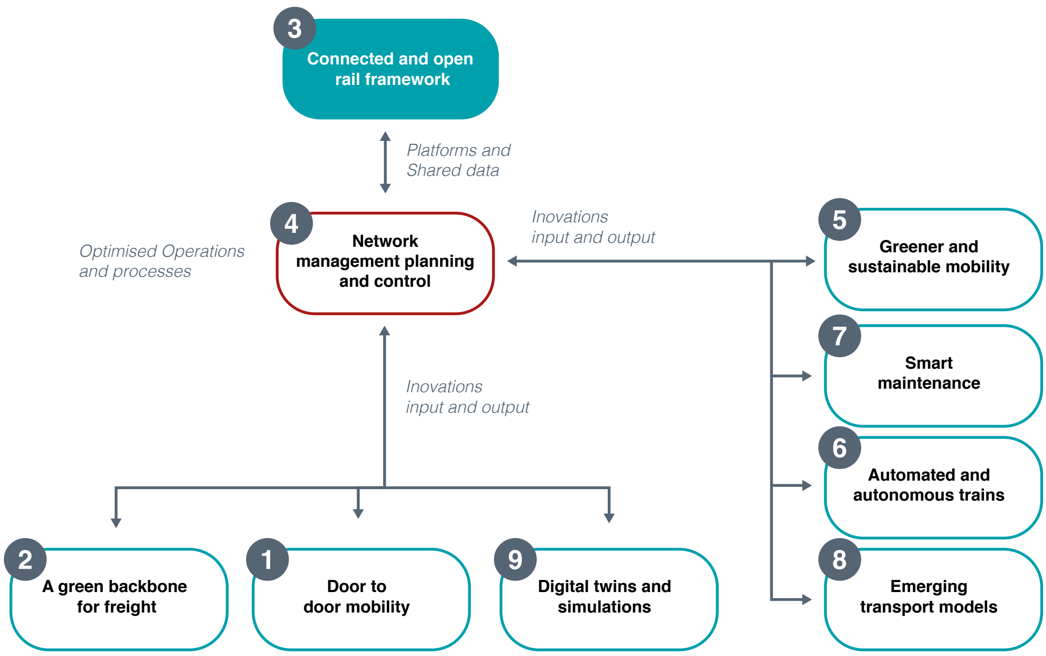
5.2 TP n°4: Network Management Planning and Control

➔ Vision & Challenges

This Transforming Project will develop a future Network management planning and control for rail operations at that will optimise national network capacity and increase punctuality, and reduces cost and supporting energy efficient train operations. The TP will develop future Network management process for Rail operators where capacity and punctuality will increase and this will be shown and demonstrated. The TP will deliver a traffic management system platform that is responsive to customer demand. The traffic management system platform of the future is part of a sustainable door to door mobility chain for people and freight where seamless co-modality is enhanced by digitalisation and automation. It will finally make rail a part of smart cities, smart regions and supportive of sharing solutions. To achieve this vision this TP will take on the following activities:

- Make use of artificial intelligence techniques and machine learning in support of operation and optimising the management;
- Data mining and management based on standardised communication layers to facilitate integration of various technical systems and support customer tailored mobility services;
- To interact with TP6 and S2R IP2, apply new standards for remote control and drive functions to deliver higher levels of automation which in turn will set a new standard for capacity utilization and deliver a more fluent traffic on the railway lines;
- To interact with TP2 based on the outputs from S2R IP5 about freight digitalisation, yard management and network management.
- Improved processes for planning and control.

This transforming project builds upon Shift2Rail IP2 and CCA works on Traffic Management and Smart Planning. It shares a common goal with TP3 - Connected and Open Rail Framework for European Mobility. It has strong links with TP1 - Smart Integration for Railways within Door-to-Door Mobility and make use of extensive simulation thanks to the works of TP9 – Railways Digital Twin, Simulation and Virtualisation. It incorporates outputs from TP2 – Rail as the Backbone of a Green Freight Logistic Chain. It provides a platform for exploiting outputs from TP6 - Assets for Automated and/or Autonomous and/or remotely piloted Operations, TP7 - Smart Asset Management and Maintenance of the Future, TP5 – Environmentally Friendly and Attractive Sustainable Mobility and TP8 – Non-Traditional and Emerging Transport Models and Systems.



➔ Challenges of the Transforming-Project

- To develop future Network management process for Rail operators and perform demonstrations.
- Continuous flow of information eases the journey, making connections between the different modes seamless
- To design the railway system of the future – higher capacity, higher punctuality and more effective
- Improved decision support planning, re-planning and punctuality prediction by data analytics, AI, simulation and optimisation
- Secure efficient and punctual railway system
- More precise and competitive freight trains by improved planning and control
- Improved information sharing and integrated decision making for yards, stations and asset management systems
- Supportive of sharing solutions through digital integration of modes

➔ Status

The empowerment of train dispatchers to plan or route the trains before they degrade the running of other trains can only be secured with a high degree of situational awareness realised through digitalisation and visualization of everything that happens on the railway. The control of the trains proactively, through planning, presupposes that information about the status of the facility, about traffic, about disturbances and about track work are available in the train control system. It also has to be presented in a smart way. This presupposes that the train control system contains all known plans for traffic and track work and more. Therefore, there is a strong connection to new tools and workplaces for production plans and for operational traffic management. Systems that deliver these tools are already on the market and being implemented. Simulation and decision support make it possible to simulate national networks and to develop decision support so actors are connected. The amount of data and new methods makes possibilities to simulate and develop decision support for corridors and cross boarder traffic. ERTMS simulations models and methods are also progressing.

➔ Proposed areas for support (classified by TRLs)

<u>Development of an AI Digital Twin</u> "Automated Resource Planning": uptaking the works from TP9, it will further develop a digital centre of simulation & analytics which covers all resources of the entire railway process (vehicle, wagons, human resources) including train operations as well as train composition which allows for a real-time (re-) scheduling of planification processes and scheduling. Further development by integrating the entire supply chain (e.g. multimodal supply chains) (TRL4-9)

<u>Decision support systems and Artificial Intelligence (TRL 2-4 and 5-8)</u>
Decision systems, data analytics and AI are enablers for creation of robust timetables and pro-active traffic management. Timetable planning and control processes will be automated or semi-automated. Connected Driver Advisory systems, ATO and future AI systems and decision support systems will be implemented step by step. It also helps IMs and RUs to re-plan when major disturbances occur.

<u>Improved simulations and ways of working (TRL 2-4 and 5-7)</u>
New simulators have an important role in realizing the novel technologies, by stepwise implementing Connected Driver Advisory Systems, ERTMS and Automatic train operation (ATO). They will also be useful for education and training of train dispatchers, train drivers and for innovating better man machine interfaces.

Experts on railways, data analytics and human factors will create and implement innovations by demonstration. The transforming project will be an enabler for visualisation, data sharing, organisation interaction and AI systems for rail operation. New technologies will lead to new organizational models and ways of working.

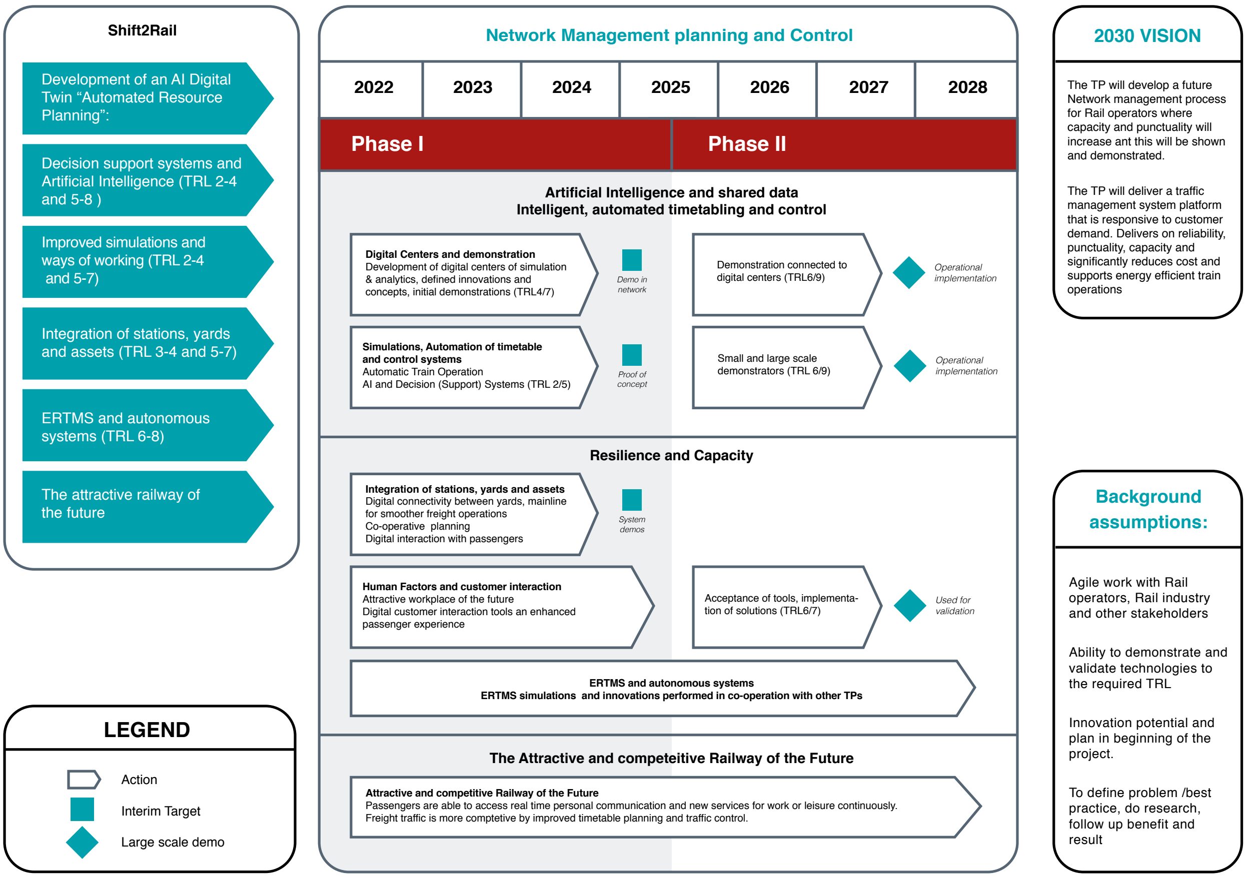
Integration of stations, yards and assets (TRL 3-4 and 5-7)
Today yards are not well digitally connected to the network, and there is a possibility to improve capacity and punctuality by improved decision support as a common information sharing and planning platform between yard manager and IM. Co-operative planning can also be of interest for passenger stations to increase departure punctuality. Improved information sharing gives yards and station more capabilities to handle disturbances. Traffic control management needs to integrate with systems for decision support such as Intelligent Asset Management Systems

ERTMS capacity and autonomous systems (TRL 4-7)
ERTMS capacity and implementation issues (effects, requirements, actions etc.) needs to be studied in dialogue between infrastructure managers, railway undertakings and system suppliers. ERTMS implementation in the European countries needs research to support solving challenges and secure ERTMS positive effects on running times, capacity, robustness and punctuality. Connected Driver Advisory Systems, ERTMS and ATO will be implemented step by step, in concert with results from other TP´s. Results will be validated by test runs at selected lines, in testing facilities, simulation systems and platforms.

The attractive and competitive railway of the future
Thanks to work of Shift2Rail IP4 as well as the strong collaboration with TP1 and TP2, passengers are able to access real time personal communication and new services for work or leisure continuously—before, throughout and after the journey. Digitalisation gives rail freight traffic possibilities to be more competitive by improved timetable planning and decision support for yards, terminals and network.

Innovative logistics services are driven by customer demand. Shipments are moved effectively, efficiently, safely and securely through the ‘’physical internet”. The rail system is fully integrated with the automated multimodal logistic chain and forms the backbone infrastructure of the physical internet, comprising new intelligent, automated cross-modal shipment transfer nodes.

