MULTI-ANNUAL ACTION PLAN

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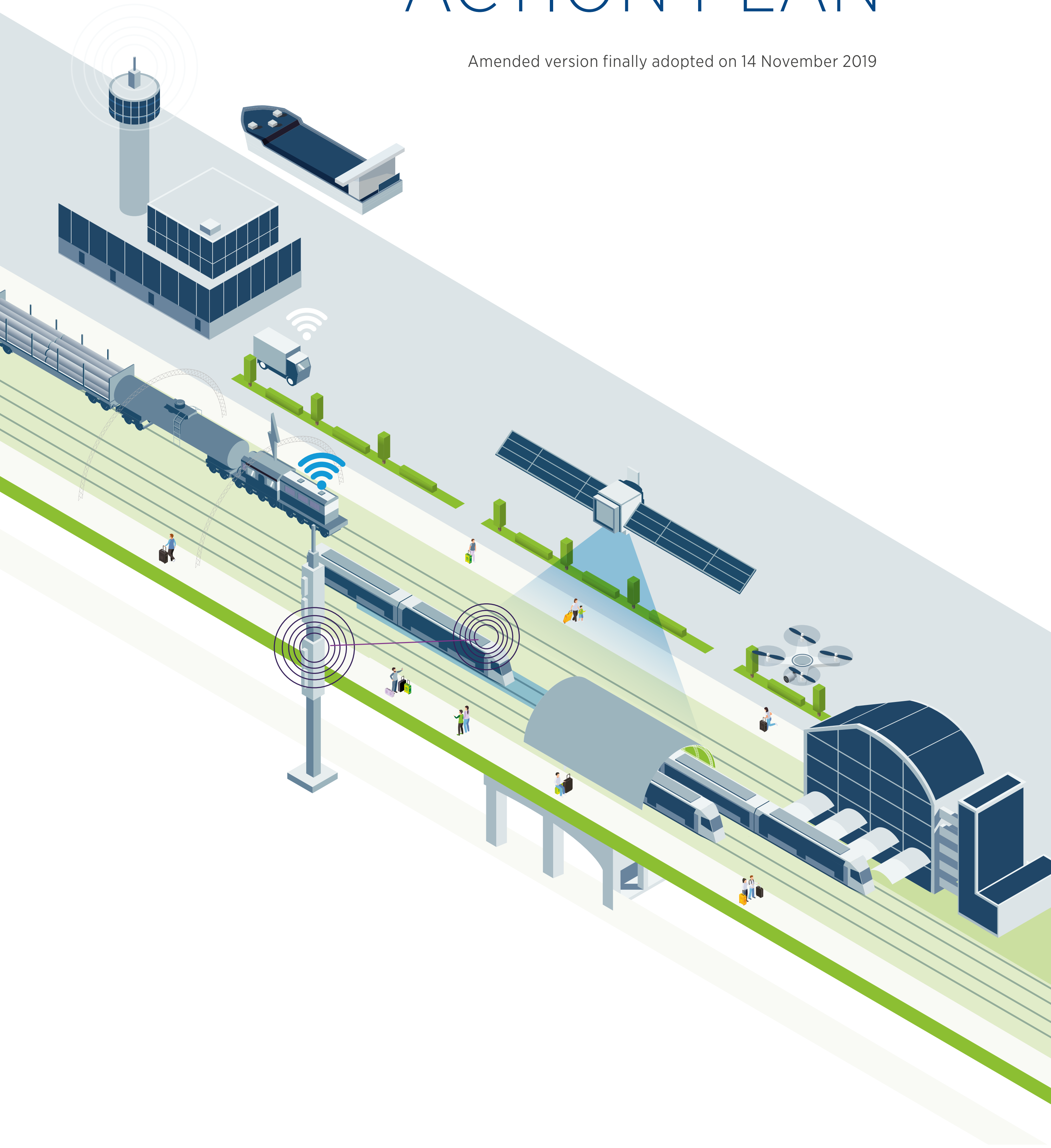

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PART A

Executive view

Multi-Annual Action Plan, Part A, Executive view adopted by the Shift2Rail JU Governing Board on 27 October 2017

Executive summary

Why act now?

Transport is the backbone of the European economy, bringing growth, jobs and prosperity. For example, railway transport-related goods and services account for more than 20 % of EU exports of goods and 8 % of EU exports of services. For centuries, the railway has been the backbone of transport, instrumental in industrial revolutions.

With evolving societal challenges, other modes of transport have overshadowed the intrinsic attractiveness and competitiveness of rail transport.

Today, although the European railway remains at the heart of transport, it needs radical change to bring it back to the forefront and enable it to act as a backbone of future digital sustainable mobility; to meet the expectations of citizens; to connect people, business and regions; and to make Europe a global hub for mobility and prosperity.

The 2015 Shift2Rail (S2R) Master Plan identifies eight key challenges faced by the European rail sector:

- strengthening the role of rail in the European transport system and the global competitiveness of European industry;
- quality of service;
- cost;
- integrating the European market;
- infrastructure;
- competitiveness;
- skills;
- innovation.

These challenges and the S2R vision offer a unique set of opportunities for the rail sector to radically transform and reaffirm its key role.

What is in the Shift2Rail Master Plan and the Shift2Rail Multi-Annual Action Plan?

The S2R Master Plan provides a high-level view of what needs to be done; it explains why and by when. It sets the framework for the research and innovation (R&I) activities to be performed as part of and beyond the S2R Programme ([1]) and the deployment activities to be carried out by all operational stakeholders, coordinated to achieve a Single European Rail Area.

The vision of the S2R Partnership is

To deliver, through railway research and innovation, the capabilities to bring about the most sustainable, cost-efficient, high-performing, time-driven, digital and competitive customer-centred transport mode for Europe

The present S2R Multi-Annual Action Plan translates the S2R Master Plan into detailed, result-oriented R&I activities to be performed to start delivering the S2R vision from 2014 onwards.

Addressing the challenges opens up three opportunities for the railway

1. to become the backbone of current and future mobility concepts (e.g. mobility as a service) and on-demand future logistics;

2. to identify and establish new market segments for exploitation;

([1]) The S2R Programme runs from 2014 to 2020, with final implementation and phasing out envisaged by 2024.

3. to enhance the overall competitiveness of the industry, both in Europe and globally.

This is what the regulation (2) tasks the S2R Joint Undertaking to do when requesting it to manage all rail-focused R&I actions co-funded by the Union. More specifically, S2R seeks to develop, integrate, demonstrate and validate innovative technologies and solutions that uphold the strictest safety standards and the value of which can be measured against, inter alia, the following key performance indicators:

- 100 % increase in rail capacity, leading to increased user demand;
- 50 % increase in reliability, leading to improved quality of services;
- 50 % reduction in life-cycle costs, leading to enhanced competitiveness;
- removal of remaining technical obstacles holding back the rail sector in terms of interoperability and efficiency;
- reduction of negative externalities linked to railway transport, in particular noise, vibrations, emissions and other environmental impacts.

To realise its vision, the railway needs to establish and develop a range of new innovation capabilities (see Section 4).

Developing these innovation capabilities requires a coordinated effort among different rail and non-rail stakeholders to drive innovation at all levels in Europe. The S2R Joint Undertaking and its Programme are designed to make a decisive contribution to delivering the essential knowledge and innovation that will provide the building blocks for developing the innovation capabilities.

The work conducted within the S2R framework is structured around five asset-specific Innovation Programmes, covering the different structural (technical) and functional (process) subsystems of the rail system. These five programmes are supported by work on five cross-cutting areas covering themes that are relevant to each of the programmes and which address the interactions between the innovation programmes and the different subsystems.

The practical demonstration of S2R R&I activities is being carried out using a combination of single technology demonstrators, integrated technology demonstrators (resulting in the innovation capabilities) and system platform demonstrators.

By the end of 2017, EUR 333.2 million (3) had already been invested in R&I activities by the partnership.

(2) Council Regulation (EU) No 642/2014 of 16 June 2014 establishing the Shift2Rail Joint Undertaking

(3) Including the Lighthouse Projects funding awarded by the European Commission in 2015 resulting from the H2020 transport call 2014 and as part of the S2R initiative in accordance with the S2R regulation for the amount of EUR 52 million.

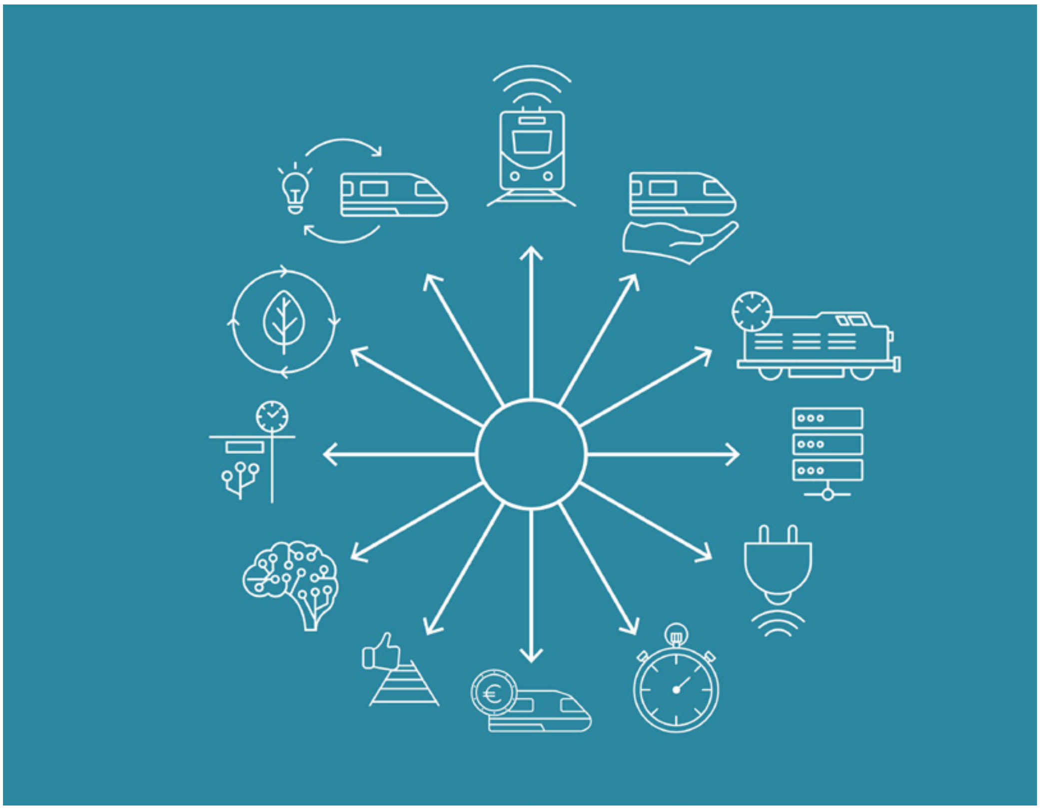

Figure 1 / ***Shift2Rail capabilities***

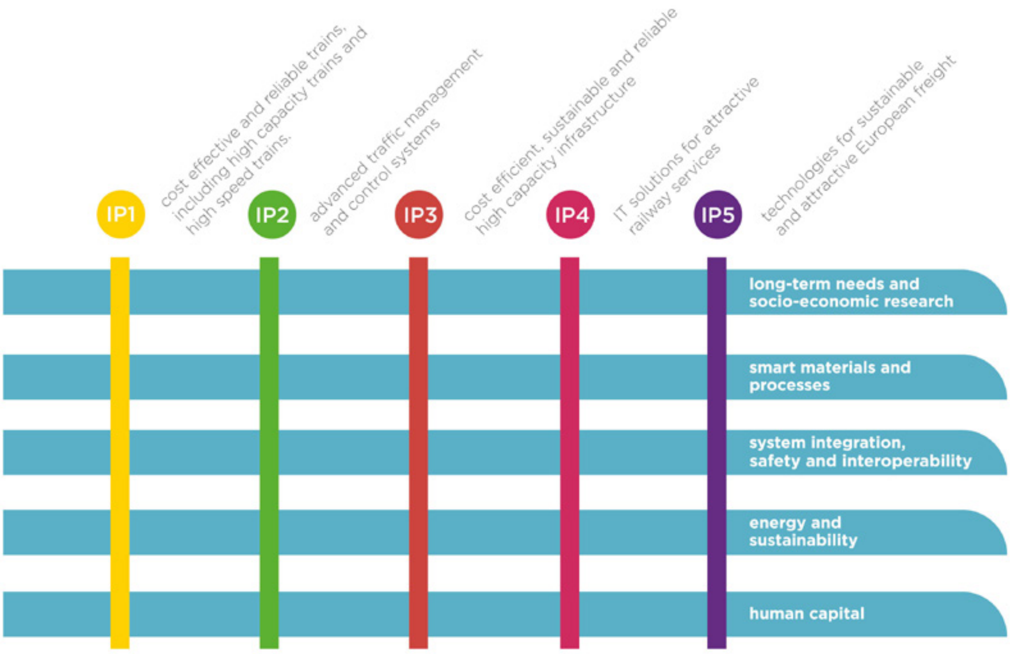

Figure 2 / ***Shift2Rail structure per IP and CCA activities***

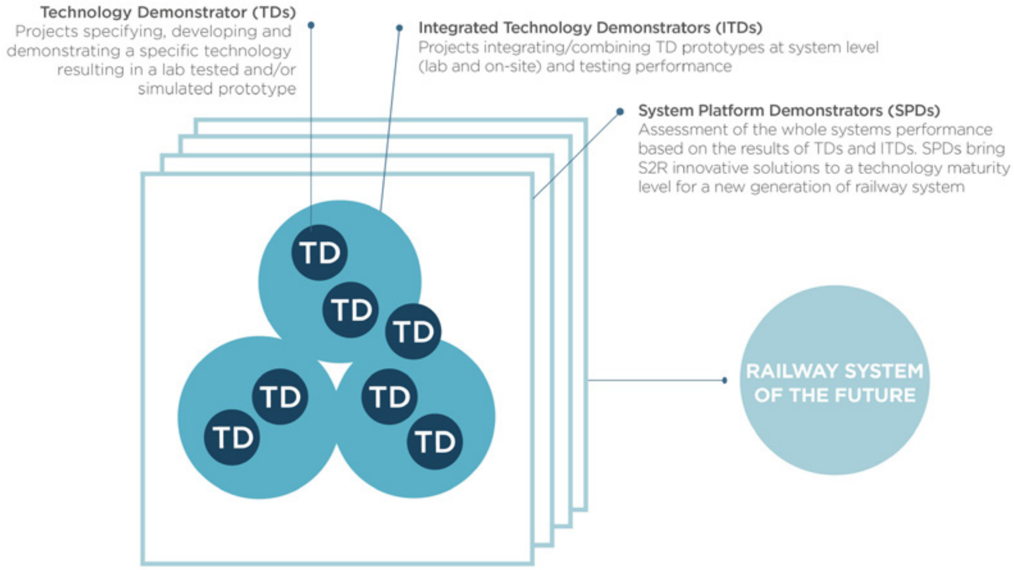

Figure 3 / ***Structure of Shift2Rail demonstrators***

What are the expected benefits?

Bringing about the technological and operational advances expected as a result of the S2R R&I activities will require active intervention. It will not happen by itself. Deployment of this complex array of innovations will involve a coordinated effort to guarantee an adequate level of consistency and achieve a Single European Rail Area. This requirement for active intervention implies a need for an understanding of the steps required in the process, of funding needs and of the essential system-of-systems interaction and complexity of the railway, in all its segments and components. Those undertaking this active role should be as near as possible to the market while retaining the necessary independence under joint governance.

The economic benefits of reaching the S2R targets through focused and coordinated S2R R&I are expected, according to the impact assessment (4) carried out as part of the S2R Programme, to be as follows:

- indirect leverage on industry R&I related to the development of industrial products exploiting Horizon 2020 (H2020) innovations worth up to EUR 9 billion in the period 2017–2023;
- the creation of additional gross domestic product at EU level of up to EUR 49 billion in the period 2015–2030, distributed among a large number of Member States;
- the creation of up to 140 000 additional jobs in the period 2015–2030;
- additional exports worth up to EUR 20 billion in the period 2015–2030 thanks to the worldwide commercialisation of new rail technologies developed under H2020;
- life-cycle cost savings of around EUR 1 billion in the first 10 years and thereafter, with continued implementation, of around EUR 150 million per year.

(4) Impact assessment accompanying the document *Proposal for a Council Regulation establishing the Shift2Rail Joint Undertaking*, SWD(2013) 535 final, Brussels, 16.12.2013.