➔ Visual Roadmap



5.3 TP n°5: Environmentally Friendly and Attractive Sustainable Mobility

➔ Vision & Challenges

The railway system has unique assets which enable it to mitigate the effects of climate change and to remain the cleanest mode of transport. It will lead decarbonisation in mobility and provide sustainable, attractive and cheap transportation for passengers and freight. The sector will have a positive effect on the climate through reducing energy consumption and decarbonisation, and on health and the environment by reducing noise and vibration, particle emissions, and resources. There will be an understanding of the effect of climate change on the railway system. An attractive and efficient railway will increase its occupancy and loading rate improving its sustainability performance, thus moving people and goods to a greener mode of transport.

Energy use will be optimised through dynamic management of the complete system which will forecast and prioritize the energy availability from subsystems and requirements from operations, also enabling transmission of energy between modes (e-buses and e-cars). State of the art technologies resilient to climate changes will be used which can be updated through the life cycle. Energy consumption of rail vehicles will be reduced by improving their efficiency and power supply infrastructure, and diesel engines will be replaced by alternative low carbon propulsion systems (including Hydrogen hybrid and battery powered trains) and next generation on-board energy storage systems.

The impact of the system (train and infrastructure) on the environment is reduced through the management of the global environmental footprint (including green-house gases and related performance norms and indicators) and reduction of local impacts. This is supported by policies on the mobility of people and goods.

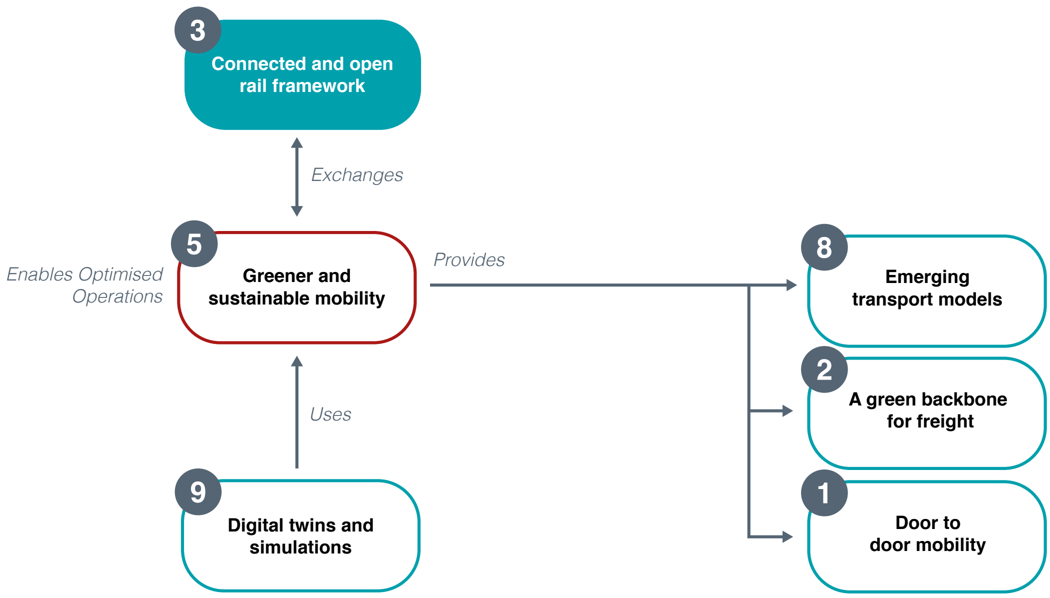
There is focus on the use of resources to promote the use of natural materials, reduce the usage of rare materials, increase availability of spare parts through additive manufacturing and a high level of recycling (especially spare parts) through the system lifecycle using eco-design concepts. There is improvement in maintenance through implementing a digital transformation programme to achieve benefits from predictive maintenance enabling intelligent management of resources and replacement of hardware with software solutions, with lower maintenance costs and higher management flexibility.

The requirements and solutions are standardized to reduce the costs, enable the use of products across the railway, there is a standard method of predicting and measuring the performance at the rail system level and the carbon use and environmental footprint of new technologies across the whole value chain. The development and implementation of technical solutions will need to be coordinated across the entire rail sector (including new ones like hydrogen suppliers) to enable the use of products across the Single European Railway Area. This requires the rail sector to specify technical requirements and business cases. The strategy will focus mainly on three spheres of influence:

- In-house activities and direct emissions which are recognized as standard & adopted
- Energy supply and its operating emissions related specific activities
- Supply chain resulting from the production and delivery of goods and services

A further challenge is that due to the volume of the rail market the major technology development is driven by other industries. Technologies progress from other Partnerships like Clean Aviation or Clean Hydrogen, or other initiatives like Batteries Europe will be taken into account to get benefit from other sectors synergies.

This transforming project builds upon Shift2Rail IP1, IP3, IP5 and CCA works on energy and environment technologies and processes. It shares a common goal with TP3 - Connected and Open Rail Framework for European Mobility. It makes use of simulation thanks to the works of TP9 – Railways Digital Twin, Simulation and Virtualisation. It provides the foundations for adaptations in TP7 – Smart Asset Management and Maintenance of the Future. possible technologies or network processes improvements that could be used by TP8 – Non-Traditional and Emerging Transport Models and Systems, TP2 – Rail as the Backbone of a Green Freight Logistic Chain and TP1 - Smart Integration for Railways within Door-to-Door Mobility.



➔ Status

Shift2Rail has started work on many of these topics which will be developed further to deployment.

TD1.1 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 will be created 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.

TD3.9 Smart Power Supply and TD3.10 Smart Metering Energy studied efficient energy management through the catenary for AC power supply (how flexible AC transmission systems can allow better energy management on the line), and energy management on the catenary for DC traction (how power electronics in medium voltage can facilitate power flow control, interface with renewables and energy storage systems).

IP5 studied last mile propulsion and next generation energy efficient propulsion systems for freight vehicles and 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. In addition, WA5.2 Noise and Vibration studied development of methods for predicting noise and vibration performance on system level including rolling stock infrastructure and its environment, ranking and characterisation of each contributing source to optimise cost benefit scenarios and comfort.

Development of the following mechanical systems has been undertaken in IP1

- Design of composite carbody components to reduce weight up to TRL 6/7
- Running gear steering systems, active suspension, new materials and new strategies to reduce weight and noise and vibration up to TRL 6/7
- Electro-mechanical brake requirements, prototyping and testing up to TRL 4/6
- Composite door leaves to reduce weight
- Eco-friendly HVAC requirements, simulations, alternative refrigerants and prototype testing
- Development of adaptable, modular interiors to meet customer expectations during train life

Roll2Rail WP6 studied attractiveness with analysis of key factors for railway sector.

➔ Proposed areas for support (classified by TRLs)

The areas of support consist of energy management for the railway and energy reducing systems for rolling stock and infrastructure, system developments to reduce emissions (including CO2) and development of supporting tools, processes and standards.

Holistic Energy Management

Development of smart energy modelling and management for the complete railway including operation of freight and passenger rolling stock. Connected Driver Advisory Systems and energy management systems where vehicles and the infrastructure know their status and operational profile and forecast and optimize energy consumption and regeneration will be developed. Future autonomous trains progress will be taken into account.

The digital energy twin of the infrastructure system integrates models of alternative propulsion systems and electrification enabling solutions to be identified considering propulsion, energy recovery, smart infrastructure and geographical aspects to determine cost effective optimum energy use and reduction of emissions at the system level.

Energy efficiency will interface with the developments in digitalization and there will be interaction with TP4 'Network Management Planning and Control' in the study of simulation and optimisation of the railway system regarding the power supply limitations and optimisation of energy consumption.

This will become the basis to determine the energy consumption of the different rail systems. (TRL 9)

Traction and On-Board Energy Storage Systems

Development and validation of traction system components to improve efficiency: energy management strategies for different train architectures, next generation propulsion, integration of the next generation control command architecture, very high frequency auxiliary converters and variable-frequency drives.

Development of alternative engine technologies (including use of synthetic fuels) to enable more efficient and decarbonised independently powered vehicles. Focus on further development, engineering and prototype of hydrogen fuel cells for multiple units, shunters / mainline locomotives and optimised hydrogen storage systems and next generation on-board energy storage integrating new technology storage elements. From TRL1 breaking through technologies to TRL8/9 to be reached.

Developments will use traction predictive maintenance progress, multi-physics modelling, virtual simulation, hardware-in-the-loop and improved approval processes to improve performance of components, system design and testing of train integration.

Infrastructure Electrification

System approach interfacing rolling stock and utility grids. Development of demonstrator prototypes and preparation for deployment based on operation analysis, considering existing systems and interoperability specifications. Integration and implementation of the systems previously developed (double side feeding in AC and studying the upgrade of existing DC power supply to higher voltage level), smart substations and overhead line that manage energy flows. Smart grids will develop standardized and regulation processes and interface with traction power systems addressing interfaces with new equipment, electromagnetic compatibility, distributed generation, cybersecurity and data exchange.

Development of renewable energy production and integrated energy storage systems to enable regeneration, and development and standardization of recharging and refilling infrastructure. **TRL7/9 to be reached**

System Developments

Vehicle systems with focus on running gear, structural components, mechanical systems, electromechanical solutions supporting airless train concepts and sustainable air conditioning systems will be developed to:

- reduce energy use through system optimisation
- integrate several functions in the same subsystem to enable the reduction of equipment size
- improve climate change resilience especially regarding interfaces, high temperatures and heavy rains.

The system design will introduce innovative development methodologies (model-based design, digital twins) to reduce the initial development, maintenance and total cost of ownership.

TRL7/9 to be reached

Impact on Health: Noise and Vibration and other pollutants

Development of tools and associated procedures to accurately predict and mitigate internal and external noise, vibration and other pollutant emissions of rolling stock and the complete system including their implementation for:

- acoustic virtual certification of rolling stock and standardization of methods for the separation of vehicle noise and track noise emissions,
- identification of appropriate parameters and development of design solutions for acoustic interior environments that enhance speech privacy,
- development of new measures to reduce exterior noise and vibration emissions and increasing their availability through validation by performance tests under real conditions
- planning, operation and maintenance of the railway considering the socio-economic consequences of its noise, vibration and particulate matter emissions
- develop new measures to reduce particle emissions such as dust absorbing systems
- develop operation and maintenance to reduce resource and increase sustainable material use through reduced use of components, which may also be replaced by software

Optimized specifications of infrastructure components as a result of a holistic optimization of the superstructure by considering all essential influencing parameters of the complete vehicle-track system, not only on noise emission but also on vibration emission.

Objectification of the perception of the efficiency of noise mitigation measures by using psychoacoustic methods in order to increase acceptance of railway noise.

Development of methods for an acoustic monitoring of railway tracks and wheels to be able to identify acoustically relevant defects on track or wheels which ensures low noise and vibration emissions in the rail network. **TRL 6/7 to be reached**

Environmental Footprint Tools and Circular Economy

Development of environmental footprint methods and tools that allow public information and monetarisation, improvement in recycling potential and practices and development of Life Cycle Assessment Databases. Development of unified standards for the assessment of the environmental footprint of materials and operating materials also considering pollution in the environment of the infrastructure. Incentive circular economy solutions which can be awarded and standardised in specific processes such as European Rail Infrastructure Building Certification Standard for the development of a European single standard for railway buildings with special regard to sustainability and corporate social responsibility covering new buildings and refurbishment. **TRL7/9 to be reached**

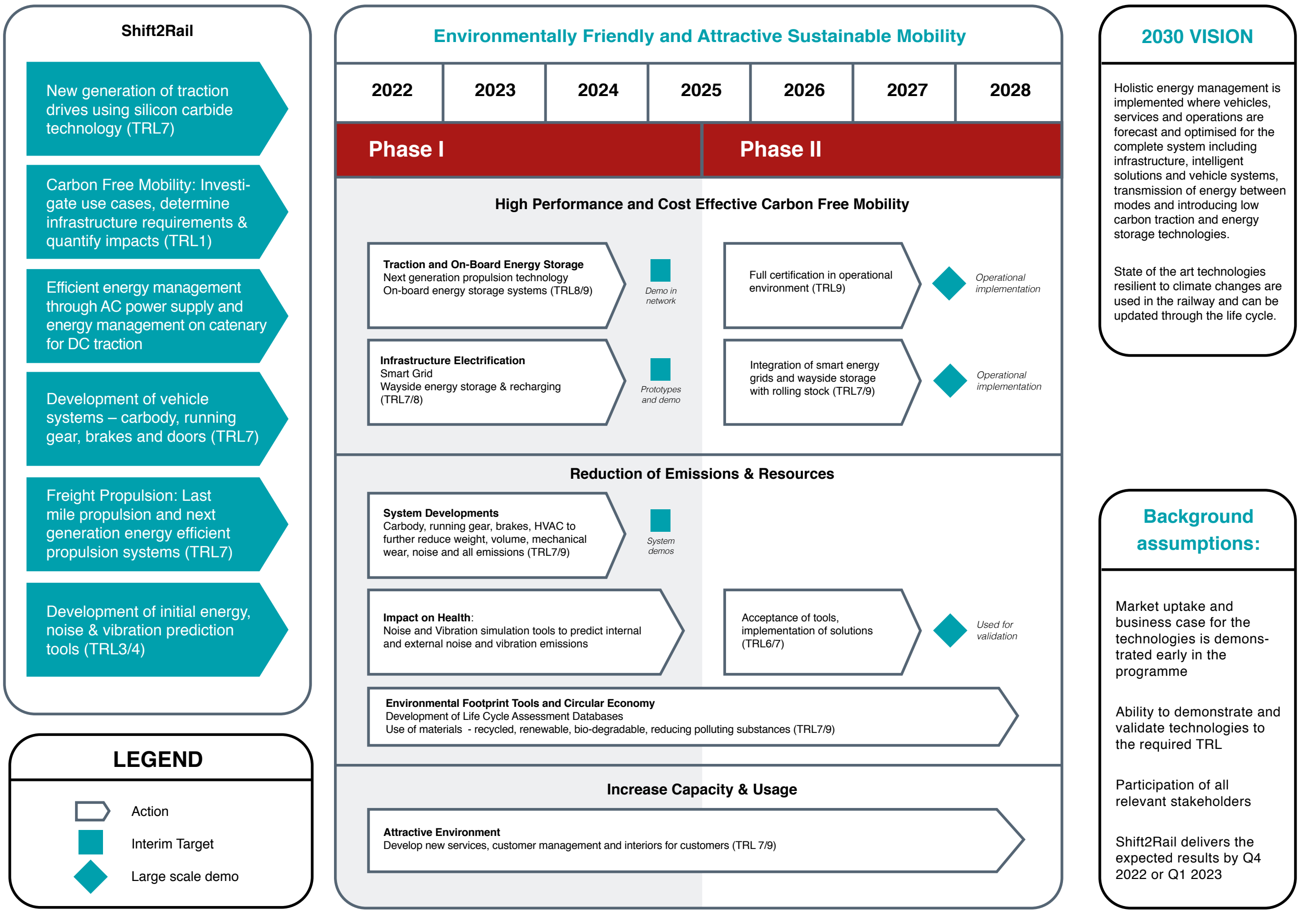
Work on manufacturing and perception adoption by considering that trains are durable (long life, storing materials and energy), have strict safety standards with high performance and customers' perception (safety and environmentally friendly of the transports they use).

Attractive Environment

Improve the capacity and attractiveness of the system through increasing the passenger flow through infrastructure and vehicles by the development of passenger flow simulation tools to optimise the

designs (doors width and positions, interfaces. Develop interior design to welcome soft mobility on-board while maintaining seating capacity. Develop safe, environmentally friendly and attractive materials to improve perceived quality of interior design and low-tech, low-energy and low-emissions on board comfort and entertainment services. Increase customer well-being through lighting & odour systems, flexible interior systems which respond to seasonal differing customer requirements, and virtual navigation as well as improvement of night trains. **TRL 7/9 to be reached**

➔ Visual Roadmap



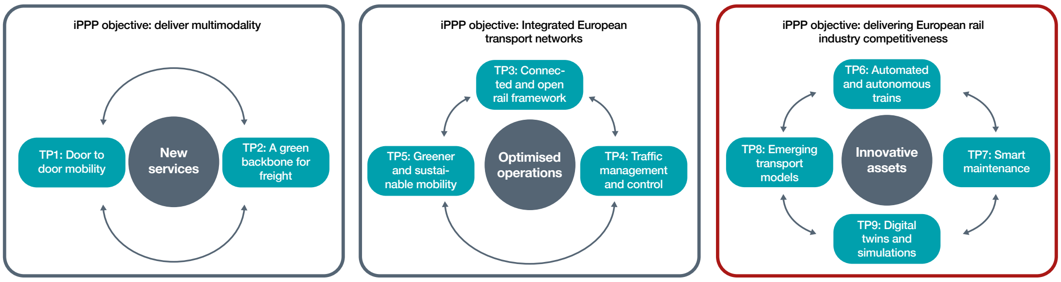
6. R&I for delivering Innovative Assets leveraging technological breakthroughs

The rail system's assets are at the core of system innovation based on massive digitalization. More automation and autonomous trains will make the system more agile.

Simulations, using more and more digital twins, will ease system management through its overall life, smart maintenance providing a system always ready for operations.

Its flexibility will support the emergence of new transport models.

The following TPs describe the innovative assets that will be delivered by the new Rail European Partnership.



6.1 TP n°6: Assets for Automated and/or Autonomous and/or Remotely Piloted Operations

➔ Vision & Challenges

Today automatic operation in metros and people movers is a reality. Most modern metro lines implement or are prepared for high grades of automation (GoA4). Experience has demonstrated enormous benefits where automatic train operation and automatic supervision (ATO and ATS) are in place, such as increased system capacity, punctuality, resilience and flexibility (by real-time adaptation to the demand) and reduced operating costs and energy consumption (up to 30% less for metro system for instance [19]), among other.

These benefits could also be provided by more automated [20] and/or autonomous [21] operations in other rail transport segments, such as regional and suburban trains, high-speed trains, freight trains or light rail and tramways. Indeed, in the future the whole railway system will require more trains operating smoothly on the same network and higher degrees of automation and connectivity for its seamless integration answering the specific needs and operational requirements (derived from the System Pillar or interfaced architectures). This also implicitly means that legacy systems (i.e. comprehensive network until 2050) and segregated railways (e.g. urban, suburban and local networks) will have to support automation to unleash a pan-European deployment of interoperable, plug&play, modular expandable and upgradable ATO and seamless automated/autonomous operation across Europe, towards zero infrastructure signalling and interfacing other autonomous transport modes where required.

Without a doubt, automation and autonomy of rail assets can directly and significantly contribute to at least two of the European Commission's priorities for the period 2019-2024: The European Green Deal (fighting climate change) and the Europe fit for the digital age (digital technologies including artificial intelligence).

19. Figure provided for Metro Madrid, according W. Carvajal, "Efficient driving of CBTC ATO operated trains", Madrid, 2017, ISBN 978-84-617-7523-1

20. Automated train operation: Deterministic algorithms fully testable and predictable behaviour (e.g. CBTC).

21. Autonomous train operation: On-the-fly decision-making based on the environment perception through artificial intelligence and machine learning whose behaviour is explicable yet not predictable.

Hence, the high level objectives of this transforming-project are to:

- To capitalise Shift2Rail's and OCORA/RCA results on ATO GoA4 over ETCS and complement them (e.g. remote driving and command, train composition…)
- To support the migration from current legacy systems to ATO GoA4 over ETCS
- To provide high degrees of automation on segregated or partially segregated networks
- To provide self-healing management functions of rolling stock enabling automation

Within this vision the existence of a standardised automation platform, covering all phases, from the architectural conception to the testing, certification and commissioning of a certain deployment, will be an essential asset complementing digital twins and advanced traffic management. This platform is key to deliver safety, compatibility, interoperability but also to facilitate migration and to keep automation affordable and cost-effective.

Segregated or partially segregated networks (such as metro, light rail networks and certain regional and suburban networks) have different operational procedures and constraints, offering an opportunity for research and development of harmonised solutions which can reach the market sooner. Similarly, opportunities for quicker deployment of harmonised solutions for autonomous (or remote controlled) movements (shunting, stabling…) that can bring many benefits sooner can be implemented and exploited for depots and yards, which in many cases are closed environments.

Automation calls for new functions based on quickly evolving technologies, such as artificial intelligence (AI), of which certification is uncertain when applied to safety related functions, and where the existing procedures and regulation may not be applicable. Such functions will rely in many cases on new generation of sensors providing artificial perception of the environment, whose reliability and accuracy highly depend on training and machine learning, increasing costs. Because of the quick evolution of such technologies and computing capability, these solutions will also have to be modular and able to evolve, to allow progressive deployments in new build systems or as evolution or add-on to existing assets, minimising the investment risk and ensuring plug&play [21], upgradeability and component interchangeability.

High degrees of automation require connectivity, between vehicles (including road vehicles), between vehicles and infrastructure, and between vehicles and users or pedestrians, through suitable communication links and information management. Such connectivity is also the cornerstone for the virtual coupling mechanism, which should really be exploited in passenger services, going beyond the existing low TRL prototypes, and paving the way for a new kind of lightweight ATP. Harmonised and fair allocation of relevant dedicated frequency bands, together with cyber-security and security applied to automation and connectivity are important challenges to be addressed.

While solutions for introducing automation in existing assets must be developed, new tailored railway vehicles must be developed in order to fully reap the benefits of automation. This includes development of a new generation of vehicle subsystems and components, such as brakes and doors, or sensors, providing safe and reliable performance for automated and autonomous operations.

Unattended train operation (GoA4) will require automated and/or remote management of vehicles and infrastructure regarding various events, such as incidents, disturbances and degraded modes. Interoperability will require harmonised operational rules to cope with such scenarios, together with ergonomics for supervision and reliable, safe and secured remote control.

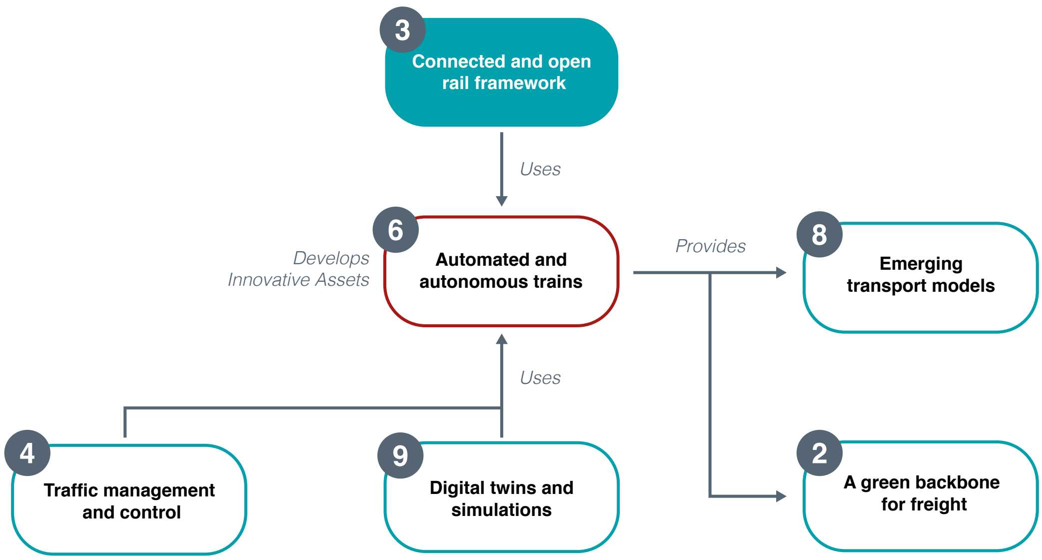
One major challenge to be faced by the European railway community is the migration from existing non automated assets and operations. The ERTMS European Deployment Plan (EDP) defines nine core network corridors for the implementation of ERTMS by 2030, to be enlarged to the comprehensive network corridors by 2050. Even by then,

22. Define the interface in a way that the system can be exchanged, extended and modified independent from the full integration and approval, according to state of the art engineering rules, process and certification required by the safety authority without any dependency to the other supplier many thousands kilometres of rail lines will remain with legacy systems in European urban, suburban and local areas. Such systems will be at the end of their lifetime. Therefore, their use for railway automation is very uncertain. Research activities should be done on how to keep these systems up and running where they are necessary.