Ensuring the proper undertaking of such activities is therefore key both today and for the future in a market segment of major importance for the EU, which already provides 400 000 highly skilled jobs in European manufacturing industries, including in numerous small and medium-sized enterprises. The rail sector overall, including maintenance and operations, is responsible for more than 1 million direct and 1.2 million indirect jobs in the EU.

In addition to the R&I roadmap and to ensure a consistent deployment strategy, other key aspects of the way forward include placing innovation within a standards and regulatory framework, developing a credible business view, implementing an efficient risk assessment strategy and establishing effective collaboration with other key organisations involved in the future of the European rail sector.

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Contents

1. Introduction

1.1. General policy context

1.1.1. European strategic vision for an integrated transport system

The 2015 Shift2Rail (S2R) Master Plan (5) describes a general policy context that remains relevant today. The European Commission is committed to a Europe 2020 strategy based on smart, sustainable and inclusive growth. This includes achieving a more competitive and resource-efficient European transport system with a view to addressing major societal issues such as rising traffic demand, congestion, security of energy supply and climate change.

With this aim, the Commission's 2011 Transport White Paper (6) ('Roadmap to a Single European Transport Area – towards a competitive and resource efficient transport system') sets out key goals to strengthen the role of rail in the transport system, given rail's inherent advantages in terms of environmental performance, land use, energy consumption and safety.

A number of these goals (Table 1) relate specifically to rail passenger and rail freight transport, while others relate more generally to urban mobility, with an indirect impact on rail.

In 2016, the European Commission published a document reporting on the pace of implementation of the 2011 Transport White Paper (7). The report highlights the relevance of the original targets, stressing the importance of taking into account rapid technological developments that are reshaping mobility concepts and opening new potentials, particularly as a result of automation and digitisation.

On 13 September 2017, the European Commission published its communication 'Investing in a smart, innovative and sustainable industry – a renewed EU Industrial Policy Strategy' (8), adding to the strategy a pillar intended to help in moving from research and innovation (R&I) to deployment:

(5) http://ec.europa.eu/transport/sites/transport/files/modes/rail/doc/2015-03-31-decisionn4-2015-adoption-s2r-masterplan.pdf

(6) http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN

(7) The implementation of the 2011 White Paper on Transport 'Roadmap to a Single European Transport Area – towards a competitive and resource-efficient transport system' five years after its publication: achievements and challenges, SWD(2016) 226 final, Brussels, 1.7.2016.

(8) COM(2017) 479 final, Brussels, 13.9.2017.

Progress is needed at all levels to ensure that our regulatory frameworks provide the necessary flexibility to allow innovation to develop. We must learn to consider the perspective of innovators as they often have less of a voice than incumbents. To this end, the Commission will apply the innovation principle through its Better Regulation Agenda. The innovation principle entails taking into account the impact on research and innovation in the process of developing and reviewing regulation in all policy domains, i.a. to ensure that EU regulation allows companies to enter markets more easily.

Table 1 / ***Summary of rail-related goals in the Transport White Paper***

FOR PASSENGER RAIL	Triple the length of the existing high-speed rail network by 2030 so that by 2050 the majority of medium-distance passenger transport is by rail and high-speed rail is used more than aviation for journeys up to 1000 km
	By 2050, connect all core network airports to the rail network, preferably the high-speed rail network
	By 2020, establish the framework for a European multimodal transport information, management and payment system
FOR FREIGHT	30 % of road freight over 300 km to shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050
	Rail freight to almost double, adding 360 billion t-km (+ 87%) compared with 2005
	Deploy the European Rail Traffic Management System on the European Core Network by 2030
	By 2050, connect all seaports to the rail freight system
	Rail freight corridors to form the backbone of the EU freight transport system
FOR URBAN MOBILITY	Halve the use of 'conventionally fuelled' cars in urban transport by 2030; phase them out in cities by 2050
	Achieve essentially CO_2-free city logistics in major urban centres by 2030
	By 2020, establish the framework for a European multimodal transport information, management and payment system

1.1.2. Reindustrialisation

The S2R Joint Undertaking (JU) also has an important role in supporting the European Commission's policy on reindustrialisation ([9]), which recognises the central importance of industry in creating jobs and growth to recover from the recession and espouses a target for industry to generate as much as 20 % of Europe's gross domestic product by 2020. By leveraging technical innovation and transforming its performance, S2R will enable the rail sector to be a key contributor to this enhanced European industrial competitiveness.

1.1.3. The Single European Rail Area

As indicated in the S2R Master Plan, the 2011 Transport White Paper points out that the creation of a Single European Rail Area (SERA) will be crucial to achieving a modal shift from road towards more sustainable modes of transport such as rail. In fact, this could serve to dramatically cut the costs of running passenger and freight trains by providing a common

([9]) For a European Industrial Renaissance, COM(2014) 14 final, Brussels, 22.1.2014.

framework of rules and regulations for rail operators in the Member States. While urban rail is excluded from the scope of the SERA, this goal remains as relevant today as it was in 2011 for all rail systems.

Since the adoption of the 2011 White Paper, a lot of progress has been made towards the goal of creating the SERA. The agreement on the 'rail recast' ([10]) considerably changed the way the rail market works, stimulating investment, improving market access conditions and strengthening the role of national rail regulators.

The recast also paved the way for the various major proposals that together form the fourth railway package, without which the European single market cannot be complete. This set of legislation, adopted in 2016 ([11]), aims to remove remaining administrative, technical, and regulatory obstacles holding back the rail sector in terms of market opening, competitiveness and interoperability.

These issues are being addressed through initiatives in three main domains:

- domestic passenger market opening – opening domestic rail passenger markets to competition, including open access lines and routes on which public service obligations have been imposed;
- infrastructure governance – ensuring that infrastructure managers perform a consistent set of functions that optimises the use of infrastructure capacity and that the organisation of infrastructure governance guarantees non-discriminatory access to rail infrastructure and rail-related services;
- interoperability and safety – removing remaining administrative and technical barriers, in particular by establishing a common approach to safety and interoperability rules to decrease administrative costs, to accelerate procedures, to increase economies of scale for railway undertakings and to avoid disguised discrimination.

Full implementation of this package should allow very large savings on both administrative and running costs for train manufacturers, operators and national regulators, while also helping new entrants into the marketplace, thereby enhancing the quality and efficiency of rail services.

In addition, the fourth railway package anticipates S2R's contribution to 'developing rail as a transport mode by promoting step-change innovations for passenger rolling stock, freight transport, traffic management systems and rail infrastructure'.

1.2. About the Multi Annual Action Plan

This document (Part A) provides an executive view of the updated Multi-Annual Action Plan (MAAP), clarifying the S2R vision and its contribution to delivering EU societal goals; it identifies the associated set of 12 new capabilities that S2R will help the railway to develop and bring to market. It describes the S2R Programme as a whole, summarising its purpose, structure, methodology and content, and focusing on the series of intermediate steps by which it will bring about a radically improved railway system (urban/suburban, regional and high-speed passenger rail, freight), shaping the future mobility of people and business. These steps will be taken through the development and implementation of the R&I activities included in the

([10]) Directive 2012/34/EU of the European Parliament and of the Council of 21 November 2012 establishing a Single European Railway Area (recast). OJ L 343, 14.12.2012, p. 32–77.

([11]) The 'technical pillar' was adopted by the European Parliament and the Council in April 2016 and the 'market pillar in December 2016. For more information, please refer to the European Commission's web page 'Fourth railway package of 2016' (https://ec.europa.eu/transport/modes/rail/packages/2013_en).

MAAP, while exploiting new technologies and following a Europe-wide system-of-systems approach that is novel for the sector.

Part A links the S2R Master Plan ([12]) and the MAAP as shown in Figure 4.

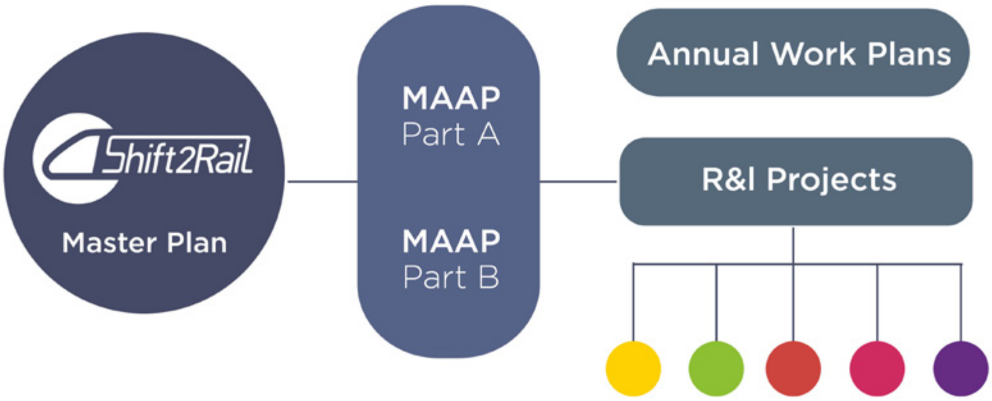


Figure 4 / ***The Shift2Rail framework***

Part A explains how the MAAP and its detailed activities (as set out in Part B), within the framework of the original S2R Master Plan, are designed to deliver the vision of a radically improved railway system. It also explains the opportunities that this could bring for the railway industry and for society as a whole.

The innovation capability delivery strategy and associated implementation plan require full cooperation between all stakeholders to prioritise and align efforts and resources. The fundamental rationale behind this process is illustrated in Figure 5.

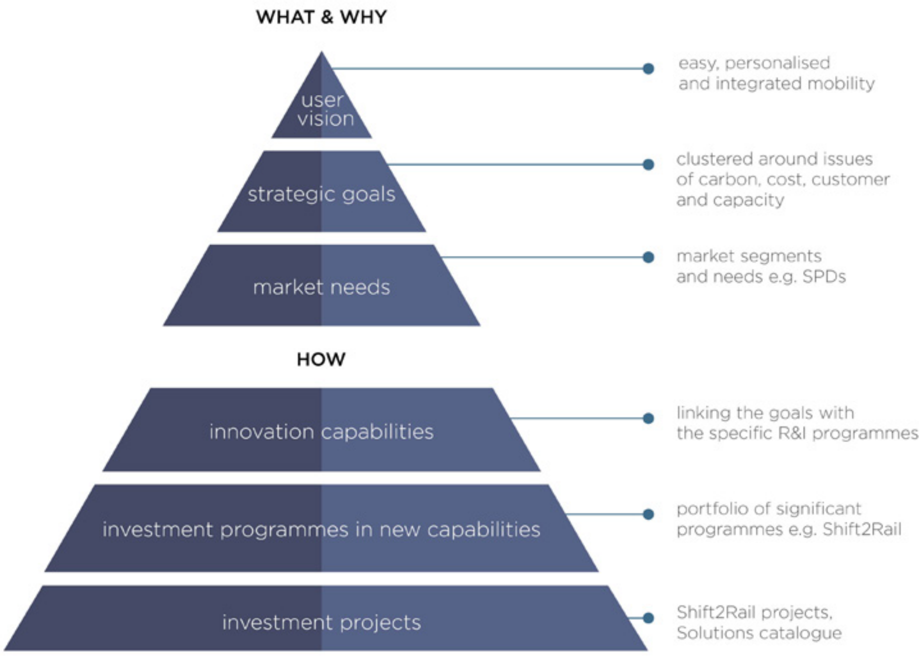


Figure 5 / ***Vision and strategy structuring principles***

([12]) Approved by the S2R JU Governing Board on 24.9.2015 and endorsed by the Council on 10.2.2015 (Decision No 4/2015 on the adoption of Shift2Rail Master Plan).

2. Challenges and opportunities

2.1. Key challenges for the European rail sector

The S2R Master Plan identifies eight key challenges faced by the European rail sector (Figure 6). If not addressed, these challenges will have an adverse effect on the continuous development of rail as a competitive transport mode and on the European rail manufacturing industry's competitiveness in the global market. However, they also offer a unique set of opportunities for the sector to expand and reaffirm its role.

*Figure 6 / **Eight key challenges faced by the European rail sector***

2.2. Key opportunities for the European rail sector

The rail sector already has a range of advantageous characteristics that set it apart from its competitors, for instance its ability to provide mass transit, journey comfort, safety, sustainable land use, a low carbon footprint and energy efficiency.

If the rail sector addresses the challenges identified above, it will open up three areas of opportunity (Figure 7):

1 to become the backbone of mobility as a service and on-demand future logistics;

2 to identify and establish new market segments for exploitation;

3 to enhance the overall competitiveness of the sector, both in Europe and globally.

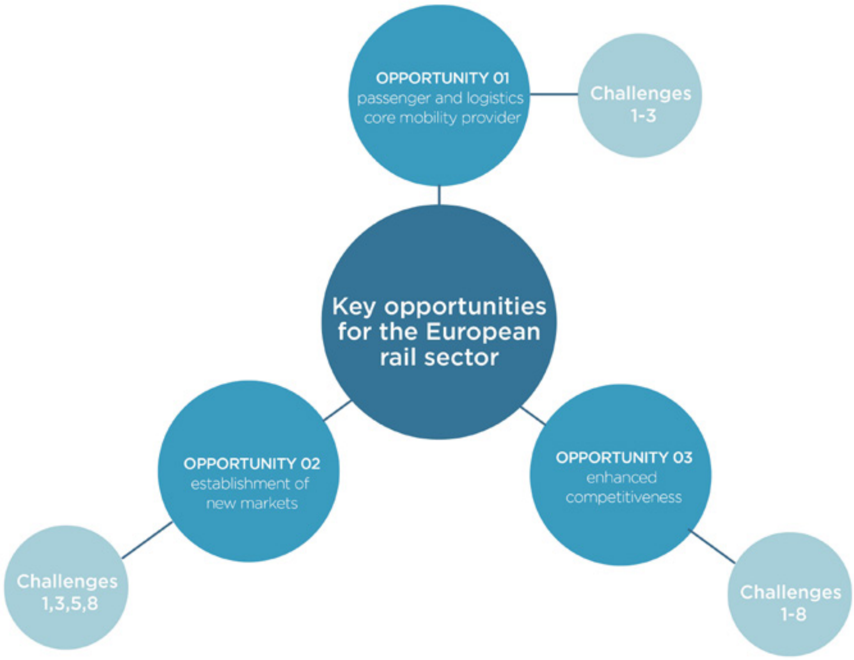


Figure 7 / ***Main opportunity clusters for the European rail sector***

Opportunity 01: passenger and logistics core provider for mobility services

Digitalisation and the rapid development of new technologies are unlocking a radically different approach to mobility, superseding modally based structures and facilitating the provision of seamless travel, with mobile devices as the interface. This creates an opportunity to capitalise on the strengths of the railway, such as mass transit capacity, comfort and high energy efficiency, by integrating it with services covering the first and last miles to offer door-to-door mobility for people and goods. The digitalisation process also creates an opportunity to achieve transformative integration of the subsystems that make up the railway.

This opportunity calls for tackling the challenge of completing the integration process and specifically establishing the set of rules and instruments needed to achieve the efficient, integrated operation of a single shared European rail system, allowing urban, regional and national systems to become part of a broader European mobility system with all the benefits that this brings.

Opportunity 02: establishment of new markets

Digitalisation, new technologies, innovation and a need to increase efficiency at all levels create an opportunity for the railway to exploit its assets and strengths to open new markets and services. This could produce unique opportunities to exploit underused capacity and network branches (e.g. closed or low-traffic regional lines) in new ways. This is also linked to diminishing societal support for large transport infrastructure projects, given the high levels of investment required and the dominance of the cost–benefit assessment approach in public office, which tends to overlook the many advantages offered by modes of transport such as rail. This is particularly relevant in the freight and high-speed segments.

Opportunity 03: competitiveness

The opportunities that the digitalisation process and rapid technological innovation and deployment bring can significantly enhance competitiveness in various key areas, such as products and systems solutions, skills, cost optimisation, improved manufacturing, new markets, and boosted productivity and performance.

Similarly, a more competitive rail system can also contribute to increasing the competitiveness of the European economy by facilitating higher productivity rates, translating into jobs and improved prosperity prospects for Europe's regions and citizens.

Through the S2R R&I programme, the European rail supply industry can create new business opportunities that:

- contribute to macroeconomic benefits such as
  - gains in employment quantity and quality,
  - improved productivity and
  - increased net exports;
- address and correct existing inefficiencies such as
  - low levels of collaboration between stakeholders,
  - lack of a true Europe-wide systems approach,
  - lack of investment in high-risk research and
  - difficulty of introducing new solutions, as they are tested only in service, in specific and willing clients' projects.

Improved competitiveness through a skills development approach creates an opportunity to engage with diverse young citizens

Improved competitiveness through a skills development approach creates an opportunity to engage with diverse young citizens and to attract them to the industry through the development of appealing, interesting and fulfilling engineering education programmes supported by stakeholders (e.g. sponsorship and apprenticeship schemes). In addition, educational training opportunities for the existing workforce can enable the development of the necessary skills to adapt to the fast-paced and complex technological changes in the sector.

Furthermore, the already advanced global standing and reputation of the European sector offers the opportunity to export the European model and vision to other markets. Similarly, a competitive and skilled European sector can transfer its knowledge to other sectors and benefit from them (e.g. in relation to automation and electrification of roads).

Rail's inherent characteristics and advantages, at the core of its competitiveness, provide a unique opportunity to meet the global demand for increased sustainability, particularly in the context of rising demographic challenges and fast urbanisation. To achieve all the potential that this opportunity brings, a strategy is needed that enhances performance through innovation in environmental aspects, safety and efficiency.

3. The S2R vision

> To deliver through railway research and innovation the capabilities to bring about the most sustainable, cost-efficient, high-performing, time-driven, digital and competitive customer-driven transport mode for Europe

Key features of this vision are set out below, highlighting the characteristics of customer-driven rail transport.

1. It is **available seven days** a week and is **reliable, resilient, safe and sustainable**.

2. A **whole-system approach** across the industry **fosters innovation** and attracts the **best talent**. **Entrepreneurs and innovators** have the **right conditions** to develop new products and services.

3. **Network capacity** is optimised to meet all requirements for passengers and freight. **Intelligent maintenance** increases train and track availability and reduces disruption and delays. World-class asset management is aligned across the industry to **improve performance**, **lower costs and reduce business risks**.

4 Flexible, real-time **intelligent traffic management** and in-cab signalling reduce headway and decrease traction energy consumption. Control centres know the precise location, speed, braking and load of every train on the network to **optimise operational performance and keep passengers informed**.

5 **Carbon emissions are minimised** by widespread electrification of the network and sustainable, energy-efficient solutions for the remaining non-electrified routes. Energy recovery systems in rolling stock and alternative fuels allow lower cost trains that run on and of the electrified network. **Sustainable Development Principles** are **embedded** in the design, construction and operation of infrastructure and rolling stock assets and the railway is resilient to climate change.

6 The **industry** is increasingly **cost-effective** as more efficiencies are introduced. Unplanned maintenance and damage to track and train are minimised through enhanced industry-wide condition monitoring. Generic designs for buildings and rolling stock interfaces are used instead of costly bespoke solutions to simplify expansion, upgrades and replacements.

7 **Operational and customer communications** are supported by equipment that can be updated with **plug-and-play fitments**. Rail services are **integrated** with other transport modes so that passengers have **seamless door-to-door journeys**.

8 **Station information systems and personalised messaging** offer passengers all the relevant information to travel **easily and reliably** to their destinations. **Passenger-friendly stations eliminate** the need for queues or physical **barriers**. Revenue collection and security are based on electronic systems.

9 An **extensive high-capability strategic freight network** with increased route availability provides freight customers with flexible and timely responses to their operational and planning requests.

Central to this vision is putting the customer in charge. This is an opportunity to deliver to European citizens the benefits of disruptive change, from today's railway transport, operations and capabilities to a user-centric railway system that excels itself.

The S2R Partnership, reflecting the rail sector's good understanding of its customers' bespoke requirements ([13]), is working towards delivering the major part of a mobility system that combines and integrates the best of all transport modes to provide optimal services for people and goods.

Rail, already central to the market segments it serves, will become further integrated into this mobility system, thereby contributing more than the benefits it provides on a stand-alone basis – such as mass transit, transport of heavy loads and efficient use of space.

3.1. Addressing key societal trends

S2R is being established within the context of a Europe experiencing important societal and other key changes. Of these 'megatrends', those identified by the European Environment Agency (EEA) as most affecting the railway are digitalisation, urbanisation and aspects of climate change ([14]). Another key societal trend in Europe is the increasing average age of the population. The S2R vision therefore considers these and responds to them.

([13]) The S2R Partnership includes the different S2R advisory bodies and working groups.

([14]) EEA, 'Assessment of global megatrends – an update', February 2017. The 11 megatrends identified by the EEA are social, technological, economic, environmental and political, with digitalisation, urbanisation and climate change being the main megatrends directly affecting the railway.

Digitalisation

Arguably, the single greatest societal impact of recent decades has been the transformation wrought by digital technology. Digital connectivity is changing the game and its continued development has expanded the demand for mobility. Users' imaginations have been set free and social and economic activity boosted, leading to increased demand for travel and distribution. S2R will harness the capabilities of the digital revolution to provide a transformed mobility system, in its design, delivery and availability to all users. This approach is not about digitalisation of current processes and procedures; rather, industry, businesses and the railway system will take the opportunity to look at how digitalisation applies to all steps of the value chain, rethinking and re-engineering business models to capture the full advantages of the present and future digital revolution. As the approach to connectivity, automation and digitalisation in the railway is part of the wider EU strategy, the key is not the development of a separate model but a clear S2R plan to implement that strategy through research, innovation and system architecture definition.

Urbanisation

For a long time, there has been movement in Europe away from rural areas to cities for both work and permanent residence. This continuing trend has already seen a tipping point in mobility requirements, with new phenomena emerging, such as the reduction in private car ownership in favour of other arrangements (e.g. leasing, car sharing), irregular, 24-hour living patterns, and readily available information and services, anywhere, any time. S2R's vision is to put in place a truly connected and permanently available mobility offer, meeting the needs of people and business. The railway already has a unique advantage through its capacity to move very large numbers of people, and it is able to provide tangible benefits to alleviate urbanisation challenges. S2R aims to build on this advantage by increasing the capacity of the system and enhancing integration with other modes of transport, leading to attractive end-to-end journey provision.

Climate change and the environment

Currently, the railway has a good environmental performance, making only a marginal contribution to transport's overall share of greenhouse gas emissions; however, as agreed at global level, further improvement is needed in line with the COP21 targets ([15]). Noise emission also remains one of the key challenges that the railway system must address.

The S2R vision is to provide, by adopting a systems approach to managing the entire value chain, mobility with zero harm to the environment, building on the railway's existing strong track record in this area. The aim is to achieve a railway producing no carbon, no emissions, no noise.

Greater uptake by European citizens in their daily journeys of an available, high-performing and attractive renewed rail offer will automatically and significantly contribute to the EU Member States' achievement of COP21 targets.

Ageing population

The population of Europe is increasing overall. The figures differ between regions, but almost everywhere the average age of citizens is increasing, as are the numbers of people with a physical impairment to their mobility. Through its R&I programme, the S2R JU aims to provide easy access to the rail system to ensure mobility for everyone, including those who have historically found it difficult to use transport systems. This will provide freedom for all people to participate to the full in social and economic life, whatever their age or capabilities.

[15] The annual Conference of Parties (COP) reviews the implementation of the UN Framework Convention on Climate Change (UNFCCC). COP21 was the 21st event since Berlin 1995 and it took place in Paris in December 2015.

In addition, reliance on the use of technology as a means of delivering mobility needs to be addressed, and information should be provided to passengers whether or not they have access to and the ability to use personal smart devices.

3.2. The need for radical transformation

In the light of these megatrends, existing models of transport provision in Europe are under severe pressure; they need a paradigm shift to meet evolving user requirements. For instance, infrastructure designed to provide a much lower level of capacity than that required for current demand is becoming a common barrier across all modes of transport, and may lead to poor service quality. This risks further restricting the economic development of European regions and Europe as a whole, creating a significant cost burden for businesses and the distribution chain, reducing competitiveness in world markets and, as a result, failing to meet users' expectations. Fundamental change to the models, based on innovative technical and operational solutions, is needed to address these challenges and specifically to create user-centric affordable mobility as a se rvice that underpins all aspects of life.

Different solutions are already coming to the market. Variations in the importance attributed to the value of time results in different mobility systems being proposed and made use of. For example, this can be seen in the use of long-range, low-cost but time-consuming bus services that meet the expectations of some categories of passenger. On the other hand, the use of the train as an office space answers the needs of those passengers who value the journey as important time to be used for work.

Some transformational technologies are already being developed, capturing the public interest and imagination, for example autonomous road vehicles. In the railway context, some such applications have been in place for a long time, albeit mostly unnoticed by the public: there is autonomous train operation in almost 40 % of the metro systems worldwide. However, there is a need to develop and implement more widespread and more sophisticated applications for mainline operation.

In a context where current mobility models and paradigms are in a state of flux, S2R will provide new rail-based capabilities that leverage the rail sector's unique features, combining and integrating them with those of other modes of transport to serve customers' mobility needs.

3.3. Customer-focused mobility

So, what might this changed system look like? There follows a description of the rail system of the future using the products originating from the S2R programme.

From a user perspective, there is confidence that, whenever someone wants to go from A to B or goods need to be delivered, it will be easy to obtain a service as soon as it is needed and to travel in comfort, securely and quickly, without needing to own or operate the vehicle – and at an affordable price. The customer wants to receive the best possible service, and his or her time is precious. The customer needs to be assured that all is going well and to be able to respecify the journey (e.g. the destination) should circumstances demand. He or she is not very concerned about the technical arrangements underpinning the service but may have a preference for certain service providers or sets of services within a competitive market. Those services conform to standards allowing system-wide interoperability, to minimise system costs while maximising their performance. Automated transits provide origin collection/destination delivery, and this is combined with a rail-based core land transport network and links to air and sea. The network allows the operation of automated, intelligent trains that respond dynamically to customer demand. Splitting and joining on the move provides maximum operational flexibility to meet customers' needs while maximising network utilisation. This results in much greater effective capacity than hitherto, based on trains running closer together, safely, so that the customer does not suffer as a result of traffic congestion, and journey durations are predictable and quick. Digital connectivity allows users to do everything they can do at home or in the office and links to other services for example on the train or at the destination. In fact, the train can become an office – or even a playground.

For logistics and distribution, too, the experience is transformed, with an end to long queues of vehicles in traffic jams, currently a regular feature near towns, ports and motorways and in bad weather. The new logistics, with next generation rail at their heart, allow always-on-time delivery, security of supply, lower levels of inventory and therefore lower system costs. The customer's choice of train as the key mode of transport contributes to breaking down barriers between the multiple modes needed to deliver goods. This is realised through synchronisation of train movements on the network and of trains with the road mode in pre- and post-haulage, improved real-time information to customers and better data exchange between parties involved in the intermodal transport chain.

Realising this vision of the future railway will depend on delivering the S2R programme.

4. A catalogue of railway innovation capabilities

To take advantage of these opportunities and to realise the vision, the railway needs to put in place a range of new innovation capabilities. These will enable it to produce value-adding products and services. As an example, the capability to run trains much closer together would allow a dramatic increase in service frequency and network capacity, with higher system utilisation and related revenue adding significant value to railway businesses.

A catalogue of 12 innovation capabilities ([16]) (Figure 8), described below, has digitalisation and automation at its core. These capabilities include one that is non-technical, yet vital for the others – focused on delivering the process of innovation itself – a capability to accelerate, develop, accept and deploy innovative products and services. For each of these capabilities, a set of necessary intermediate competences and technological advances (sub-capabilities) is described.

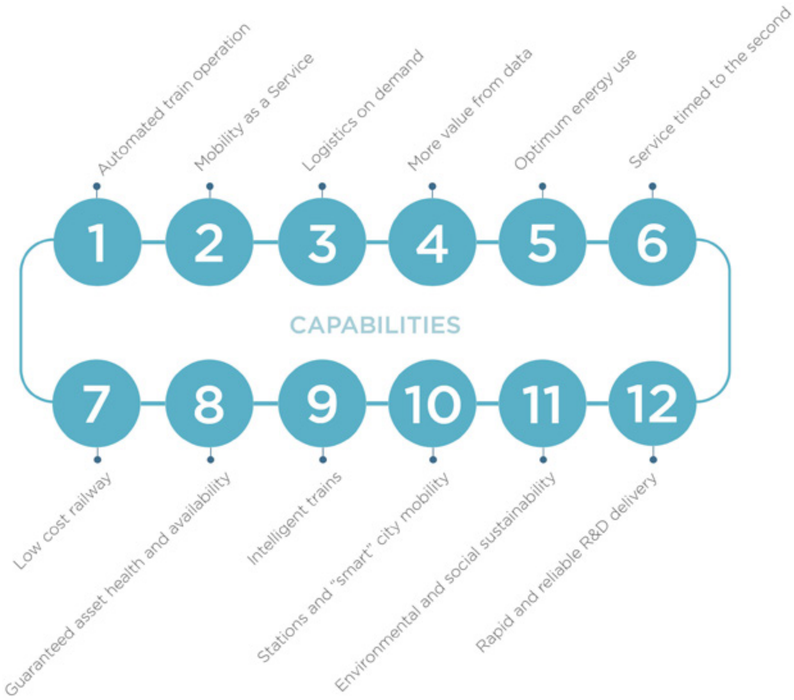


Figure 8 / ***12 capabilities required for the realisation of the Shift2Rail vision***

([16]) These capabilities have been developed in coordination with the International Union of Railways Research and Innovation Coordination Group.

Capability 1_Automated train operation

Trains are able to operate themselves and run closer together based on an automated train operation system, boosting capacity significantly on existing lines. Autonomous and remote controls ensure safe operation. Rail operations are partly or fully automated.

1A_ Automated (passenger and freight) trains run closer together with increased flexibility.
1B_ Passenger and freight train preparation processes are automated.
1C_ Vehicles split and join on the move. New operational approaches (e.g. virtual coupling, convoying, reduced headway, communication connections between trains/units) are employed.
1D_ Self-propelled automated/autonomous single units guide themselves through the system.

Capability 2_Mobility as a service

Customer demand-driven services lead the railway to provide excellent service within the overall mobility chain. Connections between rail and the other modes are seamless, making mode interchange as simple and as efficient as possible. Information is permanently available to make travel safe and efficient along the travel chain, including at stations. All customers and potential customers are connected to mobility services.

2A_ Tailored guidance on the best use of available transport services is provided so that each customer receives a personalised service.
2B_ Every journey is provided intelligently and seamlessly, with rail physically integrated with other modes.
2C_ Continuous flow of information facilitates the journey, making connections between the different modes seamless.
2D_ Electronic ticketing and payment are the norm.
2E_ Superior passenger experience and comfort are key advantages of rail over other transport modes.

Capability 3_Logistics on demand

Logistics services are driven by customer demand, with freight moved reliably in wagons designed to carry various loads. Better planning, tracking and shipment information capabilities combine to offer customers flexibility and capacity at reasonable, attractive prices. The rail system is fully integrated with the multimodal logistics chain.

3A_ Planning and scheduling are synchronised in real time with customer demand.
3B_ Flexible, interchangeable, multipurpose and smart freight transport units increase handling flexibility and unit utilisation.
3C_ Shipments are moved effectively, efficiently, safely and securely through the physical internet logistics chain.
3D_ Freight trains are able to integrate within high-intensity passenger operations.
3E_ Automated yards, intermodal hubs, ports and cross-modal interchange locations connect the rail system into the multimodal logistics chain.

Capability 4_More value from data

To deliver on all the capabilities, rail manages a growing volume of data contributing to the data economy. Collection, analysis, interpretation and prediction are automated to provide consistent, up-to-date information supporting fast, well-informed decisions and business benefits. This is achieved through a robust, resilient and secure information architecture and governance structure. Taking into account data privacy management, relevant information is shared across the industry and more widely, enabling the development of new services and applications to the benefit of the railway and its customers.

4A_ Secure, robust, scalable and resilient open architecture and protocols allow full interoperability

4B_ The internet of things (IoT) and artificial intelligence (AI) provide efficient capture, storage, management and interpretation of data.
4C_ The customer and the rail system communicate intelligently with each other.
4D_ Railway businesses exploit new data-driven revenue streams.
4E_ Big data analytics enable a range of new and improved services to be developed. State-of-the-art cybersecurity ensures reliable and secure information and communications technology services, protection of the rail system and business continuity in the event of an incident.

Capability 5_Optimum energy use

Railways maintain their position as the most environmentally friendly mode of transport by decreasing energy consumption. This is achieved, together with lowered operating costs, through the use of an intelligent energy management system. The introduction of new technologies and methods as supporting tools enables reduced and optimised demand-led energy use and energy efficiency.