Ensuring a smooth migration towards unattended train operation (GoA4) in TENT-T corridors in parallel of the deployment status of ERTMS and a seamless GoA4 among the whole pan-European rail network are key challenges to be tackled by this transforming project.

Human and social aspects should not be forgotten. First, the social acceptance of autonomous trains must be ensured, in particular in the case of long distance unstaffed trains or tramways on non-segregated lines. Second, roles, responsibilities, legal and liability issues of the involved actors should be defined specifically for automatic and autonomous operation, together with a competence management and qualification system.

This transforming project builds upon Shift2Rail IP1, IP2 and IPX works on signalling, communication and control. It makes use of the framework provided by TP3 - Connected and Open Rail Framework for European Mobility as well as of the simulation tools from the works of TP9 – Railways Digital Twin, Simulation and Virtualisation and benefit from a traffic management optimised for its technologies with TP4 – Network Management, Planning and Control activities. It provides possible technologies on automation for both and on brakes for both TP2 – Rail as the Backbone of a Green Freight Logistic Chain and TP8 – Non-Traditional and Emerging Transport Models and Systems.



➔ Status

Shift2Rail has pushed research in many key fields that will serve as the starting basis for the development of a new generation of assets for automatic and autonomous operations. In most cases high TRL demonstrators (TRL6/7) will be implemented at the end of the Shift2Rail initiative by 2022.

Results in the field of mainline signalling (i.e. IP2) must be integrated in this transforming-project, such as the ATO over ETCS up to GoA2 and the preliminary activities towards GoA4, which should be considered as a starting point for this transforming-project. The Future Railway Mobile Communication System (FRMCS) complemented by the Shift2Rail Adaptable Communication System (ACS) and cyber-security studies should be the starting point to achieve seamless, reliable and secure connectivity. Other relevant functions coming from IP2 are safe train location and train integrity function for passenger trains. Moreover, first research activities on obstacle detection, incident handling, remote driving and virtual coupling will feed this transforming-project and evolve towards higher TRL. Cross-feeding between IP2 outcomes and other segments developments such as segregated suburban railways, metro or LRT/tramway should be explored.

Coming from IP1, Shift2Rail's results in TCMS technologies are of high relevance to this transforming-project, as the TCMS will have to integrate the new functions demanding more performance. The new generation of on-board functional architecture and its hardware and software independent platform (i.e. Functional Distribution Framework - FDF, computing platform) and application profiles, complemented by the new Train Communication Network (TCN) supporting safety critical functions (mixed-criticality enabled) will be at the core of any TCMS suited for automatic and autonomous operation. This perfectly fulfils, in addition, the requirements for modularity and upgradability. Concerning connectivity, IP1 already started the development of wireless train-to-train communication complementing the aforementioned ACS and the new standardised train-to-ground communication protocols (for TCMS purposes). In addition, IP1 worked on some subsystems like brakes and doors, improving significantly their performance (e.g. safe fully electronic braking or smart sensing doors). The outcomes of these activities can already contribute to the implementation of automation in railways.

Furthermore, Shift2Rail is working on new rail Functional System Architectures for mainline railways in its IPX activities within the LinX4Rail project. The project is taking into account the architectural work done across all Shift2Rail IPs and also beyond the rail sector (e.g. aeronautics and automotive). LinX4Rail results will provide relevant inputs to the architectural activities in the TP3.

Also coming from IPX, the TAURO – Technologies for the Autonomous Rail Operation – project should be understood as a lighthouse activity to this transforming-project. Its results are key inputs here. TAURO is proposing a certification procedure for the safety related functions based on artificial perception together with a common database of both real and synthetic scenarios for AI training and later certification. In addition, this IPX project defines the interface for remote driving and command of rail vehicles to be later standardised. TAURO also analyses the feasibility of using AI for automating and/or improving some functions such as the door management or the passengers' security and safety. Last but not least, the project is also studying ways to move effectively towards automated operations during the long lasting migration phase where some class B systems will still coexist.

The current of state-of-the-art on methodologies, design rules and approval process such as the model based development, sometimes coming from other global industry standards, should be analysed for by the System Pillar to be exploited within this TP and within the whole initiative in general.

➔ Proposed areas for support (classified by TRLs)

To overcome the aforementioned challenges and achieve the vision to have more trains with different performance running on the same networks, automation can be a real game changer as experienced in other sector; the role of the staff involved in the current operations will be essential for the new generations of rail operations and to create opportunities for new jobs and growth. Developments will follow the architectural principles (i.e. Rail System Architecture Frame) defined within the System Pillar and detailed as necessary in TP3, supported by its technical framework and environment for the development and implementation of the involved functional or technical subsystems.

Development of a standard automation platform, to provide a cost-effective and safe deployment of automation and supporting migration from legacy train control systems. The platform will be valid for all segments (i.e. modular and scalable) and will follow the architectural principles defined in TP3 and the initiative-wide tools, design and modelling rules and methods proposed by the System Pillar. This area of support will include, at least, the following activities:

- Proposal for a technical and regulatory framework, applicable to both new built and existing trains, to achieve a cost-effective integration and certification of the new technologies, such as the artificial intelligence, and of authorisation processes, through virtual validation, testing and simulation concepts (from TRL3 to TRL7/8). This will require the definition and implementation of standardised test benches, simulators and a reference implementation (i.e. vendor independent) for certification, verification, testing and simulation purposes, together with new processes and regulations to be defined together with safety authorities. This activity will require the analysis of other global industry standards and procedures that could lead to proposals for their adoption in railways;

- Development of a standardised and certifiable internal and external situational awareness framework (from TRL3 toTRL7/8), including its perception layers (i.e. sensors) and artificial intelligence algorithms, to implement new on-board functions to complement existing ATP and enable safe and cost-effective automation, and reliable under any weather or environmental condition;
- Use of new generation of CCTV or other sensors and passenger information systems adapted to unstaffed vehicles by implementing artificial intelligence, prognosis and hazard or violence detection, remote assistance or autonomous troubleshooting among other features (from TRL3/4 to TRL6/7);
- Enhancement of the train positioning systems developed within Shift2Rail by adding new sensors, enabling universal track-precise positioning all the time, under any condition (resulting into possible reduction of signalling devices along tracks) (from TRL1/2 to TRL6/7);
- Development of ATO functions (from TRL2/3 to TRL 7/8), based on the functional architecture and Shift2Rail's solutions such as the FDF and required application profiles and RCA/OCORA, so that it can be kept independent from the ATP function and hence applicable to various scenarios such as the ATO over ETCS or the autonomous movements/shunting and train composition in depots, while ensuring full interchangeability, modularity, interoperability and plug-and-play solutions.
- Train-to-ground, train-to-train and train-to-X communications, starting from legacy technologies and moving towards 5G/FRMCS telecommunication networks or constellations, together with the definition of the required architectures and protocols and including migration paths from legacy networks (from TRL5 to TRL7/8). This will require coordination and development of joint solutions with other mobility elements, track devices and services;
- Development of the cooperative awareness function in the railway domain (from TRL2/3 to TRL6/7), to provide virtual coupling and swarm intelligence, as a basis for a new generation of low cost interoperable ATP for low traffic or segregated lines.

New asset concepts and subsystems best fitting the autonomy paradigm and maximising capacity, together with technical solutions for upgrading existing assets, including:

- Business and technical framework supporting implementation e.g. moving towards plug and play safety critical modules (from TRL6/7 to TRL8/9);
- New vehicle architectures tailored to automation (from TRL1 to TRL5);
- Advanced computing functionalities, supporting artificial intelligence, remote driving, command and supervision, and fulfilling additional automation requirements (from TRL3/4 to TRL6/7), assuring hardware-software independency, on the foundation constituted by Shift2Rail's functional architecture and the mixed criticality network, and OCORA/RCA;
- Design new functions for self-healing management of rolling stock systems for full automation (from TRL2 to TRL5);
- Development of additional braking functionalities (from TRL4 to TRL6) such as the variable effort emergency brake or the holding brake, based on the new generation of safe electronic brake;
- Evolution of metro automation, considering new harmonised and standardised technical solutions (including architectural principles of TP3) and operational concepts, identifying requirements with operators to efficiently improve today's metro automated operation (from TRL2 to TRL5).

Operational aspects, to tackle:

- Definition migration and roll out strategy with a focus on the funding, business and organisational impacts of automation (from TRL1 to TRL5). Proposals for deployment and business cases should be an outcome of this activity;
- Harmonisation of operational rules and procedures (from TRL 1 to TRL5).

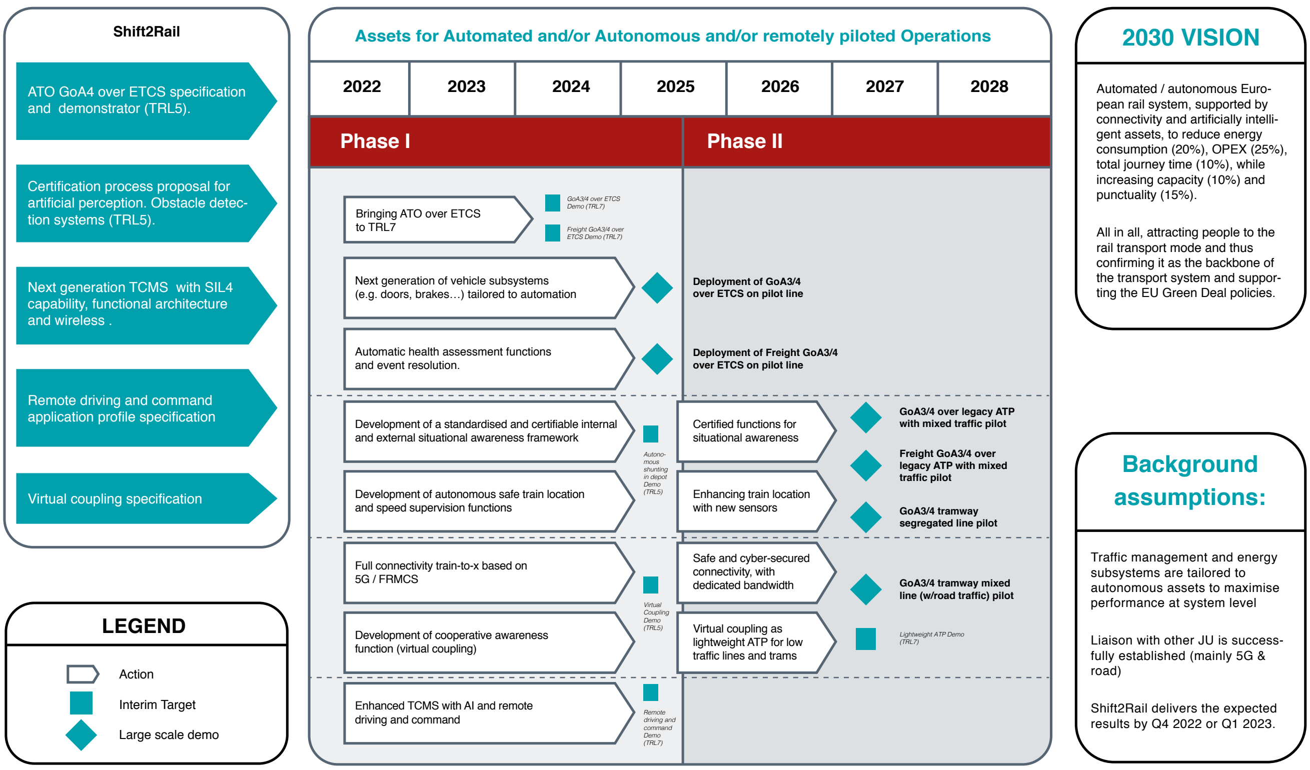
Social and human capital aspects related to automation (from TRL1 toTRL5), including acceptance and promotion of the technology, definition of roles and responsibilities, and identification of required new jobs and competences, together with the related implementation plan.