5A_ Alternative propulsion concepts such as fuel cells are introduced. Hybrid-power trains can run over non-electrified track sections. Discontinuous electrification at stations and on branch lines dramatically reduces the capital costs of extending electrification.
5B_ Automated train operation improves energy efficiency.
5C_ Optimised on-board and line-side energy storage and charging technologies (e.g. dynamic wireless power transfer) allow the railway to redistribute energy throughout the system according to supply and demand.
5D_ A high proportion of energy is recovered through regenerative braking, and small-scale energy generation and harvesting technologies feed energy-efficient trackside systems.
5E_ A fully integrated systems approach to intelligent energy supply maximises renewable energy generation and the use of smart grids, including those outside the railway system, through links with the wider energy supply sector.

Capability 6_Service timed to the second

Situational awareness, where each train's location and speed is known at all times and in real time, supports service operation timed to the second. This results in increased and enhanced operational flexibility and contributes to a more robust, resilient and reliable service, as well as faster recovery from service disruption.

6A_ Automated vehicle identification and monitoring is the basis of precise service operation.
6B_ Smart traffic management ensures that every train is in the right place and travelling at the right speed.
6C_ Automated dynamic timetables are facilitated. Automated recovery from disruption (a 'self-healing' process) quickly restores normal service.

Capability 7_Low-cost railway

New models to deliver efficient and affordable infrastructure, rolling stock and railway operation allow the rail mode to be viable in areas of low demand and to compete for new transport links. Design, service solutions and technologies draw inspiration from other sectors such as the light rail, automotive and aviation sectors.

7A_ A low-cost, affordable rail system supports the rural economy. This is supported by the application of tailored standards.
7B_ A simplified control–command system appropriate for low-intensity operation is used, allowing various degrees of autonomy.
7C_ The use of lightweight materials for rolling stock reduces maintenance costs and energy consumption.
7D_ A whole-life operating cost approach balances the use of low-cost technical assets and good-value service.

7E_ European simplified train certification processes and validation techniques reduce time taken for and the cost of product deliveries and subsequent modifications.

Capability 8_Guaranteed asset health and availability

Optimised maintenance keeps the railway continuously open, fostering minimal disruption to train services. Shared real-time monitoring of asset health by a wide array of sensors connected together in an IoT environment feeds the predictive maintenance decision-making process. Asset health and availability is further improved by machine-learning, AI and big data analytics. Robust modular units and infrastructure are easily maintained and repaired through a robotic automated system, making the operation punctual, safe and quick.

8A_ The IoT enables real-time monitoring through connected sensors (ground/air/embedded).
8B_ AI supports predictive maintenance decision-making to reduce manual interventions on infrastructure and rolling stock.
8C_ Greater use of robotics, modularity and automation simplifies maintenance and reduces the number of components.
8D_ Remote maintenance of trains and infrastructure allows operations to continue uninterrupted.
8E_ Performance-based service specifications encourage a diverse supply chain.

Capability 9_Intelligent trains

Intelligent trains are aware of themselves, their passengers/loads and their surroundings, knowing where they need to be and when, and able to automatically adjust journeys to meet demand. In addition, they intelligently feed information on infrastructure to support preventive maintenance. A network of fully intelligent trains can be self-regulating, negotiating vehicle to vehicle to decide on movement authorities and resolve potential conflicts at junctions in the network and to react to unexpected situations. The trains are also aware of and able to take account of the status of other transport modes.

9A_ Autonomous trains can monitor and regulate themselves.
9B_ Communication is possible between trains, between train and infrastructure, and between train and passenger/freight customers.
9C_ Trains feature advanced mechatronics, reducing dependence on wheel conicity and permitting simplified running gear design.
9D_ In-train signalling capability is used to resolve conflicts at junctions and stations.

Capability 10_Stations and smart city mobility

Rail is the backbone of urban mobility, with stations at the heart of smart cities, being places to work, live, meet and communicate, where individual transport modes, including public transport and long-distance rail transport, are physically connected. New station designs provide easy access and seamless interchange between transport modes, enabling railways to manage growing passenger volumes and mobility demands.

10A_ Railways are a core part of smart city mobility management systems and city fulfilment and delivery services. Stations are key to smart city governance structures and development plans.
10B_ Railways are connected to smart city mobility platforms for a seamless end-to-end journey within and beyond the city.
10C_ New designs for infrastructure and rail vehicles provide easy access and interchange between transport modes.
10D_ Flow management systems guide customers safely and efficiently through stations and to and from adjacent transport hubs and city infrastructures, using dynamic way finding, barrier-free access and multisensory information systems.
10E_ Platform management systems help passengers position themselves for their train and facilitate efficient boarding.

10F_ Security and revenue protection at stations and interchanges are based on electronic gates using smart wireless technologies, ticket detection systems and biometrics.

Capability 11_Environmental and social sustainability

Railways continue to deliver sustainable transport solutions as overall travel demand intensifies. Rail makes an increased contribution to the transport economic mix, decoupling environmental harm from transport growth. Railways are able to operate with minimal environmental impact and with a low carbon footprint. Inclusive and easy access is available for all citizens to railway facilities, products and services.

11A_ The adoption of circular economy principles enables the railway to move towards zero-waste operation.
11B_ Sustainable and ethical procurement and production reduces the carbon footprint of the railway, with a whole-life approach and a focus on inputs to the system, recycling, transport of materials, renewable energy, operations and disposals.
11C_ A climate change adaptive approach mitigates the impact of climate change on the railway.
11D_ Green technologies enable the railway to operate exhaust emissions free and with low noise and vibration levels.
11E_ Information and accessible facilities put the railway within the reach of citizens as an inclusive, affordable and accessible transport system.

Capability 12_Rapid and reliable R&I delivery

An ecosystem for R&I, based on effective collaboration, the provision of greater technology demonstration capability and the rapid integration of technology into the railways, removes barriers to the adoption of new technologies and decreases time to market.

12A_ An R&I ecosystem with centres of excellence fosters a high rate of participation in knowledge networks, opening up new forms of collaboration, facilitating technology transfer from other industry sectors and keeping railway skill sets fresh.
12B_ The sector has a strong commercial focus and awareness of the maturity levels of new technologies. There is a well-coordinated and fast decision-making process, reducing time to market.
12C_ Virtual testing and efficient implementation processes speed up production and deployment of new products. There is close cooperation within the sector on standardisation and testing. Component-driven development and modularised products are key elements of rapid deployment of innovation to the market. Railways have a permanent focus on disruptive technologies, using their challenges to increase their innovation capabilities and speed.
12D_ Agile development approaches, labs, hackathons and early involvement of customers are elements of customer-centric innovation. Open labs invite end users/customers to be part of the innovation process.

5. S2R roadmap to deliver the innovation capabilities

Developing these capabilities will require a coordinated effort to drive innovation at all levels. S2R is designed to make a decisive contribution to delivering the essential knowledge that will provide the building blocks for such capabilities.

As indicated in the S2R Master Plan, the work conducted within the S2R Programme is structured around five asset-specific Innovation Programmes (IPs), covering all the different structural (technical) and functional (process) subsystems of the rail system. These five IPs are supported by work on five cross-cutting activities (CCA) covering themes that are relevant to each of the programmes and which address the interactions between the IPs and the different subsystems. This overall programme structure is shown in Figure 9.

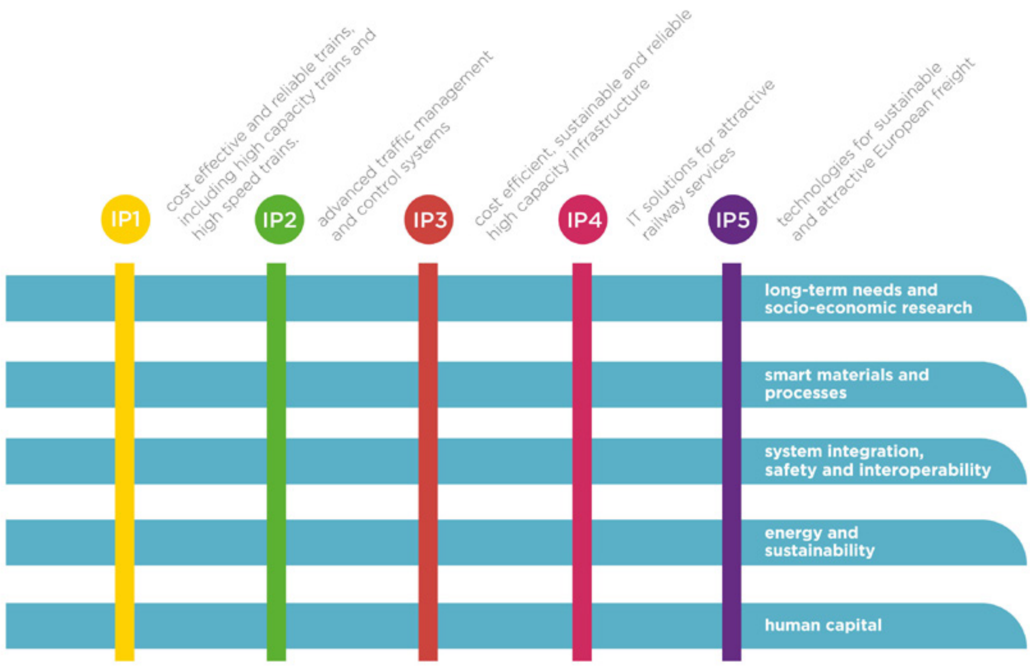


Figure 9 / ***Shift2Rail overall structure***

S2R addresses the IPs and CCA by funding R&I activities that range from fundamental research (technology readiness level (TRL) 0 to 3), through applied research (TRL 3 to 5) to demonstration activities (TRL 5 to 7), i.e. from exploring ideas through technological and operational developments demonstrated at laboratory level to system prototype demonstrations in operational environments. The following existing and established market segments are being considered:

- high-speed passenger rail;
- regional passenger rail;
- urban/suburban passenger rail;
- rail freight.

S2R Members are also required to conduct additional activities to leverage the effect of the R&I activities undertaken. These additional activities are not eligible for financial support from S2R and are not included in this MAAP, but they contribute directly to the broader objectives set out in the S2R Master Plan.

5.1. The Shift2Rail research and innovation structure

Demonstration activities are a priority within S2R, as they enable the rail sector to:

- visualise and test the transformations that are being created;
- quantify the impact of each new technology, either alone or in combination with other innovations;
- provide a first estimate of the potential for improvement in the sector at multiple levels of the transport network (regional, national and EU);
- enhance the perceived innovation potential of the sector and revitalise the industry by attracting the next generation of top graduates from universities across Europe.

The demonstration of technical achievements, up to TRL 7, is being based on the threefold architecture presented in Figure 10, namely technology demonstrators (TDs), integrated technology demonstrators (ITDs) and system platform demonstrators (SPDs).

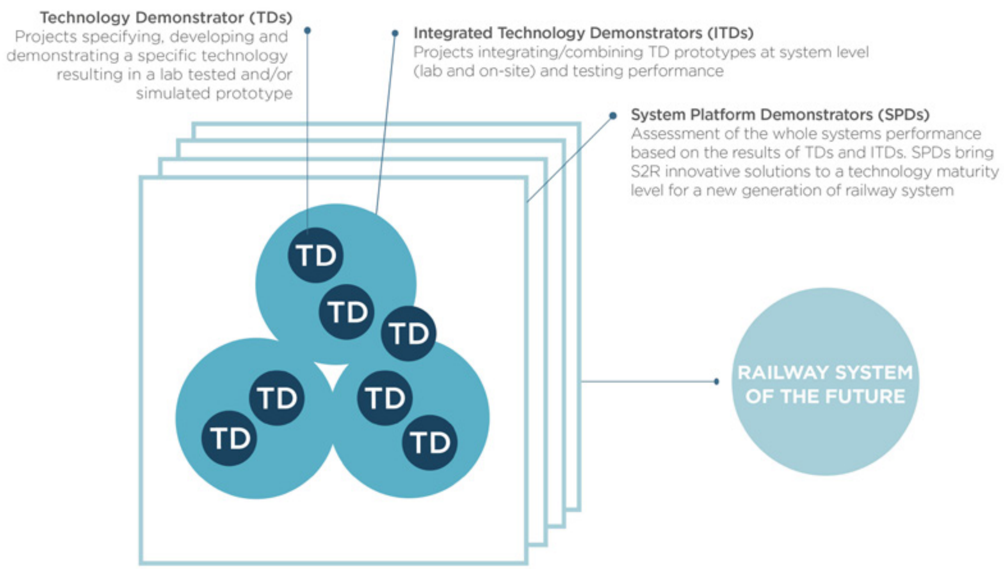


Figure 10 / ***Structure of Shift2Rail demonstrators***

Technology demonstrators

TDs focus on the development or adoption of innovative technologies and models within the rail subsystems identified in the IPs. They are designed to enable groundbreaking progress in key areas such as traction, automated train operation, and intelligent diagnosis and maintenance systems, all linked to the capabilities discussed in Section 4. The innovations developed may consist of software and/or hardware systems.

Before being combined into ITDs, each TD is tested in one or more prototypes to assess the individual performance of the technologies developed, and, where possible, demonstrate conformity with the technical requirements that apply to the product developed. These tests can be performed in labs or existing trains, and are differentiated if different business segments are targeted.

Integrated technology demonstrators

ITDs allow the testing of combinations of components and subsystems already verified and validated in TDs; they will contribute to establishing the innovation capabilities. Their aim is to demonstrate the innovation potential of the components in different subsystems and systems, taking into account functional and operational specifications and the technical interfaces among the various TDs.

ITDs also enable an analysis of compliance with regulatory requirements. The validation of technologies will be followed up with a controlled approach to future authorisation and certification work, all of which forms part of the necessary steps towards ensuring the capabilities identified can be deployed.

System platform demonstrators

Ultimately, S2R will carry out proof and analysis of rail systems, designs and functions on fully representative innovative railway configurations in an integrated environment, simulating real operational conditions.

SPDs are conceived to simulate and virtually test the interaction and impact of the various innovative systems resulting from S2R activities in the specific environments of each of the relevant market segments.

These SPDs are shaped by the evolving impact assessment of key transversal issues critical for the sector, including the societal trends discussed in Section 3 of this part of the report (e.g. an ageing population, digitalisation).

The design of the SPDs takes into account the characteristics of each market segment, its challenges and needs, and promising market opportunities. Based on this initial assessment, the SPDs will demonstrate how the correct aggregation of different innovations can greatly contribute to improving the performance of the sector. This will be based on an analysis of detailed key performance indicators on simulated models and measured against the S2R objectives as defined in the Master Plan. In this respect, it is possible that the deliverables of a single TD might be relevant to more than one of the different railway transport segments. The results of one TD may therefore be demonstrated in more than one SPD if it is considered that these results correspond to the business needs of several rail market segments.

The exact design of each SPD is part of the work to be done in the S2R JU's System Integration Working Group, taking into account input from the broader stakeholder community, as well as relevant results of S2R projects (lighthouse projects, open calls and member-only projects).

5.2. How S2R will achieve its vision

The five asset-specific IPs and the five CCAs, as seen in Figure 9, form the basis of the S2R R&I programme and are described in detail in the S2R Master Plan (for more details, see Section 2).

Their contribution to achieving the necessary capabilities to enable the vision to be realised is being assessed though the completion of building blocks. A building block is understood as a complete and distinct enabler of one or more capabilities that is formed of (a) TD outcome(s).

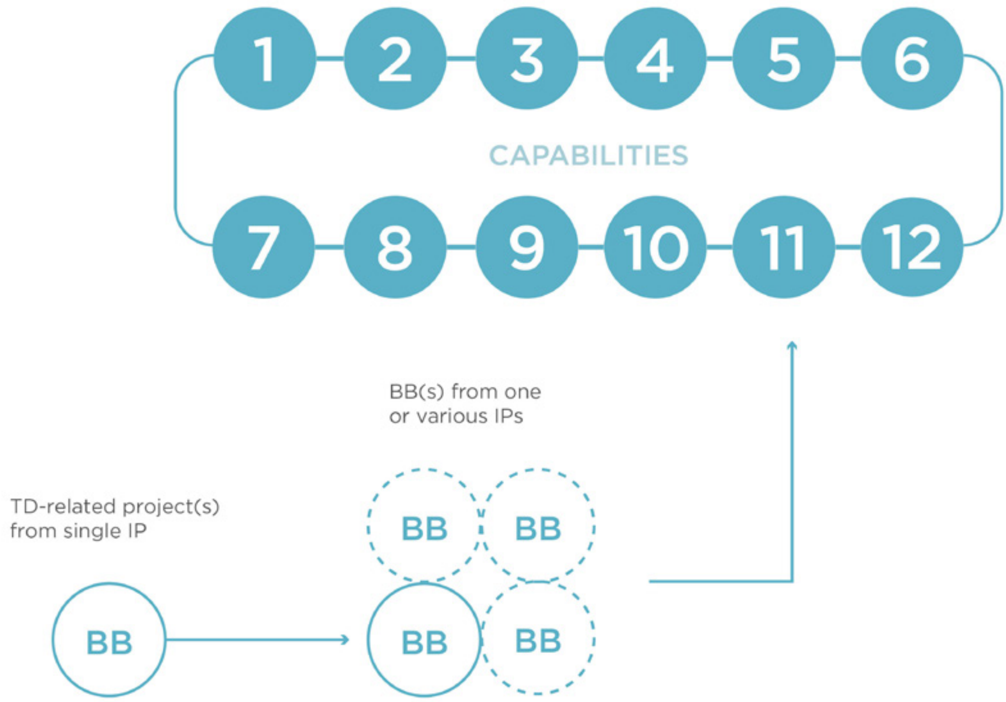


Figure 11 / ***Building blocks (BBs) approach to capabilities***

IP1_Cost-efficient and reliable trains, including high-capacity trains and high-speed trains

Figure 12 summarises the building blocks associated with the various TDs planned as part of IP1 and their related deliverables.

IP1	TD1.1 Traction	BB1.1.1 New Power Electronics BB1.1.2 Independent wheel traction BB1.1.3 High reliability & availability traction BB1.1.4 Traction EMI & acoustic noise reduction BB1.1.5 Virtual certification of traction BB1.1.6 Standardisation of key traction components	→	D1.1_1 SiC Light and small traction equipment AC (regional) D1.1_2 SiC light and small traction equipment DC (metro) D1.1_3 High-speed IRW Traction
	TD1.2 TCMS enablers	BB1.2.1 Wireless TCMS BB1.2.2 Drive-by-data BB1.2.3 Functional distribution architecture BB1.2.4 Virtual placing on the market of TCMS	→	D1.2_1 New technology TCMS for metro segment D1.2_2 New technology TCMS for regional segment
	TD1.3 Carbodyshell	BB1.3.1 Composite-hybrid carbodyshell	→	D1.3_1 Metro hybrid carbodyshell D1.3_2 High-speed hybrid carbodyshell
	TD1.4 Running gear	BB1.4.1 Bogie sensors and mechatronics BB1.4.2 New materials for bogies BB1.4.3 Noise and vibration BB1.4.4 Virtual certification of bogies	→	D1.4_1 New instrumentarised bogies & health status system D1.4_2 New materials demonstrator
	TD1.5 Brakes system enablers	BB1.5.1 Safe control & adhesion management BB1.5.2 Efficient force generation BB1.5.3 Authorisation process	→	D1.5_1 New ECB demonstrator
	TD1.6 Doors and access system	BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions BB1.6.2 Light Door and Improved Comfort (acoustic & thermal)	→	D1.6_1 New entry demonstrator
	TD1.7 Train modularity in use	BB1.7.1 Interiors modularities BB1.7.2 Driving cabs of the future	→	D1.7_1 Interiors demonstrator D1.7_2 Cab demonstrator
	TD 1.8 Heating, ventilation, air conditioning and cooling (HVAC)	B1.8.1 Eco-friendly HVAC	→	D1.8_1 Eco-friendly HVAC demonstrator

Figure 12 / ***IP1 Building blocks (BBs) and deliverables associated with its technology demonstrators (TDs)***

Similarly, IP1 technological building blocks can be mapped to the capabilities they contribute to, as shown in Figure 13.

IP1	TD1.1 Traction	TD1.2 TCMS enablers	TD1.3 Carbodyshell	TD1.4 Running gear	TD1.5 Brakes system enablers	TD1.6 Doors and Access System	TD1.7 Train modularity in use	TD 1.8 Heating, Ventilation, Air conditioning and Cooling (HVAC)
1. Automated train operation		BB1.2_1 BB1.2_2		BB1.4_1	BB1.5_1	BB1.6_1	BB1.7_2	
2. Mobility as a Service		BB1.2_1		BB1.4_1		BB1.6_1 BB1.6_2	BB1.7_1	
3. Logistics on demand								
4. More value from data	BB1.1_3	BB1.2_1 BB1.2_2 BB1.2_3		BB1.4_1		BB1.6_1		
5. Optimum energy use	BB1.1_1 BB1.1_2	BB1.2_1	BB1.3_1	BB1.4_2	BB1.5_1 BB1.5_2	BB1.6_2		BB1.8_1
6. Service operation timed to the second		BB1.2_1		BB1.4_1	BB1.5_1 BB1.5_2	BB1.6_1	BB1.7_1	
7. Low cost railway	BB1.1_1 BB1.1_2 BB1.1_3 BB1.1_5 BB1.1_6	BB1.2_2 BB1.2_3 BB1.2_4	BB1.3_1	BB1.4_1 BB1.4_2 BB1.4_4	BB1.5_3	BB1.6_1 BB1.6_2	BB1.7_1	BB1.8_1
8. Guaranteed asset health and availability	BB1.1_3	BB1.2_1		BB1.4_1				BB1.8_1
9. Intelligent trains	BB1.1_3	BB1.2_1		BB1.4_1	BB1.5_1 BB1.5_2	BB1.6_1		BB1.8_1
10. Stations and smart city mobility		BB1.2.1				BB1.6_1	BB1.7_1	
11. Environmental and social sustainability	BB1.1_4			BB1.4_3	BB1.5_1 BB1.5_2			
12. Rapid and reliable R&D delivery	BB1.1_5 BB1.1_6			BB1.4_4				

Figure 13 / ***Alignment of IP1 building blocks (BBs) with capabilities***

IP2_Advanced traffic management and control systems

Figure 14 summarises the building blocks associated with the various TDs planned as part of IP2 and their related deliverables. The building blocks and TDs shown in the figure are those that are considered likely to make the biggest contribution to the achievement of the capability in question. Additional IP2 TDs may have an influence on a capability but are deemed more general. For instance, adaptable communications (TD2.1) and cybersecurity (TD2.11) are linked to the need for communication between all systems and thus contribute in some degree to all the capabilities.

IP2	TD2.1 Adaptable communications for all Railways	BB2.1_1 Definition of a Multi Bearer Technology including SatCom BB2.1_2 System open to exploit the use PLMNs BB2.1_3 System resilient to the evolution and needs of the signalling system	→	D2.1_1 New communication system adaptable to the needs of the different Railway market segments
	TD2.2 Railway network capacity increase (ATO up to GoA4 – UTO)	BB2.2_1 Definition of the architecture for application of ATO (GoA2 up to GoA4) BB2.2_2 Definition of the model for improving punctuality and quality of service reducing energy consumption	→	D2.2_1 ATO (from GoA2 up to GoA4) for different Railway market segments
	TD2.3 Moving block enablers	BB2.3_1 MB Prototypes able to be applied and customised to each railway market segment BB2.3_2 Operational Procedures due to the application of MB	→	D2.3_1 MB Prototypes able to be applied and customised to each Railway market segment D2.3_2 Operational Procedures due to the application of MB
	TD2.4 Fail-Safe Train Positioning (including satellite technology)	BB2.4_1 GNSS application in railway for safe train localisation BB2.4_2 Reduction of trackside train detection systems BB2.4_3 Interoperability with ERTMS/ETCS core	→	D2.4_1 Safe Train Location based on GNSS and adapted to the dierent railway application and market segments D2.4_2 Definition of the most suitable augmentation systems for railway
	TD2.5 On-board Train Integrity	BB2.5_1 Safe on-board train detection and tail position BB2.5_2 On-Board energy generation and harvesting for OTI	→	D2.5_1 OTI adapted according to train characteristics D2.5_2 On-Board Energy generation and harvesting prototypes
	TD2.6 Zero On-site Testing	BB2.6_1 Definition of a dedicated system test architecture for lab test BB2.6_2 Specification of standardised method to derive and describe test cases BB2.6_3 Identify common test process framework	→	D2.6_1 Common simulation architecture for improving lab tests D2.6_2 Common testing procedures adapted to every stage of system development
	TD2.7 Formal methods and standardisation for smart signalling systems	BB2.7_1 Formal and semi-formal methods for requirement capture, design, verification and validation, proposing open standards BB2.7_2 Standardisation of crucial interfaces between parts of selected state of the art interfaces (FIS and FFFIS).	→	D2.7_1
	TD2.8 Virtually Coupled Train Sets (VCTS)	BB2.8_1 Identify feasibility and safety issues of the virtual coupling concept BB2.8_2 Define system, architecture and functional ratios BB2.8_3 Identify impact on whole railway system	→	D2.8_1 Complete feasibility and safety analisys of the Virtual Coupling concept in the railway environment D2.8_2 Functional architecture and railway system impact analysis
	TD2.9 Traffic Management Evolution	BB2.9_1 Standardization of frameworks, data structures, real time data management, messaging and communication infrastructure BB2.9_2 Plug- and-Play of functional service application modules BB2.9_3 Standardized workstation addressing heterogeneous working processes	→	D2.9_1 Modular, scalable and plug-and-play supervision structure D2.9_2 Standard TMS workstation
	TD2.10 Smart radio-connected all-in-all wayside objects	BB2.10_1 Use of radio means for commanding/controlling Object Controllers BB2.10_2 Define a suitable Object Controller open to radio communication BB2.10_3 Allow the signalling system to direct communication of train to wayside object controller BB2.10_4 Define a suitable energy generation and harvesting system	→	D2.10_1 Radio connected Object Controller able to be distributed and installed on trackside D2.10_2 Energy generation and harvesting for wayside OC
	TD2.11 Cyber-security	BB2.11_1 Definition of a security system dedicated to railway BB2.11_2 Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection	→	D2.11_1 Development of a cyber security system for railway D2.11_2 Generic protection profiles dedicated to railways and guidelines for implementing security-by-design in the railway sector D2.11_3 Build up a network for providing common cyber security approach also in degraded and emergency situations

Figure 14 / ***IP2 building blocks (BBs) and deliverables associated with IP2 technology demonstrators (TDs)***

These IP2 technological building blocks can be mapped to the capabilities they contribute to, as shown in Figure 15.

IP2	TD2.1 Adaptable communications for all Railways	TD2.2 Railway network capacity increase (ATO up to GoA4 – UTO)	TD2.3 Moving block enablers	TD2.4 Fail-Safe Train Positioning (including satellite technology)	TD2.5 On-board Train Integrity	TD2.6 Zero On-site Testing	TD2.7 Formal methods and standardisation for smart signalling systems	TD2.8 Virtually Coupled Train Sets (VCTS)	TD2.9 Traffic Management Evolution	TD2.10 Smart radio-connected all-in-all wayside objects	TD2.11 Cyber-security
1. Automated train operation	BB2.1_1 BB2.1_2 BB2.1_3	BB2.2_1 BB2.2_2	BB2.3_1 BB2.3_2	BB2.4_1 BB2.4_2 BB2.4_3	BB2.5_1 BB2.5_2			BB2.8_1 BB2.8_2 BB2.8_3	BB2.9_1 BB2.9_2 BB2.9_3	BB2.10_1 BB2.10_2 BB2.10_3 BB2.10_4	BB2.11_1 BB2.11_2
2. Mobility as a Service									BB2.9_1 BB2.9_2 BB2.9_3		
3. Logistics on demand		BB2.2_1 BB2.2_2						BB2.8_1 BB2.8_2 BB2.8_3	BB2.9_1 BB2.9_2 BB2.9_3		
4. More value from data	BB2.1_1 BB2.1_2 BB2.1_3								BB2.9_1 BB2.9_2 BB2.9_3		BB2.11_1
5. Optimum energy use		BB2.2_1 BB2.2_2							BB2.9_1 BB2.9_2 BB2.9_3		
6. Service operation timed to the second	BB2.1_1 BB2.1_2 BB2.1_3	BB2.2_1 BB2.2_2	BB2.3_1 BB2.3_2	BB2.4_1 BB2.4_2 BB2.4_3	BB2.5_1 BB2.5_2			BB2.8_1 BB2.8_2 BB2.8_3	BB2.9_1 BB2.9_2 BB2.9_3	BB2.10_1 BB2.10_2 BB2.10_3 BB2.10_4	
7. Low cost railway	BB2.1_1 BB2.1_2 BB2.1_3	BB2.2_1 BB2.2_2	BB2.3_1 BB2.3_2	BB2.4_1 BB2.4_2 BB2.4_3	BB2.5_1 BB2.5_2	BB2.6_1 BB2.6_2 BB2.6_3	BB2.7_1 BB2.7_2	BB2.8_1 BB2.8_2 BB2.8_3	BB2.9_1 BB2.9_2 BB2.9_3	BB2.10_1 BB2.10_4	BB2.11_1 BB2.11_2
8. Guaranteed asset health and availability	BB2.1_1 BB2.1_2 BB2.1_3								BB2.9_1 BB2.9_2 BB2.9_3	BB2.10_1 BB2.10_2 BB2.10_4	BB2.11_1 BB2.11_2
9. Intelligent trains	BB2.1_1 BB2.1_2 BB2.1_3	BB2.2_1 BB2.2_2	BB2.3_1 BB2.3_2	BB2.4_1 BB2.4_2 BB2.4_3	BB2.5_1 BB2.5_2			BB2.8_1 BB2.8_2 BB2.8_3	BB2.9_1 BB2.9_2 BB2.9_3	BB2.10_1 BB2.10_2 BB2.10_3	BB2.11_1 BB2.11_2
10. Stations and smart city mobility	BB2.1_1 BB2.1_2 BB2.1_3										BB2.11_1 BB2.11_2
11. Environmen-tal and social sustainability											
12. Rapid and reliable R&D delivery						BB2.6_1 BB2.6_2 BB2.6_3	BB2.7_1 BB2.7_2				

Figure 15 / ***Alignment of IP2 building blocks (BBs) with capabilities***

As an example, the matrix depicted in Figure 15 shows that achieving Capability 1 (automated train operation) requires contribution from most of the IP2 TDs.

- TD2.2: the development of automated train operation towards a high degree of automation acts as the basis for further enhancements, such as automated train preparation and self-controlled trains.
- TD2.3: moving block is a fundamental operational characteristic required for any future improvement of line capacity and the achievement of flexible services based on trains running closer together.
- TD2.4: fail-safe train positioning, which includes Global Navigation Satellite System (GNSS) technologies, is a key intermediate technology for any evolution towards new train operational concepts.
- TD2.5: on-board train integrity is essential for implementing any operational system based on train self-localisation while reducing the need for trackside train detection systems (e.g. track circuits or axle counters).
- TD2.8: virtual coupling aims to check the real feasibility of having trains running closer within their absolute braking distance. It is categorically the key TD to enable a move towards a new paradigm in railway systems.
- TD2.9: the contribution of traffic management is deemed essential for further improvements in terms of new functions as it will be needed for the application of the new operational concepts.
- TD2.10 paves the way for the introduction of train-to-wayside direct communications as a facilitator of a future train-centric system.
- Automation implies improvements to communications (TD2.1) and security (TD2.11).

IP3_Cost-efficient, sustainable and reliable high-capacity infrastructure

Figure 16 summarises the building blocks associated with the various TDs planned as part of IP3 and their related deliverables.