It is an essential component with a clear roadmap to deliver to the rail operating community vehicles, infrastructure and an overall system largely based on secure and safe automation, subject to clear business models answering socio-economic needs. Development of large scale demonstrators based on the previous developments, bringing them to higher TRL9, which will be evaluated for market readiness, leading to certification, in order to facilitate the market uptake, such as:

- Automated (GoA3/4) and connected passenger and/or freight operation based on ATO over ETCS (i.e. on a core network corridor);
- Autonomous (GoA3/4), interoperable and connected passenger and/or operation on any type of system shared with mixed non-automated traffic;
- Autonomous (GoA3/4) and connected urban line in open environment (e.g. tramway, LRV), implementing cooperative awareness as global ATP (i.e. extended to autonomous and connected cars in tramways).

To achieve these demonstrators, intermediate steps are suggested, such as autonomous shunting in depots or the remote driving and command.

➔ Visual Roadmap



6.2 TP n°7: Smart Asset Management and Maintenance of the Future

➔ Vision & Challenges

European rail transport is a necessity for a modern society, providing environmental, safe and efficient movement of goods and people. Planned and welcomed Multimodal and Integrated European transport networks will for the coming decades largely interact with existing railway assets, with new challenges for maintenance as well as requirements of future assets. With the extensive use of transport systems continuously serving European residents, the potential of smart asset management and maintenance contributing to the European Green Deal is significant. Building and maintaining rail transport systems is still environmental costly and must improve, especially as more rail services will be needed to solve existing challenges and meet societal demands. Operation and Maintenance can benefit from the ongoing digitalisation of rail transport and its assets. The full potential of digitalisation will require descriptive asset metrics, sensor systems, and data analysis techniques for predictive and prescriptive maintenance. Green solutions and support for digitalisation will be provided by three interrelated research areas to deliver European rail industry competitiveness:

- Cost-effective design, commissioning, construction and maintenance (looking at short, mid and long terms interventions)
- Digital technologies and data analytics
- Maintenance execution and asset homologation methods

Design, construction and maintenance will be made more cost-efficient by integrating new and already existing solutions coming from the market and related funded research. Codes, standards and regulations will need to be adapted to new solutions and technology, while still keeping systems safe and operational. Significant savings will be made in both monetary and carbon dioxide equivalents. Improved transparency and motivated requirements will allow for better market in rail industry for both customers and suppliers. Design and construction cost efficiency will range from foundation, via tracks and structures, to systems and vehicles, providing a globally leading industry.

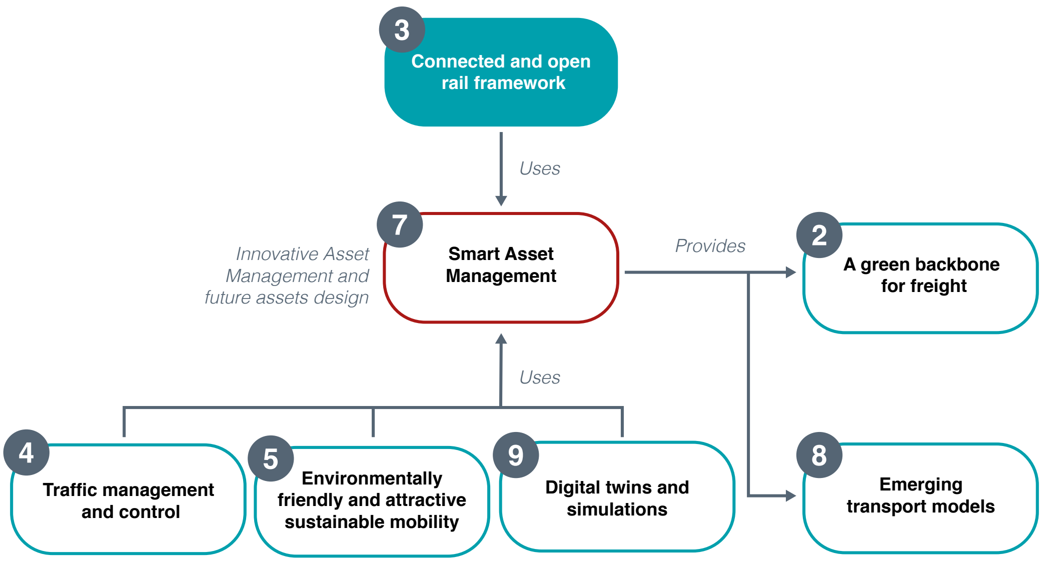
Maintenance procedures and homologation of new technology will be enhanced. Procedures include new technology and methods, to be applied efficiently based on asset condition and required performance. Robots and new tools will be developed to perform maintenance when needed, to the optimal extent for a predictable outcome. New technology will reach the market faster by proposals for modernised homologation. Digitalisation of the homologation process will give not only faster routes to market but also increased safety and at a reduced cost. Asset tracking and geolocalization will afford greater awareness of system conditions and required interventions by Infrastructure Managers, as well as by Technology Suppliers. The research methodology will be hypotheses driven, to leverage findings in cooperation with other Transforming Projects. Maintenance procedures will support the development of cost-efficient design, commissioning, construction and maintenance.

Supporting technologies for asset identification and monitoring, and innovative materials, will lay out the foundations needed for smart management and maintenance. Dedicated sensor systems, tools for human interfaces, robots for automated inspection and maintenance execution, legalisation aspects, are all examples of challenges needed to be addressed. Work will be structured and designed as modular applications to facilitate integration in digital transformation and to reduce risks. A modular approach gives a foundation for faster implementation, acceptance and continuous improvements. When applicable technologies will be adopted from other industries, to speed up and improve the implementation of smart asset management in the railway context.

TP7 will leverage the integrated R&I Programme of the Partnership, contributing to a high integration and cooperation between different actors both within and outside the rail ecosystem, allowing mitigation of maintenance impacts, contributing to a more robust, resilient, and reliable service as well as to faster recovery from service disruption, along with a reduction of the economic impact. Knowledge from digital transformation will also feed back into the design, construction, manufacturing as well as operation and maintenance processes. TP7 will deliver also design solutions that are more cost effective to build, as well as to operate and maintain, compared to today's practice. In the framework provided by TP3 to complete the leap to smart and prescriptive asset management, TP7 will encompass:

- Assets descriptive metrics to highlight impending faults, as outputs from TP9, and georeferencing concepts applicable across different business projects
- The provisioning of test facilities (labs and tracks) for a thorough validation of the asset descriptive metrics based on realistic data and operator experience, which can accelerate development and reduce time-to-market
- Considerations regarding the integrated data marketplace, related to common data model definition, data integration and reuse, data ownership, storage and communication
- A new tailored design paradigm for Assets which will enable remote monitoring and autonomous robotic intervention when applicable, with low impact on system operation
- Cost/benefit-based decision criteria as well as migration strategies for the incremental adoption of the new asset design paradigms and transformation requirements
- A tight coupling with traffic management systems improvements from TP4

This transforming project builds upon all IPs and CCA activities of Shift2Rail related to assets management/ maintenance, especially IP3, leveraging all achievement at system level and pushing the boundaries of automation. This Transforming Project makes use of the framework provided by TP3 - Connected and Open Rail Framework for European Mobility as well as of the simulation tools from the works of TP9 – Railways Digital Twin, Simulation and Virtualisation, and the design concepts in TP5 – Environmentally Friendly and Attractive Sustainable Mobility and benefit from a traffic management optimised for its technologies with TP4 – Network Management, Planning and Control activities. It provides possible technologies on maintenance automation to TP2 – Rail as the Backbone of a Green Freight Logistic Chain and TP8 – Non-Traditional and Emerging Transport Models and Systems.



➔ Status

The current Shift2Rail projects achieved several goals in the specific Innovation Programmes:

- Innovation Programme 1 (Rolling stock): a significant step has been taken at communications level by developing standard wireless communication systems, both within the vehicle and between train and ground, which will facilitate the flow of data necessary to implement advanced maintenance
- Innovation Programme 2 (Signalling): the TMS evolution takes into account the direct connection with the results of the asset status nowcasting and forecasting, in order to optimize possessions

- Innovation Programme 3 (Infrastructure): new and optimized strategies, frameworks, processes and methodologies, tools, products and systems for risk based, prescriptive analytics and holistic Asset Management
- Innovation Programme 4 (IT Solutions): different exploitation of existing IT services and/or provision of additional on-demand IT services, by providing operators with tools and techniques to improve the perceived reliability of the entire ecosystem.
- Innovation Programme 5 (Freight): looking into asset management from a maintenance perspective, especially addressing condition based maintenance.
- Cross Cutting Activity: development of a common smart maintenance concept including standardisation of data relevant for condition based maintenance
- Innovation Programme X (IPX): a conceptual data model for support of information exchange, enabling connection between a broad range of railway assets.

➔ Proposed areas for support (classified by TRLs)

The proposed concept will bring prescriptive capabilities into an integrated asset management framework covering all the technological and physical elements of the integrated "system of systems", as well as motivated and transparent requirements for construction and maintenance. Progress is envisioned in the following areas:

Cost-effective design, commissioning, construction and maintenance:

- Digital modelling of physical phenomena and logistic simulation of complex interventions, based on TP9 and via a database of field and laboratory data (physical models), to use as input to AI and integration of Building Information Modelling (BIM) tools to standardize railway system configuration
- Use digital twins from TP9 into the planning and optimization of vehicle (component) and infrastructure maintenance
- LCC automated models able to evaluate how to prevent a failure or a critical loss of functionality will influence the operational costs of maintenance and how much an asset management decision (such as "repair or replace") will affect the overall life cycle cost and environmental footprint
- Impact of new production processes, technologies in maintenance operations and supervision
- Modernised codes and standards allowing for innovation, and competition.
- Reduced material usage whilst prolonged efficient time in service for both vehicles and tracks.
- Vehicle friendly tracks and at same time track friendly vehicles.

Maintenance procedure and homologation methods:

- Identification and quantification of root failure causes and degradation models, definition of maintenance limits and thresholds for subsystems or components
- Determination of dynamic maintenance limits by methods of artificial intelligence
- Transfer of human expert knowledge about influences on degradation, degradation history, maintenance efficiency, maintenance history, past renewals into AI expert systems providing interpretable diagnosis, prediction and maintenance planning.
- Verification of algorithms to achieve prescriptive maintenance of subsystems or components, detecting weakness before malfunction
- development of non-invasive solutions to increase automated inspection, using the IoT paradigm for assets software update or "self-healing", based on standalone sensors, satellites, diagnostic trains, robots and drones

- Process mining of maintenance execution to enable Artificial Intelligence optimization to reduce failures and operation disruption,
- Design and deployment of robotic equipment for maintenance execution, using principles like swarm robotics and biomimicry, replacing maintainers in unhealthy and heavy work tasks
- Development of Human Machine Interfaces to monitor the status of railway networks and oversee maintenance execution

Supporting technologies and innovative materials

- Sensor technologies for passenger/freight vehicles enabling automated detection, analysis, visualisation and geo-localisation of coming abnormal conditions (ice on contact line, shocks with infrastructure, vegetation, vehicle component or operation anomalies, surveillance, loss of lubrication)
- Smart Infrastructure & Reliable civil engineering structures able to provide smart data monitoring, analysis & prediction;
- Critical evaluation of the impact on current maintenance practices and regulations of the introduction of AI based tools and methods, with specific emphasis on safety relevant contexts
- Vehicle -based smart maintenance technologies.
- Automated technologies (e.g. Drones, Robots etc.) for maintenance execution
- Development of Human Machine Interfaces (HMIs) based on augmented reality and natural language processing for interaction of human operators with AI expert systems for diagnosis, prognosis, maintenance planning and remote maintenance execution
- Cooperative planning tools for mitigating the impact of asset management by balancing the different goals of railway actors, i.e. Infrastructure Managers, Rolling Stock Maintainers and Rail Service Providers,
- To optimize the amount and quality of data to be provided as input to prognosis and health assessment models
- Railway Check Points: development of a European standard railway check point to automatically detect damages, surveying state of health & condition of train consists as well as their individual elements (locomotives, coaches, wagons) for both passenger and freight service, and therewith contributing to a high level of ATO-security.
- Performance based maintenance through smart data analysis for vehicles which take into account all available vehicle parts and data. This information will be combined with other available data (e.g. from railway check points or workshops) Standardisation/Harmonisation is of high importance so that data from different vehicles/fleets, infrastructure manager can be all over Europe combined and analysed
- Safety and legal aspects of AI based approaches to asset management.