IP3	TD3.1 Enhanced Switch & Crossing System Demonstrator	BB3.1.1 Enhanced S&C whole system modelling, simulation and design BB3.1.2 Enhanced S&C design incl. materials and components BB3.1.3 Enhanced control, monitoring and sensors systems	→	D3.1_1 On-track full scale test and assessment of S&C system and sub-system improvements
	TD3.2 Next Generation Switch & Crossing System Demonstrator	BB3.2_1 Enhanced materials for optimised asset lifecycle costs BB3.2_2 Intelligent self-diagnostics systems with embedded RCM BB3.2_3 Nano-technologies for self-healing/ lubricating materials BB3.2_4 Alternative vehicle guidance techniques	→	D3.2_1 Small scale prototype and virtual testing D3.2_2 Full scale prototype and virtual testing
	TD3.3 Optimised Track System	BB3.3_1 Improved efficiency of product development, virtual testing and certification BB3.3_2 Detailed understanding and qualification of track deterioration BB3.3_3 Enhanced maintenance technologies and methods BB3.3_4 Tailored materials and solutions for track components	→	D3.3_1 Implementation of optimised track system demonstrators
	TD3.4 Next Generation Track System	BB3.4_1 Predictive models integrated with measured operational data BB3.4_2 Seamlessly integrated monitoring concepts BB3.4_3 Large scale introduction of optimised and sustainable materials BB3.4_4 High performance noise and vibration isolation systems	→	D3.4_1 Implementation of next generation track system demonstrators
	TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade Demonstrator	BB3.5_1 Enhanced bridge and tunnel inspection, and improvements BB3.5_2 Enhanced tunnel repair to extend extended life at reduced costs BB3.5_3 Prolonged bridge service life BB3.5_4 Bridge dynamics	→	D3.5_1 Prolonged service life of bridges and tunnels with reduced need for traffic disrruption D3.5_2 New approaches for bridge dynamics design methods
	TD3.6 Dynamic Railway Information Management System (DRIMS) Demonstrator	BB3.6_1 DRIMS IT architecture BB3.6_2 DRIMS data mining and analytics	→	D3.6_1 DRIMS demonstrator
	TD3.7 Railway Integrated Measuring and Monitoring System (RIMMS) Demonstrator	BB3.7_1 RIMMS tracks BB3.7_2 RIMMS switches & crossings BB3.7_3 RIMMS signalling BB3.7_4 RIMMS operations	→	D3.7_1 RIMMS demonstrator
	TD3.8 Intelligent Asset Management Strategies (IAMS)	BB3.8_1 Risk and asset management based strategy BB3.8_2 Decision support tools BB3.8_3 Clever and smart maintenance BB3.8_4 Work methods and automated tools	→	D3.8_1 IAMS demonstrator
	TD3.9 Smart Power Supply Demonstrator	BB3.9_1 Smart control and protection system BB3.9_2 Virtual demonstration of smart 50Hz substation	→	D3.9_1 Smart power supply demonstrator
	TD3.10 Smart Metering for Railway Distributed Energy Resource Management System Demonstrator	BB3.10_1 Smart Electrical Monitoring	→	D3.10_1 Smart metering for railway distributed energy resource management system demonstrator
	TD3.11 Future Stations Demonstrator	BB3.11_1 Crowd management in high capacity stations BB3.11_2 Improved station designs and components BB3.11_3 Improved accessibility to train-platform interface BB3.11_4 Safety management in public areas	→	D3.11_1 Large scale experiment Liverpool st. station D3.11_2 Improved small stations demonstrator D3.11_3 New approaches for platform-train interface design methods D3.11_4 Technical manual of options and associated benefits/limitations for safety management

Figure 16 / ***IP3 building blocks (BBs) and deliverables associated with IP3 technology demonstrators (TDs)***

These IP3 technological building blocks can be mapped to the capabilities they contribute to, as shown in Figure 17.

IP3	TD3.1 Enhanced Switch & Crossing System Demonstrator	TD3.2 Next Generation Switch & Crossing System Demonstrator	TD3.3 Optimised Track System	TD3.4 Next Generation Track System	TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade Demonstrator	TD3.6 Dynamic Railway Information Management System (DRIMS) Demonstrator	TD3.7 Railway Integrated Measuring and Monitoring System (RIMMS) Demonstrator	TD3.8 Intelligent Asset Management Strategies (IAMS)	TD3.9 Smart Power Supply Demonstrator	TD3.10 Smart Metering for Railway Distributed Energy Resource Management System Demonstrator	TD3.11 Future Stations Demonstrator
1. Automated train operation		BB3.2_4		BB3.4_1 BB3.4_2			BB3.7_4	BB3.8_2 BB3.8_3 BB3.8_4			
2. Mobility as a Service											BB3.11_1 BB3.11_2 BB3.11_3 BB3.11_4
3. Logistics on demand								BB3.8_2 BB3.8_3			
4. More value from data	BB3.1_1 BB3.1_3	BB3.1_1 BB3.2_2	BB3.3_2	BB3.4_1 BB3.4_2	BB3.5_1	BB3.6_2	BB3.7_1 BB3.7_2 BB3.7_3 BB3.7_4	BB3.8_2 BB3.8_3 BB3.8_4	BB3.9_1	BB3.10_1	BB3.11_1 BB3.11_2 BB3.11_4
5. Optimum energy use		BB3.2_1 BB3.2_2		BB3.4_3					BB3.9_1 BB3.9_2	BB3.10_1	BB3.11_2
6. Service operation timed to the second		BB3.2_2 BB3.2_3 BB3.2_4		BB3.4_1 BB3.4_2				BB3.8_1 BB3.8_2 BB3.8_3 BB3.8_4			
7. Low cost railway	BB3.1_1 BB3.1_2	BB3.2_1 BB3.2_2	BB3.3_1 BB3.3_2 BB3.3_3 BB3.3_4	BB3.4_2	BB3.5_1 BB3.5_2 BB3.5_3 BB3.5_4	BB3.6_1 BB3.6_2	BB3.7_1 BB3.7_2 BB3.7_3 BB3.7_4	BB3.8_1 BB3.8_2 BB3.8_3 BB3.8_4	BB3.9_1 BB3.9_2		BB3.11_2 BB3.11_3
8. Guaranteed asset health and availability	BB3.1_1 BB3.1_2 BB3.1_3	BB3.2_1 BB3.2_2 BB3.2_3 BB3.2_4	BB3.3_2 BB3.3_3 BB3.3_4	BB3.4_1 BB3.4_2	BB3.5_1 BB3.5_2 BB3.5_3	BB3.6_2	BB3.7_1 BB3.7_2 BB3.7_3	BB3.8_2 BB3.8_3 BB3.8_4			
9. Intelligent trains		BB3.2_2	BB3.3_2	BB3.4_1 BB3.4_2 BB3.4_3 BB3.4_4	BB3.5_1					BB3.10_1	
10. Stations and smart city mobility		BB3.2_1 BB3.2_2 BB3.2_3 BB3.2_4	BB3.3_1 BB3.3_2 BB3.3_3 BB3.3_4		BB3.5_1 BB3.5_2 BB3.5_3 BB3.5_4	BB3.6_1 BB3.6_2	BB3.7_1 BB3.7_2 BB3.7_3 BB3.7_4	BB3.8_1 BB3.8_2 BB3.8_3 BB3.8_4	BB3.9_1 BB3.9_2	BB3.10_1	BB3.11_2 BB3.11_3
11. Environmental and social sustainability	BB3.1_1 BB3.1_2 BB3.1_3	BB3.2_1 BB3.2_4	BB3.3_2 BB3.3_3 BB3.3_4		BB3.5_3 BB3.5_4 BB3.5_5			BB3.8_2	BB3.9_1	BB3.10_1	BB3.11_2
12. Rapid and reliable R&D delivery	BB3.1_1		BB3.3_2 BB3.3_3 BB3.3_4	BB3.4_1	BB3.5_1 BB3.5_2 BB3.5_3 BB3.5_4	BB3.6_1 BB3.6_2	BB3.7_1 BB3.7_2	BB3.8_2 BB3.8_3	BB3.9_1 BB3.9_2	BB3.10_1	

Figure 17 / ***Alignment of IP3 building blocks (BBs) with capabilities***

IP4_IT solutions for attractive railway services

The building blocks associated with the various TDs planned as part of IP4 and their related deliverables are summarised in Figure 18.

IP4	TD4.1 Interoperability framework	BB4.1_1 Reference Ontologies and resolvers BB4.1_2 Services registry BB4.1_3 Converter Tools BB4.1_4 Semantic discovery, query, aggregation Engines	→	D4.1_1 Package resolvers
	TD4.2 Train Travel Shopping	BB4.2_1 Travel shopping orchestrator BB4.2_2 Meta-Travel solution constructor BB4.2_3 Travel expert managers BB4.4_1 Collection of static data BB4.4_2 Collection of dynamic-data BB4.4_3 Real-time event processing BB4.6_1 Data management	→	D4.2_1 Integration of multi-modal shopping BBs
	TD4.3 Booking & ticketing	BB4.3 _1 Orchestration of ticketing mechanisms for multi-modal journeys BB4.3 _2 Operations of ticketing back-office including lifecycle of parameters BB4.3 _3 Validation of entitlements (e.g. card-centric, EMV)	→	D4.3_1 Integration of multi-modal booking and ticketing BBs
	TD4.4 Trip ticketing	BB4.1_1 Collection of static-data BB4.4_2 Collection of dynamic-data BB4.4_3 Real-time event processing	→	D4.4_1 Integration of trip-tracking mechanisms BBs
	TD4.5 Travel companion	BB4.5_1 Secured-cloud based platform (e.g. preferences) BB4.5 _2 Interaction through smart devices BB4.5 _3 Geo-navigation functions BB4.5 _4 Device tapping functions	→	D4.5_1 Integration of travel companion BBs
	TD4.6 Business Analytics Platform	BB4.6_1 Data management BB4.6_2 Descriptive and predictive analytics BB4.6_3 Visualisation	→	D4.6_1 Integration of Business Analytics features BBs
	TD4.7 Overall IP4 Coordination and demonstration		→	D4.7_1 IP4 Ecosystem Release D4.7_2 End-user centric ecosystem D4.7_3 Co-modal ecosystem demonstration D4.7_4 Large scale MaaS demonstration

*Figure 18 / **IP4 building blocks (BBs) and deliverables associated with IP4 technology demonstrators (TDs)***

These IP4 technological building blocks can be mapped to the capabilities they contribute to, as shown in Figure 19.

IP4	TD4.1 Interoperability framework	TD4.2 Train Travel Shopping	TD4.3 Booking & ticketing	TD4.4 Trip ticketing	TD4.5 Travel companion	TD4.6 Business Analytics Platform	TD4.7 Overall IP4 Coordination and demonstration
1. Automated train operation							
2. Mobility as a Service	BB4.1_1 BB4.1_2 BB4.1_3 BB4.1_4	BB4.2_1 BB4.2_2 BB4.2_3 BB4.4_1 BB4.4_2 BB4.4_3	BB4.3_1 BB4.3_2 BB4.3_3	BB4.4_1 BB4.4_2 BB4.4_3	BB4.5_1 BB4.5_2 BB4.5_3 BB4.5_4		Integrates all BBs for Capabilities 2
3. Logistics on demand							
4. More value from data	BB4.1_1 BB4.1_2 BB4.1_3 BB4.1_4	BB4.4_1 BB4.4_2 BB4.4_3 BB4.6_1		BB4.4_1 BB4.4_2 BB4.4_3	BB4.5_1 BB4.5_2 BB4.5_3 BB4.5_4	BB4.6_1 BB4.6_2 BB4.6_3	Integrates all BBs for Capabilities 4
5. Optimum energy use							
6. Service operation timed to the second							
7. Low cost railway							
8. Guaranteed asset health and availability							
9. Intelligent trains							
10. Stations and smart city mobility							Integrates all BBs for Capabilities 10
11. Environmental and social sustainability							
12. Rapid and reliable R&D delivery							

Figure 19 / ***Alignment of IP4 building blocks (BBs) with capabilities***

IP5_ Technologies for sustainable and attractive European rail freight

The building blocks associated with the seven TDs planned as part of IP5 and their related deliverables are summarised in Figure 20.

IP5	TD5.1 Fleet Digitalisation and Automation	BB 5.1.1 Condition-based maintenance BB 5.1.2 Automatic coupling BB 5.1.3 Freight ATO / C-DAS	→	D5.1_1 Freight ATO & electrification and telematics demonstrator
	TD5.2 Digital Transport Management	BB 5.2.1. Improved methods for time table planning BB 5.2.2. Real-time yard management & SWL system BB 5.2.3. Real-time network management BB 5.2.4. Intelligent Video Gate Terminals	→	D5.2_1 Freight OPS Managing / Marshalling Terminals, Hubs, Yards, Sidings demonstrator
	TD5.3 Smart Freight Wagon Concepts	BB 5.3.1. Running gear BB 5.3.2. Core market wagon BB 5.3.3. Extended market wagon BB 5.3.4. Telematics and Electrification	→	D5.3_1 Freight wagon design demonstrator
	TD5.4 New Freight Propulsion Concepts	BB 5.4.1. Last Mile propulsion systems BB 5.4.2. Long Trains up to 1500 m BB 5.4.3 Freight Loco of the future BB 5.4.4 Hybridisation of legacy shunters	→	D5.4_1 New freight propulsion concepts demonstrator
	TD5.5 Business analytics & Implementation strategies	BB5.5.1 Identification of market segments BB5.5.2 Development of KPI's BB5.5.3 Migration Plan	→	D5.5_1 Implementation strategies and business analytics

*Figure 20 / **IP5 building blocks (BBs) and deliverables associated with IP5 technology demonstrators (TDs)***

These IP5 technological building blocks can be mapped to the capabilities they contribute to, as shown in Figure 21.

IP5	TD5.1 Fleet Digitalisation and Automation	TD5.2 Digital Transport Management	TD5.3 Smart Freight Wagon Concepts	TD5.4 New Freight Propulsion Concepts	TD5.5 Business analytics & Implementation strategies
1. Automated train operation	BB5.1_2 BB5.1_3	BB5.2_1 BB5.2_2 BB5.2_3 BB5.2_4			
2. Mobility as a Service					
3. Logistics on demand	BB5.1_2 BB5.1_3	BB5.2_1 BB5.2_2 BB5.2_3 BB5.2_4	BB5.3_1 BB5.3_2 BB5.3_3 BB5.3_4	BB5.4_1 BB5.4_2 BB5.4_3 BB5.4_4	BB5.5_1 BB5.5_3
4. More value from data	BB5.1_1 BB5.1_3	BB5.2_2 BB5.2_3 BB5.2_4	BB5.3_2 BB5.3_3 BB5.3_4		BB5.5_1 BB5.5_2
5. Optimum energy use	BB5.1_2 BB5.1_3	BB5.2_1 BB5.2_2 BB5.2_3 BB5.2_4		BB5.4_1 BB5.4_3 BB5.4_4	
6. Service operation timed to the second	BB5.1_1 BB5.1_2 BB5.1_3	BB5.2_1 BB5.2_3	BB5.3_2 BB5.3_3 BB5.3_4		
7. Low cost railway	BB5.1_3		BB5.3_1 BB5.3_2 BB5.3_3	BB5.4_1 BB5.4_4	BB5.5_1
8. Guaranteed asset health and availability	BB5.1_1 BB5.1_3		BB5.3_4		BB5.5_3
9. Intelligent trains	BB5.1_3		BB5.3_2 BB5.3_3 BB5.3_4	BB5.4_2 BB5.4_3 BB5.1_3	
10. Stations and smart city mobility	BB5.1_2 BB5.1_3	BB5.2_2 BB5.2_3 BB5.2_4	BB5.3_4		
11. Environmental and social sustainability				BB5.4_1 BB5.4_2 BB5.4_3	
12. Rapid and reliable R&D delivery					

Figure 21 / ***Alignment of IP5 building blocks (BBs) with capabilities***

CCA_ Cross-cutting activities

The building blocks associated with the 11 work activities (WAs) planned as part of CCAs and their related deliverables are summarised in Figure 22.