Here below are reported the main outcomes expected from the project:

- Development of solutions for robotic maintenance: prototypes [TRL4/5] and demonstrators to use in realistic operation scenarios [TRL5/6] increasing industrial competitiveness
- Maintenance solutions and technology providing efficient digital transformation [TRL6-TRL8]
- Self-diagnosis and predictive maintenance of vehicles and infrastructure enabled by a combination of sensors and machine learning methods [TRL6-TRL8]
- Facilitation of and investments in remote maintenance and zero on site intervention
- Adoption of Automation of Maintenance in procedures, rules and EU/National regulations
- Fostering the integration between the design principles of future railway systems and the effective management of legacy products
- Automation of processes' holistic management and cooperative decision-making towards high resilient railways.

- Solutions for new railway design for reduced maintenance impacts significantly contributing to Green Deal [TRL7/8]
- Maintenance methods, limits and efficiency meeting the needs of modernised rail transport with higher automation, more tonnage and increased reliability. [TRL7/8]

The achievement of the objectives mentioned above will be demonstrated by completed and qualified solutions tested based on the stakeholder experience in operational environments, in the following contexts:

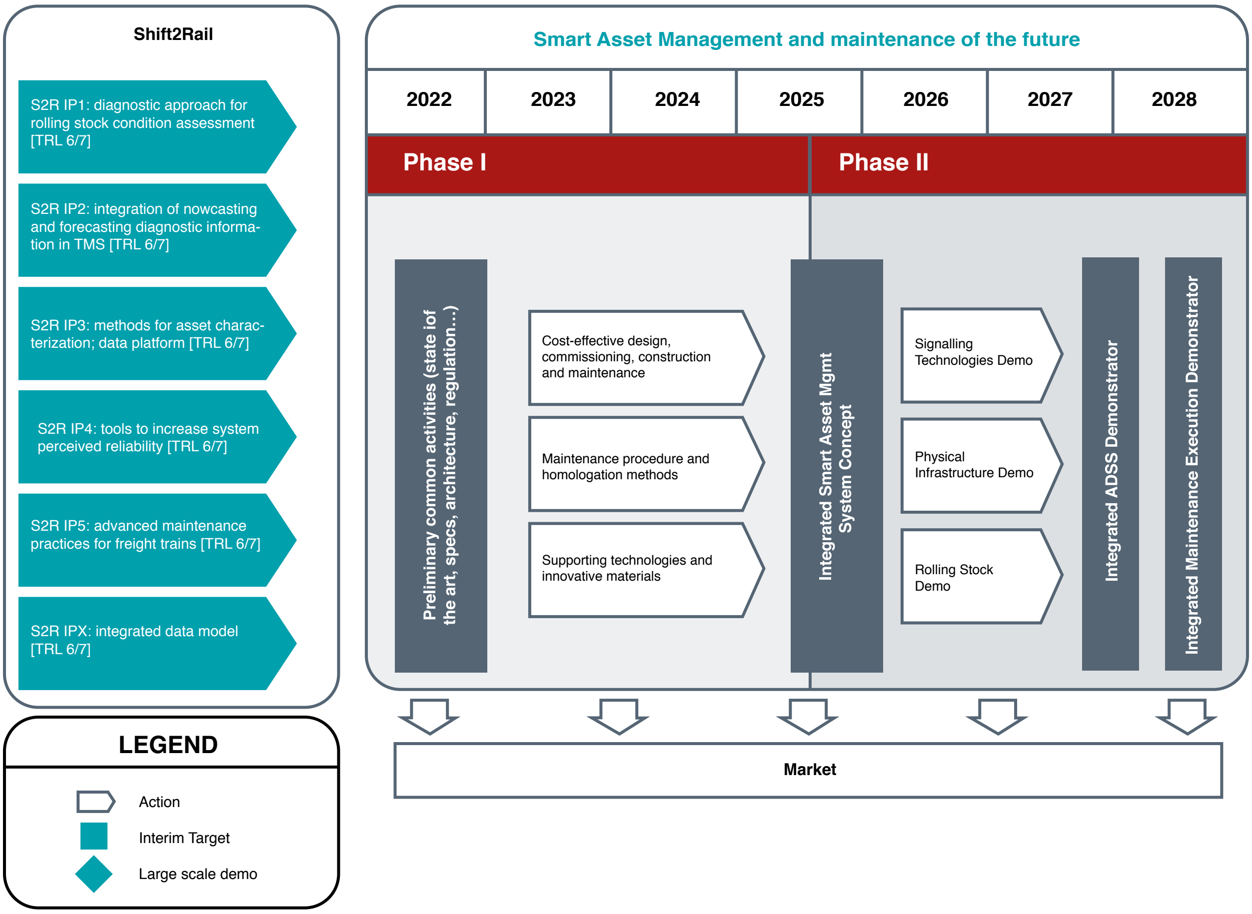
- Signalling technologies (wayside and on board)
- Physical infrastructure (geotechnics, civil structures and track)
- Rolling stock (passenger service, freight and light/urban)

These demonstrators will be also integrated in the Advanced Decision Support System to validate its capabilities in terms of holistic management, integration and cooperation among assets, technologies actors, standards and regulation. Also real examples of Automated Maintenance execution will be provided.

The expected outcomes from the project on an aggregated level are: strengthened European rail industry competitiveness with more qualified activities, in a relatively large sector; higher volumes and more cost-effective rail transportations on existing lines; less CO2 from maintenance of existing lines and construction of new assets; and final enabling of positive effects generated in other TPs.

➔ Visual Roadmap

This Transforming project is expected to run for six years.



6.3 TP n°8: Non-traditional and Emerging Transport Models and Systems

According to the ERRAC "Rail 2030 Research and Innovation Priorities" one priority of R&I for the future railway system should be to develop new mobility solutions for seamless integration of transport modes, for smaller, faster and more frequent trains, new types of rail transport solutions or stations and terminals as mobility hubs. In this context, the focus is on the future viability of the existing and further developed railway system in line with the European Green Deal.

Therefore, beyond major transformation to rail systems as we know them, the R&I Programme should include the development of a rail based fully automated Multi-Modal Mobility-System for passengers and goods with automation embedded by design, standardised, scalable and compatible with all transportation modes, satisfying actual and future societal needs and also the exploration of new land based guided systems for passengers and goods.

On the other hand, rapidly evolving new technologies, in some cases still very premature ideas or not yet brought to the table, are becoming possible alternatives for land transport. The programme will assess such technologies within the context of mass transport, observe their prototyping, understand their feasibility and market opportunities as well as synergies with traditional rail systems.

This Transforming Project, consequently, shall consist of two parts, both consistent with the European Strategy for sustainable and smart mobility. On the one hand (A), it should be dedicated to advance some more mature new ideas for future railway related systems that can enter the R&I lifecycle and, on the other hand (B), scouting and exploring new ideas for guided transport systems for people and goods that may be further developed within the life of the programme. It will create an ecosystem capable to manage and embrace innovation and consumer driven creation of new land guided transport technologies.

➔ Part A

Vision & Challenges

The **Vision** of the project Part A is to develop a rail based fully automated Multi-Modal Mobility-System for passengers and goods, standardised, scalable and suitable for all transportation modes, according to the actual needs of the end users and the actual traffic situation in the different modes, with three key elements:

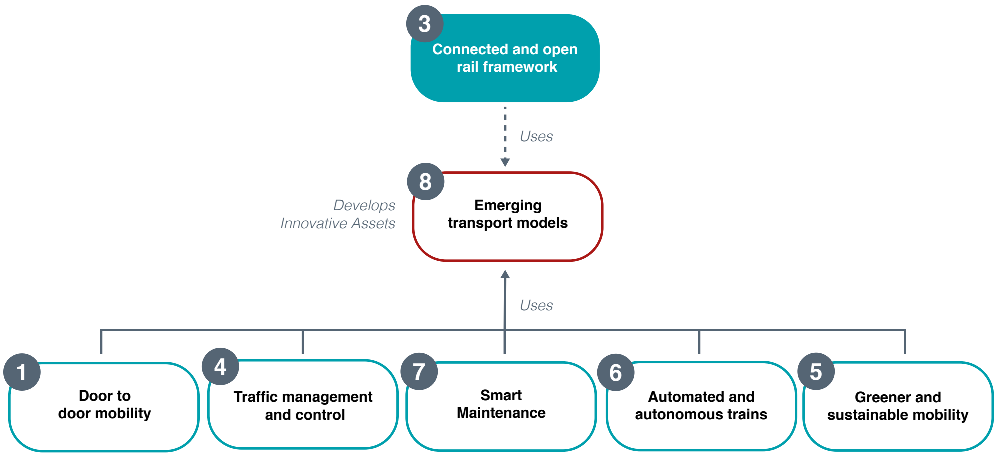
- ***Moving Infrastructure*** – intermodally connected by "Pods"
- ***Open Platform*** – based on common standards and standardised interfaces
- ***Disruptive Operation Models*** – for existing infrastructure

Seamless physical integration between modes of transport is what is herewith proposed as one of the keys for future mobility networks to a reliable and convenient passenger and freight transport, which remains the backbone of sustainable urban and rural area development as well as for an environmentally friendly freight transport. It provides safe, energy efficient and affordable mobility options low noise mobility options for everyone and ensures easy accessibility.

Maximum convenience through a unique journey and maximum reliability of the journey by usage of all available transportation modes with one "moving infrastructure" are advantages brought forward by this TP for the travellers. In addition, what this TP proposes generate positive effect on the environment as the journey will be totally electrified thanks to the capabilities of the "moving infrastructure" itself which will be in use most of the time, so that downtimes and land usage could be reduced, and a maximum efficiency will be achieved. An increased degree of automation in terminals, ports, logistics centres, parking facilities, and at borders contributes to more efficient freight handling, fewer operational errors and reduced costs.

The **Challenge** will be to change from a diverse use of individual and public transport only partially "physically connected" to a unique and collaborating public transport system under the aspect of high sustainability and environmental friendliness. It is a game changer to reinforce the railway position in the future mobility market based on cutting-edge technology for automatisation, digitalisation and electrification as backbone of future multi-modal mobility. It modifies the traditional roles and relationships in the railway as well as other transportation systems to achieve a seamless integration in the M.O.D. ecosystem by bringing new radical approaches in the field of vehicle design and control, traffic management systems, an overarching framework for integrated logistic support (ILS) and of augmented decision support utilising Artificial Intelligence (AI) for operation and maintenance. Besides technological developments the challenge, which can only be handled in a joint approach of a wide set of industrial players and the public bodies, will be to reach the minimum level of deployment, as the system needs a wide implementation (scope, variety and amount), to be viable and to work. The concepts and developments must show a clear benefit on short notice, providing reasons for large investments, and show clearly how they can either work together with MaaS and DRT concepts or will be even an integral part of them.

This transforming project will in some instances (depending how much different the emerging transport will need to be modelled in the system) makes use of the framework provided by TP3 - Connected and Open Rail Framework for European Mobility. It can benefit from the work of TP4 – Network Management, Planning and Control activities, TP1 - Smart Integration for Railways within Door-to-Door Mobility, TP5 – Environmentally Friendly and Attractive Sustainable Mobility, TP6 - Assets for Automated and/or Autonomous and/or remotely piloted Operations, TP7 - Smart Asset Management and Maintenance of the Future.



Status

Todays' travelling from door-to-door is challenging and stressful, overcrowded in any transport mode, be it be in the air, on the road or on rail tracks. The key requirement of end users - passenger and freight - is simple but unavailable: Convenient, safe and affordable in-time door-to-door transport by day or at night. A disruptive way to reach these requirements should be, not that the passenger or the freight interchanges, but instead that they are interchanged in a personalised transportation box.

Autonomous rail transportation is still a field for research. Rail needs to change to become collaborative with the automotive industry, which is developing technologies for autonomous road traffic. Based on existing solutions (e.g. fully automated people mover and underground systems) and future solutions for automatic train operation and new developments for autonomous rail operation (e.g. autonomous trams) this TP would like to bring physical multi-modes public transportation to the next level.

Proposed areas for support (classified by TRLs)

Early Stage Research Actions (TRL 2-3)

Key areas of research include:

- Analysis and case study of different interfaces, regulations and standards regarding different transportation modes (trains, cars, buses, trucks, cable cars, ships, helicopters, aircrafts, drones)
- Defining interconnections & interfaces between existing offers in the field of public transport, mobility services, logistics and future M.O.D. systems
- State-of-the-art study / benchmarking: autonomous transportation solutions (rail, road, air etc.), swap-bodies rail/road, handling systems, ILS and IL etc.
- Analyse the conditions for moving goods from road to rail or shipping or flying, and propose measures in specific transport flows

Development Research Actions (TRL 3-6)

Development projects will work on existing and new technologies deployed in real systems, including:

- Development and demonstration of autonomous driven rail vehicles (Pods) with sensor systems meeting all rail operational and certification requirements, complete situational awareness supported by perception and connectivity, including enhanced TCMS, to overcome the complexity and cost of actual automatic train operations
- Development and demonstration of scalable platform pod carriers and scalable Pods tailored to automation and capable to change the mode of transport by standardized interfaces and, if possible, in an autonomous way; solutions should be light, modular and cost-effective
- Customer oriented services supporting automation and unstaffed transport by iCCTV & PIS for automatic handling of passengers and goods, as well as violence detection and autonomous troubleshooting
- Development of innovative solutions for rail operations with regard to measures that improve the cost efficiency and lead times of the railway, such as vertical loading of load carriers, catenary-free systems and Pod launchers, and automatic and virtual couplings as a replacement of the automatic train protection based on wayside systems
- Use of a multi-modal traffic management system (TMS) for the M.O.D. Systems
- Development of efficient and automatic terminals and ports, incl. development of standardized load carriers (Pods), Stations, charging/recharging areas, maintenance shops, etc.
- Development and demonstration of a holistic ILS framework, incl. flexible loosely coupled IL concept, IL platform aimed in a multi-modal transportation context
- Development and demonstration of distributed security mechanism for enablement data, information, and model exchange between transportation modes
- Development of and demonstration of AI-empowered analytic services for RAMS
- Development of low-cost solutions (vehicle, infrastructure, …) for regional lines, low density lines (focus on low cost)

Innovation Actions (TRL 5-8)

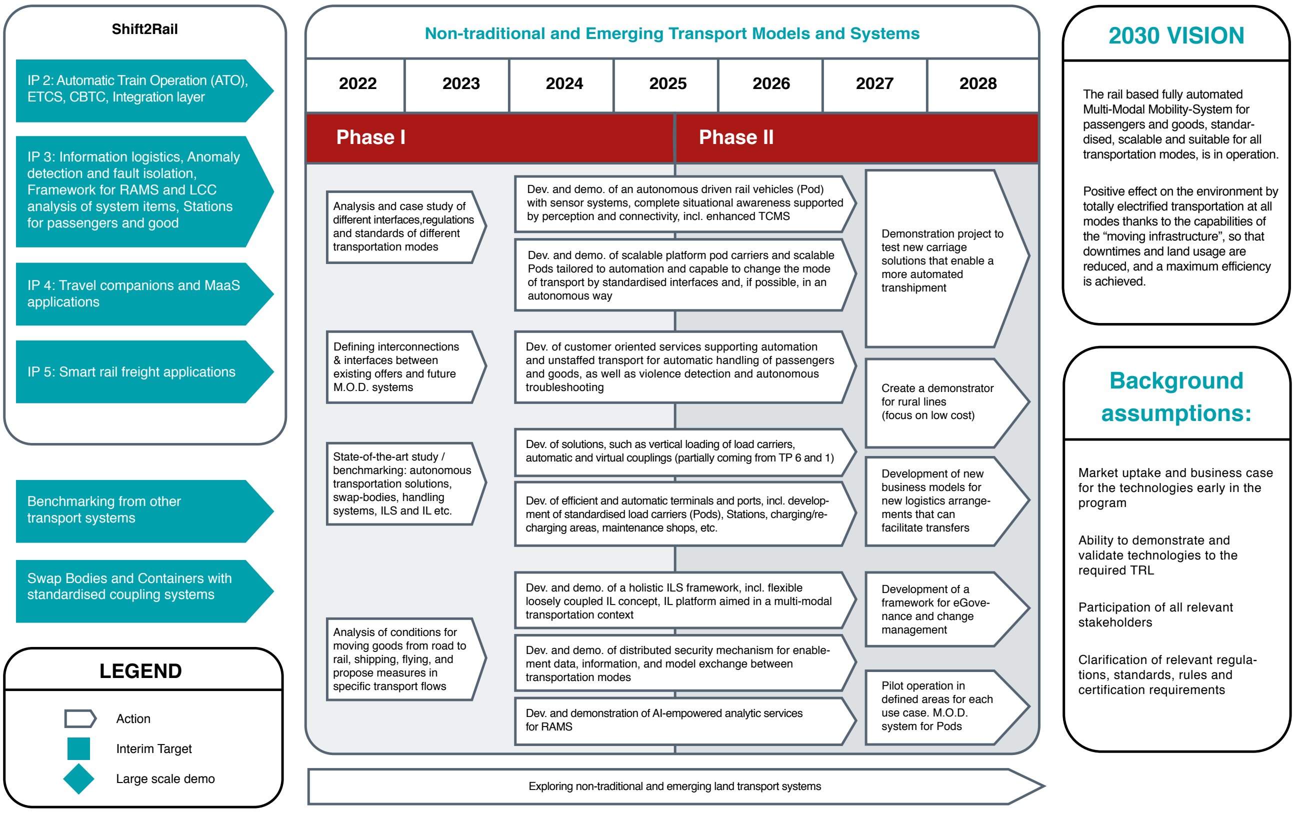
Multiple demonstration projects over 2021-2027 will be demonstrating the capability of M.O.D: system:

- Demonstration project to test new carriage solutions that enable a more automated transhipment

- Create a demonstrator for rural lines (focus on low cost)
- Development of new business models for new logistics arrangements that can facilitate transfers
- Development of a framework for e-Govenance and change management
- Explore possible migration plans by inventorying infrastructure managers' development plans and identifying appropriate points in the European transport system as a suggested basis for an introduction of new transport technologies

Pilot operation in defined areas will be executed for each use case. M.O.D. system for Pods will be developed for both passenger and cargo markets. Simultaneously there is a need to develop technologies for switching the Pods between the different infrastructures. The demonstrators may be operated manually until reaching a certification for automated and autonomous operation.

➔ Visual Roadmap



➔ Part B

Vision & Challenges

This part of the Transforming Project will be dedicated to exploring non-traditional and emerging track-bound transport systems.

- ***Hyper-speed systems*** - as evolution of the current high-speed rail or maglev systems or possible new track-bound transport systems for public and freight transport to be interfaced and integrated with the current rail systems and other modes of transport
- **Unconventional track-bound transport system – as** cableway, funicular, maglev, or monorail systems – as a supplement to existing systems for public urban rail transport
- ***Breakthrough ideas to be assessed as part of the scientific work of the nest JU***

The objective is to create opportunities for innovators into those future systems to bring forward ideas via a scientific approach in close cooperation with the Scientific Committee of the future R&I Programme.

This work will create the opportunity to recognise that innovation is vital and economically relevant for the evolution of land transport and mobility concretely via engaging and responsibly generating new ideas, preserving technological neutrality with a due diligent and consistent programme approach.

This will also mean finding the appropriate time and resources, i.e. funding, that would support the evaluation of feasibility and development of such emerging concepts.

To perform such activities, dedicated pathways, possibly building upon other experiences already in place with H2020, such as the European Innovation Council, should be explored and set up within the next rail R&I programme.

The outcome of this work can also be the basis for extending the scope of other proposed TPs or for new dedicated TPs.

6.4 TP n°9: Railways Digital Twin, Simulation & Virtualisation

➔ Vision & Challenges

Vision

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. This will enable the opportunity to develop a new class of “digital twin” of the assets by merging the knowledge on the fundamental behaviour of systems and sub-systems along with their digital simulation 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 may be applied to transform many different aspects of the business. In particular, a digital representation of real railway system (infrastructure, vehicles and operation) with will allow visualizing, simulating and predicting current and future status of the system. It will allow trouble-free transportations by predicting future events and support the development and deployment of “untested” innovations. The Digital Twin will cover all rail market segments and their subsystems, including urban.

The development of a framework “railway digital twin” will cover the entire railway sector and system 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.

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 foreseen. 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.

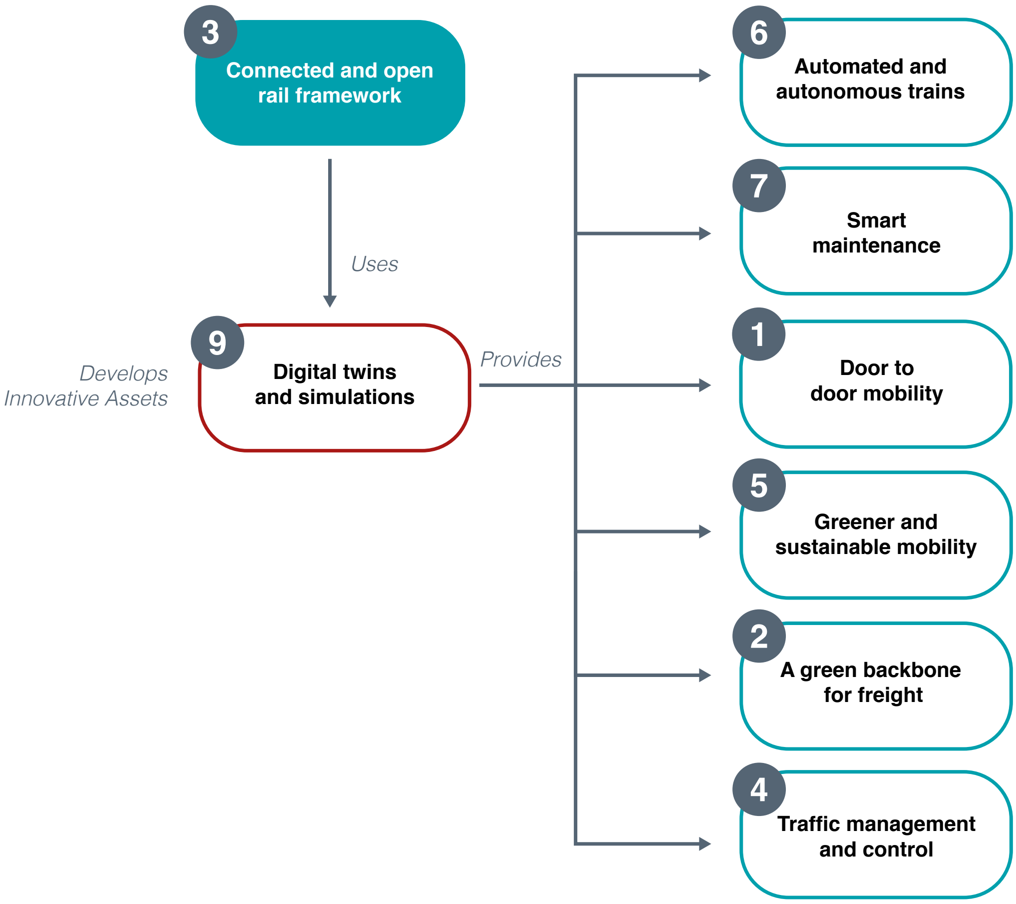
Design based on verified performances all along the design cycle can be achieved by the Digital Twin approach, rather than design based on specifications. This would ensure a quicker development cycle: in the current approach if performance is not met at the end of the development cycle, it has to be restarted from the beginning. The proposed approach would lead to a continuous check that the performances are met all along the development cycle.