CCA	WA1 Socio-economic	BBA1_1 Societal needs analysis BBA1_2 Influences to 2022, 2030, 2040 from Mega-Trends, Scenarios, Disruptions, Key Factors BBA1_3 Societal development by transportation BBA1_4 Key success factors for a successful railway system. Perceptions, Mobility patterns BBA1_5 Rail Transport Governance BBA1_6 Shift2Rail Societal Effects BBA1_7 Rail as a design tool in societal development BBA1_8 SPD use case and scenario specification, application, result, analysis and wider effects	→	DA.1_1 Options/possibilities for an improved railway system based on a structured requirement and obstacle list related to customer experience (passenger) DA.1_2 Strategic input for future business models for the railway system based on scenario analysis DA.1_3 Specifications of SPDs to be used to show effects of S2R innovation for all four use cases DA.1_4 Definition and delimitation of societal objectives of relevance for the railway sector and the individual use cases
	WA2 KPI method development and integrated assessment	BBA2_1 Reference scenario BBA2_2 Sub-system structure BBA2_3 Sub-level KPIs BBA2_4 Tool specification and development BBA2_5 Validation of the KPI model	→	DA.2_1 An initial KPI model that shows qualitatively the TDs' and IPs' influences on the top level Shift2Rail targets
	WA3.1 Safety	BBA3.1_1 Management of a safety level according to the risk assessment model BBA3.1_2 Quantification of safety improvements by using a risk assessment model	→	DA.3.2_1 Global risk assessment model
	WA3.2 Standardisation	BBA3.2_1 Strategic analysis of the S2R activities in terms of standardisation and regulation BBA3.2_2 Definition of the S2R organisation managing standardisation and regulation BBA3.2_3 Benchmark of existing organisation and processes towards innovative standardisation BBA3.2_4 S2R internal standardisation processes BBA3.2_5 Transfer of the S2R inputs to standards	→	DA.3.2_1 Management of S2R results and regulation
	WA3.3 Smart Maintenance	BBA3.3_1 Scope definition and CBM maintenance concepts BBA3.3_2 Data selection, Data analysis and pattern recognition BBA3.3_3 Conclusion for maintenance and Integration into maintenance process BBA3.3_4 Information identification, share monitoring data and standardisation	→	DA.3.3_1 Common condition based maintenance concept for infrastructure and rolling stock
	WA3.4 Smart Materials	N/A*	→	
	WA3.5 Virtual certification enablers	BBA3.5_1 Development of generic methods and process BBA3.5_2 Overview of the generic methods and process	→	N/A
	WA4.1 Smart mobility	BBA4.1_1 Simulation tool	→	DA4.1_1 Summary of analysed disruption types DA4.1_2 Description of enhanced model prototype
	WA4.2 Integrated Mobility Management (I2M)	BBA4.2_1 Technical assessment and integration BBA4.2_2 Upgrade of integration layer BBA4.2_3 TMS application supporting high efficient Freight Operations BBA4.2_4 Advanced rules and business logic supporting high efficient freight operations BBA4.2_5 Advanced rules and business logic supporting high efficiency passenger operations BBA4.2_6 Plug-ins to enable integration of services	→	DA4.2_1 Demonstrator
	WA5.1 Energy	BBA5.1_1 Interface with other S2R Groups and External Energy Groups BBA5.1_2 Energy calculation methodology BBA5.1_3 Assessment of energy improvement	→	DA5.1_1 Development of a common energy calculation methodology DA5.1_2 First estimate of energy saving due to Shift2Rail innovations

	WA5.2 Noise and vibration	BBA5.2_1 Technical assessment and integration on system level of N&V tasks BBA5.2_2 Evaluation and monitoring of impact on traffic noise scenarios of Shift2Rail innovations BBA5.2_3 Exterior noise simulation model and separation technique BBA5.2_4 Interior noise simulation model BBA5.2_5 Ground Borne Vibration Prediction Methods BBA5.2_6 Sources and subassemblies characterisation methodologies BBA5.2_7 New methodologies and technologies	→	DA5.2_1 Exterior noise simulation model DA5.2_2 Interior noise simulation model D5A.2_3 Ground-borne Vibration Prediction Methods DA5.2_4 Sources and subassemblies characterisation methodologies
	WA6 Human Capital	BBA6_1 Change of job profiles BBA6_2 Qualifications and skills BBA6_3 Creating agile organisations for increased flexibility & autonomy for blue collar workers BBA6_4 Customer-oriented design of mobility	→	DA6_1 Identification of all relevant stakeholders on the human capital side DA6_2 Required changes and respective actions for an adequately qualified labour force in the various railway staff categories DA6_3 Recommendations to tackle the impact and risks (e.g. occupational health, employee motivation) induced by changes in the work of the employees DA6_4 Options for journeys with simplified/ reduced customer activities (passenger) to improve customer experience
* Related activites are carried out in dedicated Ips				

Figure 22 / ***CCA building blocks (BBs) and associated deliverables***

These CCA building blocks can be mapped to the capabilities they contribute to, as shown in Figure 23.

CCA	WA1 Socio-economic	WA2 KPI method development and integrated assessment	WA3.1 Safety	WA3.2 Standardisation	WA3.3 Smart Maintenance	WA3.4 Smart Materials	WA3.5 Virtual certification enablers	WA4.1 Smart mobility	WA4.2 Integrated Mobility Management (I2M)	WA5.1 Energy	WA5.2 Noise and vibration	WA6 Human Capital
1. Automated train operation	All eight BBs cover all twelve capabilities	All five BBs cover all twelve capabilities	all BB3.1	All BB3.2	All BB3.3	Related activites are carried out in dedicated Ips	All BB3.5	All BB4.1	BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-6	All BB5.1		All eight BBs cover all twelve capabilities
2. Mobility as a Service									BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6			
3. Logistics on demand				All BB3.2				All BB4.1	BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-6			
4. More value from data				All BB3.2	All BB3.3		All BB3.5		BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6	All BB5.1		
5. Optimum energy use				All BB3.2		Related activites are carried out in dedicated Ips			BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-6	All BB5.1		
6. Service operation timed to the second				All BB3.2				All BB4.1	BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6	All BB5.1	BBA5.2_3 BBA5.2_5	
7. Low cost railway				All BB3.2		Related activites are carried out in dedicated Ips	All BB3.5		BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6	All BB5.1	BBA5.2_2 BBA5.2_7	
8. Guaranteed asset health and availability			BBA3.1_1		All BB3.3				BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6			

9. Intelligent trains	All eight BBs cover all twelve capabilities			All BB3.2	All BB3.3	Related activites are carried out in dedicated IPs			BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-6	All BB5.1		All four BBs cover all twelve capabilities
10. Stations and smart city mobility						Related activites are carried out in dedicated IPs		All BB4.1	BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6			
11. Environmental and social sustainability							All BB3.5		BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6	All BB5.1	All BB5.2	
12. Rapid and reliable R&D delivery					All BB3.3	Related activites are carried out in dedicated IPs	All BB3.5		BBA.4.2-1 BBA.4.2-2 BBA.4.2-3 BBA.4.2-4 BBA.4.2-5 BBA.4.2-6	All BB5.1	All BB5.2	

Figure 23 / ***Alignment of CCA of building blocks (BBs) with capabilities***

6. Deployment

Bringing about the technological and operational advances expected as a result of the S2R R&I activities will require active intervention. It will not happen by itself. Deployment of this complex array of innovations will involve a coordinated effort to guarantee an adequate level of consistency and achieve the SERA. This requirement for active intervention implies a need for an understanding of the steps required in the process, of funding needs and of the essential system-of-systems interaction and complexity of the railway, in all its segments and components. Those undertaking this active role should be as near as possible to the market while retaining the necessary independence under joint governance.

Joint and coordinated deployment is predicated on a sound appreciation of the business case for change, at both corporate and societal levels, the requirements associated with standardisation and regulation, the timescales relating to opportunities for the insertion into the railway of new technical solutions, and a professional approach to risk management. As successful deployment will depend on interfaces with a range of organisations beyond the railway, a collaboration strategy at European level is also required.

6.1. The business view

The economic benefits of delivering the S2R Programme targets have been identified in the impact assessment of the S2R JU proposal ([17]):

- indirect leverage on industry R&I related to the development of industrial products exploiting Horizon 2020 (H2020) innovations worth up to EUR 9 billion in the period 2017–2023;
- the creation of additional gross domestic product at EU level of up to EUR 49 billion in the period 2015–2030, distributed among a large number of Member States;
- the creation of up to 140 000 additional jobs in the period 2015–2030;
- additional exports worth up to EUR 20 billion in the period 2015–2030 thanks to the worldwide commercialisation of new rail technologies developed under H2020;

([17]) Impact assessment accompanying the document *Proposal for a Council Regulation establishing the Shift2Rail Joint Undertaking*, SWD(2013) 535 final, Brussels, 16.12.2013.

- life-cycle cost savings of around EUR 1 billion in the first 10 years and thereafter, with continued implementation, of around EUR 150 million per year.

Methodology for a societal business case

The Union's resources are limited. Goods and services are scarce resources, time is short, and good health and a clean environment require resources. Citizens' and businesses' needs and wishes, meanwhile, are substantial in many regards. Therefore, both society and the individual must always make choices about how to use resources best, even when the choosing any given option will have many effects that are uncertain and when the cost cannot be established with certainty in advance'. The method used to make socioeconomic profitability assessments is socioeconomic analysis, also known as cost–benefit analysis (CBA).

These assessments are of course relevant for the European rail sector. By looking at the overall effects of changes in the rail system, the true benefits can be analysed and determined. For S2R, this is a cornerstone of the approach to deciding what are the best measures and projects to meet societal expectations of the future rail system.

To do this, a systematic approach is necessary. The model used is socioeconomic analysis. The profitability calculation carried out when performing this type of analysis is a summary of the costs and revenue generated by an activity or project. The calculation estimates the net value of the resources produced/created (revenue) and the resources consumed/used (costs) and thus the net change in total assets contributed by the activity/project in question. 'Resources' means goods, services and other types of tangible and intangible assets, i.e. all that can be used for consumption or production. A business profitability calculation or private finance or government finance calculation aims to assess the net value of the economic effects on a company, organisation or individual. A socioeconomic profitability calculation, on the other hand, aims to calculate the total net worth of all economic effects for all citizens in society.

CBA uses methods for evaluating resources and benefits that are not market-prone, which a business economics calculation methodology does not use; in addition, socioeconomic analysis includes effects for all citizens, not just the effects for the organisation in question.

A socioeconomic profitability calculation includes all the positive and negative resource and utility effects of a measure, both direct and indirect. All effects on real resources should be included in the calculation, whether they are market-priced or not. For the effects that are not priced, a valuation in money using estimated values, so-called shadow prices, can be made. The result that a socioeconomic calculation shows is the net contribution of an activity or project to the value of society's total real resource.

The analysis and results can be designed to show how the economic impact and net results are distributed across different sectors of society, regions and/or citizenship groups, for example genders, age groups or socioeconomic groups. However, in traditional CBA, no valuation of distribution effects is made. What distribution effects can be considered more or less desirable is basically a political issue. These types of analyses and value judgements are therefore usually made in addition to the socioeconomic analysis.

Socioeconomic profitability assessments are carried out to determine if a measure is good for society or not, or to assess which measure is best among several possible ones. However, when using words such as 'good' and 'best' in this context, it is important to be aware of the principles and conditions that are the basis for the analysis.

Socioeconomic efficiency means that we have efficiency in production, that is to say, we produce the products that are most in demand from consumers and that production is at the lowest possible cost. Thus, socioeconomic efficiency requires that all that is produced has a value for the buyers/users at least equal to the cost of producing and providing it. Socioeconomic efficiency also means efficiency in consumption, i.e. the goods produced are consumed by people who ask for them the most.

Total socioeconomic efficiency means that society's resources, in terms of goods and services, natural resources and the environment, time and energy, etc., are used in such a way that the total value of the total resources is as large as possible from the citizens' point of view. This means that the citizens' combined benefits from society's total resources should be as great as possible, both today and in the future. Socially profitable measures contribute to socioeconomic efficiency, provided that we choose only profitable measures or, if options are limited, the measures that are most economically viable.

Socioeconomic analysis must take into account both the direct and the indirect effects of the measure being evaluated, while avoiding double counting. The direct and indirect effects can also be described as primary and secondary effects. The primary effects are effects on individuals, companies and organisations, and parts of the public sector directly affected by the options to be evaluated. The secondary effects are those that arise as a consequence of direct price, production and consumption changes.

CBA should also include the secondary effects of the evaluated measure. These effects consist of effects on secondary markets, i.e. markets other than those initially affected by the measure (primary markets). If the measure has significant effects on the main market, significant effects may also arise for partners, competitors and subcontractors.

6.2. Standards and regulatory needs

'The innovation principle entails taking into account the impact on research and innovation in the process of developing and reviewing regulation in all policy domains, i.a. to ensure that EU regulation allows companies to enter markets more easily' ([18]).

With this in mind, standards and standardisation have been highlighted in the Europe 2020 strategy as pivotal in supporting the EU's R&I activities, in reaffirming the important role of standards for innovation as sources of competitiveness and in underpinning smart, sustainable and inclusive growth.

In general, standardisation is sought at EU level for the rail sector because it helps to:

- eliminate technical barriers to trade and increase market access for all operators;
- ensure interoperability and reduce the risk of becoming locked in to proprietary solutions;
- create certainty and confidence for users looking to adopt new technologies.

S2R focuses on innovation that will take place only if R&I, industrialisation and wide market uptake are combined. Therefore, the solutions that will be developed have to be highly interoperable and provide the required level of standardisation for long-term, easy and cost-efficient operation and maintenance of the railway system.

A high level of standardisation is needed at the interfaces of the internal constituents of the subsystems that S2R targets through its different TDs to produce the expected system results, including procedures to implement innovatory upgrades throughout a product's life, as a means of adapting to technological obsolescence or meeting the final customer's changing needs. This will be needed, for example, at the interfaces between the on-board train control and monitoring system and the connected train functions such as traction, door control and brakes.

Careful management of the functional interactions of the different layers of the railway system, from subsystem constituents up to the structural and non-structural subsystems,

([18]) COM(2017) 479 final, Brussels, 13.9.2017.

is therefore a condition that must be met to achieve significant progress on the operational reliability of the overall railway system.

Within the intricate European railway system, no change can be made to a subsystem without carefully checking the potential consequences for other stakeholders and, in many cases, without making changes to the European railway's body of established standards and regulations.

The very ambitious research results expected from S2R will need the agreement of the whole sector, starting with the identification of operational and maintenance constraints on innovation and continuing throughout the whole programme. Consensus building will take the form of a collective appraisal of the results, leading to the specification of new voluntary interface standards and, in some cases, changes to standards and regulations belonging to the European railways interoperability directive.

For these reasons, S2R is working closely with the standardisation bodies in Europe and with the European Union Agency for Railways (ERA) and actively contributing to the Rail Standardisation Coordination Platform for Europe, created by the European Commission's Directorate-General for Mobility and Transport.

In addition, S2R is making use of its User Requirements Working Group and Implementation and Deployment Working Group to reach out to a wide range of partners able to represent all the actors in the marketplace, and not just those who will be direct contributors to the S2R R&I activities.

The benefits of the envisaged integration of standardisation aspects into the R&I process are numerous ([19]) and have been explored in past research projects; they include:

- making the results available to a wide range of stakeholders, and offering opportunities to discuss, disseminate and promote project outcomes;
- helping to ensure that the project results are used well beyond the duration of the project;
- acting as a powerful tool for bringing research and new technologies to the market.

However, while timely and well-designed standards can support innovation, premature, late or inappropriate standards may have detrimental impacts on innovation. Therefore, the overall S2R Programme benefits from a standards-focused harmonisation process across all its projects, and an overall S2R standardisation roadmap is being developed.

6.3. Risk management

A standard assessment approach is followed for the systematic capture, analysis and mitigation of risks associated with the current S2R JU R&I programme. A risk is understood as an undesired event or series of events that reduces confidence in the MAAP and which, if it were to take place, might represent an obstacle to delivering the timely, coordinated and efficient deployment of the planned activities. Risk management is an activity requiring regular attention and periodic updates to ensure that the monitoring procedures are working correctly. The annual activity report to the S2R Board contains such periodic risks updates.

([19]) Blind, K., *The impact of standardization and standards on innovation*, Manchester Institute of Innovation Research, Manchester, February 2013; The European Committee for Standardization and the European Committee for Electrotechnical Standardization (CEN-CENELEC), *How to link standardization with EU research projects: advice for CEN and CENELEC Members*, CEN-CENELEC, Brussels, 2013.

The S2R risk registry is updated at the end of each year. In the registry, risks are categorised according to their relevance, and descriptions of appropriate mitigation plans, aimed at reducing or eradicating the potential effects of any given risk, are provided.

Table 2 indicates the main risks associated with the S2R Programme activities and the financial administration of the JU, as well as the corresponding risk mitigation actions. It results from a risk management exercise performed within the JU during Q2 and Q3 2017.