The need of using real physical networks for authorization processes will be significantly reduced by virtual validation and certification processes and technologies with higher maturity degrees. Probabilities of success will be introduced. The digital twin will provide a much more realistic framework for virtual certification, already addressed in Shift2Rail than individual subsystem simulation when strong connections with other subsystems are needed (like Hardware in the loop (HIL) testing philosophy).

With digital twins, the railway business will be more effective through a more transparent and fairer tender process in combination with an increase of cost-effectiveness for contracted work. The digital representation can be used as the basis for quotations with increasingly more accurate information to bidding partners, thus reducing uncertainties and risks. The number of unproductive planning site visits will be significantly reduced in favour of more productive site works.

The Digital Twin will seek to benefit as much of possible carried out in BIM in terms of object definition and standardization (IFC for rail, ISO/IEC) and will be connected to common data environment created for railway projects during design and construction phase.

This transforming project builds upon all IPX, IP1, IP3 and CCA activities of Shift2Rail related to virtualisation of assets. It will use the data structure provided by TP3 and could also incorporate new elements in its model, in particular on the connection interfaces with other transport modes from the works of TP3 - Connected and Open Rail Framework for European Mobility. Being a sort of "transversal digital innovative asset" in itself, it provides the tools for simulation and prediction to all other TPs with the exception of the TP8, which deals with alternative transport models and systems.



➔ Challenges

Setting a digital twin needs a system architecture framework. The development of this framework, started in the Shift2Rail IPX projects LinX4Rail1&2, has to be consolidated in view of the Digital Twins use cases. Developments in silos and of limited scope and usages would result in a poor performance and a lack of global system performance and efficiency. Data modelling and system models have to be harmonized in order for the sub-systems simulation to be activated efficiently without the cost of building complicated and costly interfaces. The aim is to develop interoperable Digital Twin for sub-systems that will be able to play in a coordinated way thus facilitating the European interoperability of the railway system in the European network.

It should be noted that only shifting stakeholder's mind-set from owning / storing data to sharing / having access to data will unlock the potential of Digital Twin.

Four macro operational technical challenges and one supporting challenge related to digital twins shall be addressed:

- Visualizing continuously the state and the "Utilisation rate and remaining time to failure" of the systems: infrastructure, rolling stock;
- Simulating with the best compromise between accuracy and real time capabilities in the prediction, the actual behaviour of the system in following some key elements of the system (TMS, rescheduling after disruption, energy available at peak situations etc…);
- Predicting future state, anticipate the failures and develop preventive measures (in real time develop contingency plan operational plans). Implementing new developments to be carried out in TP7, TP5 and TP4 should enable such predictions. The state of the art prediction systems cannot predict in real time the future state of the system yet.
- Automating the design and planning processes of infrastructure Asset (Automated Planning with BIM).

An additional challenge is to have a harmonised system architecture and data organisation able to support the challenges listed above in an open, interoperable way whilst preserving the requirements of some of the parties' privacy in terms of data confidentiality. The system functional architecture is developed in the System Pillar and the TP3 support its implementation with the appropriate data structure and TP interfaces.

The digital twin is designed to provide all the railway sub-systems (all together or separately) with a computable digital abstraction at multiple levels (assets, subsystems, operations) of the rail system as a whole, involving multiple autonomous stakeholders with different responsibilities, different capabilities and perimeters of control, and being constructed incrementally in time. Its successful deployment will probably require addressing the development of a networked distributed architecture.

An agreed framework on rights and obligations associated with use of a digital twin is also of utmost importance for successful deployment. Recommendation for education/training in order to develop the capabilities of involved partners, change of mind-set and altered skills are also important challenges to consider.

Currently, the use of physical/ functional models and deterioration mechanisms is mostly used in view of design and not for real–time predictions as required specifically for digital twins. Specific developments in each technical domain or adapted to subsystems will be required for proper implementation in digital twins.

Furthermore, the use of machine learning or more generally Artificial Intelligence (AI) algorithms is rather restricted to monodisciplinary fields, whereas a great potential in multidisciplinary analysis could be revealed within the frame of digital twin use. Such innovative uses would require enhanced capacities in terms of sensors, Internet of the Things (IoT), data transfer, storage, high performance distributed computation, and visualisation performance.

➔ Status

The recent European collaborative works carried out within the Shift2Rail programme already paved the way for the Digital Twin.

The following activities can be mentioned, zero onsite testing for the CCS domain (X2Rail-3, X2Rail-5), general specifications and developments for virtual certification, specific activities for the Shift2Rail IP1 rolling stock (PIVOT with bogies), IP3 infrastructure (In2Smart2, In2TrackX), energy management (IN2STempo), CCA noise auralisation and visualization, IP5 freight (FR8RAIL), etc.

The Shift2Rail IPX LinX4Rail project starting end of 2019 sets the grounds for a shared vision of the railway system architecture, as well as for development of a CDM (Conceptual Data Model).

UIC projects RTM (RailTopoModel) and OntoRail, associated to LinX4Rail 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.

Such an approach should enable the development of a global and shared digital twin.

As the Digital Twin is a digital representation of all physical assets and their interactions, for practical applications of playable simulation framework, some processes/rules for specific cases which lead you to improve prediction of failures or possible events will be inserted. 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-system increased, also digitally through simulation.

This TP creates value only when used in the other "vertical" TP previously described, this is the nature of this transversal activity.

➔ Proposed areas for support (classified by TRLs)

In this TP, only system subjects will be addressed. The specific development to each technical and operational domain will be carried out in the relevant TPs. For non-specific activities (e.g. research on the use of advanced computational techniques), research should be eased by using the results from other sectors.

The visualisation part of the twin will include existing asset information and models developed from in-situ optic data collection, which are then used for asset recognition and automatic image analytics.

The development of Digital Twins (both at system and subsystem level) requires a holistic approach that relies on the following pillars:

- **Visualization.**
  The Digital twin must be able to present to various stakeholders in a comprehensive way, different views of the current state of the system (rolling stock, infrastructure) as well as its usage intensity along with its history (past use, history and contents of maintenance operations). This implies in particular advanced intelligent measurement technologies.
  From current TRL 5-6 -> TRL 6-7

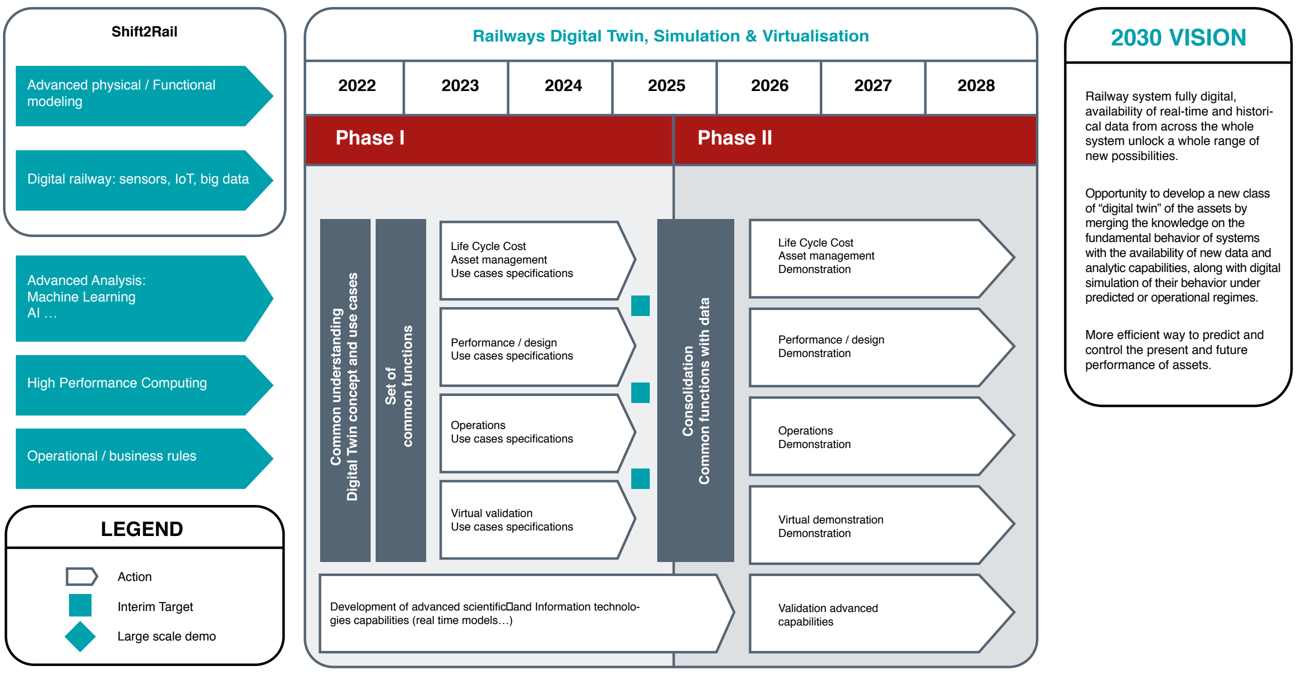
- **Simulation**
  Digital twins require mathematical models that allow to mimic the real behaviour of systems / subsystems. In order to develop these models, it is required to combine relationships based on physical/analytical laws, and new tools based on Machine Learning/Artificial Intelligence, expert knowledge
  From current TRL 1-4 -> TRL 5-7

- The use of **advanced computational and communication techniques** will be required in order to obtain quasi real-time solutions. The use of big data and cloud computing techniques will be of upmost importance.
  Nothing really on the market but technologies are partly available.
  TRL 7-9 to be reached.

- **Prediction**
  Digital twin should have prediction capabilities coming from the combination of simulation models fed by operational inputs.
  Given the fragmentation of the existing products on the markets, working for managing bigger sub-systems or systems will be of utmost importance.
  Accurate predictions are necessary in order to transform the conventional maintenance into maintenance based on the current health state of the different assets, analysing the impact of operational changes.
  To be developed – Currently TRL 1-4 -> 5-7
  Optimize subsystem design, on multi-criteria basis,
  To be developed – Currently TRL 1-4 -> 5-7
  Reduce lead time, time to market and cost of new products by means of virtual homologation and certification
  From current TRL 1-4 -> to be pushed to TRL 6-9
  Decision support systems will also be of use to develop operational scenarios both for planning maintenance goals
  Currently TRL 1-4 -> to be pushed to TRL 6-9
  and later for operation recovery in case of an incident, but this domain is less mature.

The development and use of Digital twin require inputs from different areas (infrastructure, vehicle, operational boundary conditions, etc.), meaning that a comprehensive and distributed architecture with the ability to leverage networked digital resources will maximise the digital twin developments for the overall railway system.

➔ Visual Roadmap



ERRAC, Rail Strategic Research and Innovation Agenda

Published and printed by: Click Click Graphics

Legal deposit: December 2020

www.errac.org