Table 2 / ***Results of the SR2 risk management exercise performed in 2017***

RISK IDENTIFIED	ACTION PLAN
Inadequacy of the MAAP to meet the evolving needs of users and stakeholders' expectations	During 2017, a revised version of Parts 1 and 2 (now called Part A) of the MAAP will be finalised and Part 3 (now called Part B) updated, taking into consideration the new top-down approach
In accordance with the H2020 rules of participation, and considering the resources available on a yearly basis, the programme must be implemented through projects financed by annual grants. This may result in a piecemeal approach instead of innovative solutions towards a new integrated, connected and automated railway system. This may result in questioning of the sound financial management of the implementation process through grants, especially with regards to Members selected through open competition and commitment	Qualitative mitigating measures are to be identified and implemented to contain and monitor the identified risks. This is to be realised through the Governing Board (GB), System Integration Working Group (SIWG), and IP steering committees (SteCos), which maintain a programme view rather than a piecemeal project view. During 2017, the sound financial management risks will be further assessed and any appropriate measures identified implemented accordingly
Delays or inadequacies in the completion of activities funded by grants that are complementary or are prerequisites for grants to be awarded under the Annual Work Plan (AWP) 2018 may result in an inability to implement activities under the AWP 2018	Ensure through programme management regular activity monitoring and reporting on projects, including gate reviews, to determine whether specific actions need to be taken with regard to a specific project (reorientation, early closure, etc.)
Cross-project collaboration to achieve the programme objectives could be at risk because of silo projects or IP approaches	To be addressed through significant involvement of the SIWG, decoupling the IP structure from AWP topics, and further fostering use of the common S2R cooperation tool and sharing functionalities
S2R JU Members fail to deliver on additional activities	An additional activities plan is contained in the membership agreement. Work with the Members on preparation and implementation of the certification and reporting requirements is to be carried out
Lack of adequate dissemination of results may result in vague information to the end user/interested parties and could compromise the JU's impact	The JU is working towards a joint dissemination plan, monitoring dissemination actions and promoting project results
There is a risk of the projects underspending the resources available	Together with the other Members, the JU has put in place reporting and monitoring systems that should detect any risk of underspending and make it possible to take the necessary corrective measures
TDs may not be achieved or may be only partially achieved because of lack of resources (staff, money, assets etc.); members' changing priorities, members merging or stepping out; insufficient or late delivery/ input from the projects	To be addressed through proper planning and regular follow up by the SteCos/SIWG, plus project control gates and regular reporting to the GB
Demonstrations may not be interoperable because they represent a single-company solution	To be addressed through a collaborative approach under the Grant Agreement (GA), plus project control gates and regular reporting to the GB

RISK IDENTIFIED	ACTION PLAN
Project development may not be aligned with the S2R Programme	To be addressed through a programme perspective in the GA, plus regular follow-up by the SteCos/SIWG and regular reporting to the GB
Operational demonstrations may not be achieved or may be only partially achieved because of difficulties in obtaining authorisations	To be addressed through anticipation and regular follow-up by SteCos/SIWG, plus ERA involvement and regular reporting to the GB
S2R solutions may not reach the market owing to a lack of coordination and resources at deployment level	Investigate a possible instrument to support deployment at EU level and implement JU strategy/ support
Stakeholders' (including Members') acceptance of S2R solutions may be partial or limited	Decision made on a consensus-based approach in SteCos/SIWG/GB, plus involvement of the User Requirements Working Group and the Implementation and Deployment Working Group (How are S2R solutions accepted? Develop strategy)
There could be a significant cut in the EU budget	The JU Membership will put in place all measures required to provide all the elements to the budgetary authority to reduce such a risk
Governance: organisational complexity may impact the S2R JU's global objectives	On the one hand, the S2R JU will focus on delivering the programme results and, on the other hand, it will assess and put in place measures to make its governance more effective and efficient
High turnover of staff and insufficient number and/or quality of applications owing to contract conditions	Within the budget constraints, prepare a career plan for staff; ensure business continuity
Lack of back-up for JU key functions	Put in place replacement plan (back-up) where possible, including through external support (interim, expert, outsourcing)

6.4. Strategy for collaboration with other organisations

In order to achieve its programme and the task of managing 'all rail-focused research and innovation actions co-funded by the Union' ([20]), the S2R JU is working closely with the European Commission's Directorate-General for Mobility and Transport, as well as the Directorate-General for Research and Innovation, ERA, the European GNSS Agency and other Union bodies and agencies.

The relationship between the S2R JU and the Commission is established in the S2R regulation, as well as in the relevant delegation agreement, and it involves daily exchanges covering all aspects of the S2R Programme and railway transport policy.

With particular regard to ERA, the S2R JU should 'bring in the experience and expertise of ERA on issues relating to interoperability and safety' through different measures of cooperation. In a similar manner, the relationship between ERA and the S2R JU is to be interpreted in the light of the JU's role of managing 'all rail-focused research and innovation actions co-funded by the Union' ([21]).

In order to ensure that the results from the S2R projects do not encounter regulatory blocking points because of their novelty (as far as safety and interoperability are concerned, mainly in relation to compliance with the rail Technical Specification for Interoperability), the S2R JU has established with ERA and the Directorate-General for Mobility and Transport a process for collaboration at project level.

([20]) Council Regulation (EU) No 642/2014 of 16 June 2014 establishing the Shift2Rail Joint Undertaking

([21]) Article 2(i) of the S2R statutes annexed to the S2R regulation.

In order to maintain good relations with different users of or entities involved with the railway system, the S2R JU has established two main working groups.

- The User Requirements Working Group is composed of S2R JU members and non-members and assists the JU in ensuring that technical solutions developed as part of S2R meet the specific needs of all relevant end users.

- The Implementation and Deployment Working Group is composed of S2R JU members and non-members and tests the operational reliability of the results of S2R, thus contributing to more rapid uptake and large-scale deployment of the solutions developed through S2R activities.

These two working groups have been clustered together for the time being as the User Requirements and Implementation and Deployment Working Group.

In addition, the S2R JU maintains bilateral relations with various rail sector stakeholders and their representatives (the Association of the European Rail Manufacturing Industry, the International Union of Railways, the International Association of Public Transport, the Community of European Railway and Infrastructure Companies, the International Union for Road–Rail Combined Transport, the European Committee for Standardization and the European Committee for Electrotechnical Standardization, the European Telecommunications Standards Institute, etc.).

7. A maintained vision of the railway

The acceleration in new technologies produced by different branches of science, building upon experiences in different sectors, requires that the MAAP is regularly updated and maintained, without losing focus on delivering results for passengers and freight business. The MAAP is regularly updated and maintained taking into account contributions from the stakeholders of the railway value chain, within the S2R JU membership and beyond. It is expected that the present document will be subject to review as the Horizon 2020 programme draws to a close; by then, the initial results of S2R will have been demonstrated, and they will pave the way for the deployment of the available innovative solutions. In addition to the R&I activities planned to take place 2020, a critical area of the MAAP will be the creation of a more specific deployment strategy as part of an overall system architecture supported by quantified business cases. The market uptake and deployment of the S2R innovative solutions will be essential to delivering the railway system of the future as the backbone of connected intermodal sustainable mobility for passengers and goods.

MULTI-ANNUAL ACTION PLAN

PART B

Technical content

Multi-Annual Action Plan, Part B, Technical content adopted by the Shift2Rail JU Governing Board on 14 November 2019

There is a need to maintain the original MAAP adopted by the S2R JU Governing Board on 27 November 2015 as reference document in cases of doubts with regard, for example, type of assets that the Members other than the Union committed to provide for demonstration activities.

Contents

Abbreviations

3D	three-dimensional
AC	alternating current
AI	artificial intelligence
ATO	automated train operation
ATO-OB	onboard ATO system
ATO-TS	trackside ATO system
AWP	annual work plan
CAE	computer-aided engineering
CAPEX	capital expenditure
CBA	cost–benefit analysis
CBTC	communications-based train control (urban rail)
CCA	cross-cutting activity
CCS	control, command and signalling
C-DAS	connected driver advisory systems
CDM	conceptual data model or canonical data model
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CER	Community of European Railway and Infrastructure Companies
CFM	call for members
CSIRT	computer security incident response team
DAS	driver advisory systems
DC	direct current
DRIMS	dynamic railway information management system
EIT	European Institute of Innovation and Technology
EMC	electromagnetic compatibility
EMV	Europay, Mastercard and Visa
EN	European norm
EoT	end of train
ERA	European Railway Agency
ERRAC	European Rail Research Advisory Council
ERTMS	european rail traffic management system
ETA	estimated time of arrival
ETCS	European Train Control System
ETE	entitlement/token/embodiment
EU	European Union

EVC	European Vital Computer
FACTS	flexible AC transmission system’
FFFIS	form-fit functional interface specification
FIS	freight information system
FIS	functional interface specification
FP7	seventh EU framework programme for research
FRS	functional requirement specification
FSM	full service model
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GOA	grade of automation
GSA	European GNSS Agency
H2020	Horizon 2020 (EU framework programme for research and innovation)
HST	high-speed train
HVAC	heating, ventilation, air conditioning and cooling
HW and SW	hardware and software
I2M	integrated mobility management
IA	integrated assessment
IAM	intelligent asset management
IAMS	intelligent asset management strategies
ICT	information and communications technology
IEC	International Electrotechnical Commission
IF	interoperability framework
IGBT	insulated-gate bipolar transistor
ILS	integration layer services
ILU	intermodal loading unit
IM	infrastructure manager
IOT	internet of things
IP	innovation programme
IPX	innovation programme X
ISAC	information-sharing and analysis centre
ISO	International Organization for Standardization
IT	information technology
ITD	integrated technology demonstrator
JU	joint undertaking
KPI	key performance indicator
LCC	life-cycle cost
LRV	light-rail vehicle

LTE	Long-Term Evolution (standard for wireless communication)
MAAP	multi-annual action plan
MaaS	mobility as a service
MB	moving block
MIU	modularity in use
N&V	noise and vibration
NFC	near-field communication
OBU	on-board unit
OC	open call
OCORA	open CCS on-board reference architecture
OPEX	operating expenses
OTI	on-board train integrity
PRM	people with reduced mobility
PTI	platform–train interface
QOS	quality of service
R&D	research and development
R&I	research and innovation
RAM4S	reliability, availability, maintainability, safety, security, sustainability, supportability
RAMS	reliability and maintainability system
RBC	radio block centre
RCA	reference CCS architecture
RCM	reliability-centred maintenance
RDERMS	railway distributed energy resource management system
RIMMS	railway integrated measuring and monitoring system
ROI	return on investment
RU	railway undertaking
S&C	switches and crossings
S2R	Shift2Rail
SERA	single European rail area
SIC	silicon carbide
SIL	safety integrity level (according to IEC standard 61508)
SIRI	service interface for real time information
SMES	small and medium-sized enterprises
SPD	system platform demonstrator
SPECTRUM	solutions and processes to enhance the competitiveness of transport by rail in unexploited markets
SRPG	smart railway power grid
SRS	software requirement specification

T2T	train to train
TAF	telematics applications for freight
TAF-TSI	telematics applications for freight – technical specifications for interoperability
TAP	telematics applications for passengers
TAP-TSI	telematics applications for passengers – technical specifications for interoperability
TCMS	train control and monitoring system
TCN	train control network
TD	technology demonstrator
TEN-T	trans-European transport network
TIMS	train integrity monitoring system
TMS	traffic management system
TRL	technology readiness level
TSI	technical specification for interoperability
TSP	transport service provider
TTDB	train topology database
UIC	International Union of Railways
UNIFE	Association of the European Rail Manufacturing Industry
UNISIG	Union Industry of Signalling (UNIFE subgroup)
UTO	unattended train operation
VCTS	virtually coupled train sets
WA	work area
WLCN	wireless consist network
WLTB	wireless train backbone
WMMS	wayside measuring and monitoring systems
WP	work package

About the Multi-Annual Action Plan

The S2R JU Multi-Annual Action Plan shall consist of two parts:

- Part A - Executive View, adopted by the S2R JU Governing Board on 27 October 2017;
- Part B - Technical Content, adopted by the S2R JU Governing Board on 14 November 2019.

There is a need to maintain the original MAAP adopted by the S2R JU Governing Board on 27 November 2015 ([1]) as reference document in cases of doubts with regard, for example, type of assets that the Members other than the Union committed to provide for demonstration activities.

Part A of the MAAP clarifies the S2R vision and its contribution to delivering EU societal goals. It identifies the associated set of 12 new innovation capabilities that S2R will help the railway to develop and bring to market. It describes the S2R Programme as a whole – summarising its purpose, structure, methodology and content – and focuses on the series of intermediate steps by which it will bring about a radically improved railway system (urban/suburban, regional and high-speed passenger rail, freight), shaping the future mobility of people and business. These steps will be taken through the development and implementation of the R&I activities included in Part B of the MAAP, while capturing new technologies and following a Europe-wide system-of-systems approach that is novel for the sector.

Part A links the S2R Master Plan and the MAAP, and it explains how the MAAP and its detailed activities (as set out here in Part B), within the framework of the original S2R Master Plan, are designed to deliver the vision of a radically improved railway system. It also explains the opportunities that this could bring for the railway industry and for society as a whole. The innovation capability delivery strategy and associated implementation plan require full cooperation between all stakeholders to prioritise and align efforts and resources.

The present document, Part B of the MAAP, 'Technical content', focuses on the reprioritised R&I activities that were initially included in the 2015 MAAP and ensures sufficient alignment with Part A of the MAAP. Part B of the MAAP is based on the legal commitments undertaken by the Members other than the EU (hereinafter the Members, industry Members or other Members) of the S2R JU in their respective revised Membership Agreements signed with the S2R JU following the adoption of Governing Board Decision No 18/2019 on the outcome of the invitation to S2R JU Associated Members to submit an answer in view of the realignment of their activities and additional commitment to the S2R JU Programme.

In addition, Part B of the MAAP introduces a demonstration plan for the various technology demonstrators (TDs) and incorporates new ideas, solutions and technologies that have become relevant for the S2R Programme since the last edition of the MAAP. Part B of the MAAP summarises the major demonstrations and technological developments resulting from the research and innovation (R&I) work. For each TD/work area (WA), a link with the innovation capabilities of Part A of the MAAP has been made. The demonstration work for each specific technological objective is presented, with a focus on the activities to be carried out and with the technology readiness level (TRL) and the market application expected for each demonstrator.

These demonstrations will enable a more accurate quantification of the impact of each new technology, either alone or in combination with other innovations, by enabling the creation of integrated technology demonstrators (ITDs). ITDs will combine the testing of different solutions in a single demonstrator, which will allow for a more collaborative systems approach to innovation, breaking down any silos between subsystems and enabling the identification at an early stage of compatibility issues relating to the integration of different solutions.

([1]) https://shift2rail.org/wp-content/uploads/2013/07/S2R-JU-GB_Decision-N-15-2015-MAAP.pdf

Finally, the 2015 MAAP will remain as Part C of the MAAP, as it remains a reference document with regard to provision of assets in the specific context of demonstration activities.

This MAAP does not have the objective of setting out the R&I activities to be undertaken or continued in the next European Union's R&I programming period (Horizon Europe); rather, it aims, among other things, to bridge the current S2R Programme and R&I from 2021.

SECTION 1 – OVERVIEW OF THE PROGRAMME'S SCOPE AND STRUCTURE

1. Summary of major demonstrations and technological developments

Demonstration activities are a priority within S2R, as they will provide evidence of the impact on passenger mobility and freight transport of the technological and/or operational innovative solutions resulting from the R&I work performed within the S2R Programme. They are complemented by relevant business cases developed as part of the programme's cross-cutting activities (CCAs).

They are concrete actions intended to deliver on EU policies and meet market needs, within a coordinated framework of EU-funded activities where each project gains from the others, enhancing not only R&I quality but also overall European knowledge.

Demonstrations will enable the entire rail sector to visualise and test practically the transformations that are being created. They will also enable a more accurate quantification of the impact of each new technology (either alone or in combination with other innovations). Demonstration activities will also help in providing a first estimate of the potential for improvement in the sector at the levels of the regional, national and EU transport networks; that is, of what can be expected as a result of the innovations in question.

These key demonstrations will contribute through several 'building blocks' to achieving the new rail capabilities described in Part A of the MAAP and further detailed in Section 2 for each of the TDs and WAs.

It will also enhance the perceived innovation potential of the sector and revitalise the industry by attracting the next generation of top graduates from universities across Europe.

S2R is fostering synergies across sectors and initiatives, learning from other sectors, and exporting knowledge and technology to the EU mobility and transport overall. The S2R Programme will scout progress and developments in different fields and consider how such developments can be embedded in rail systems, as relevant. It will include synergies with other national and EU-funded R&I programmes, start-ups and international programmes.

S2R will also promote the creation of ITDs, which will combine the testing of different solutions in a single demonstrator, thus achieving economies of scale for the project. This will allow a more collaborative systems approach to innovation, breaking down any silos between subsystems and developers. It will also help in identifying at an early stage compatibility issues relating to the integration of different solutions.

The demonstration of technical achievements, up to TRL 7, will be based on the threefold architecture presented in Figure 1: TDs, ITDs and system platform demonstrators (SPDs).

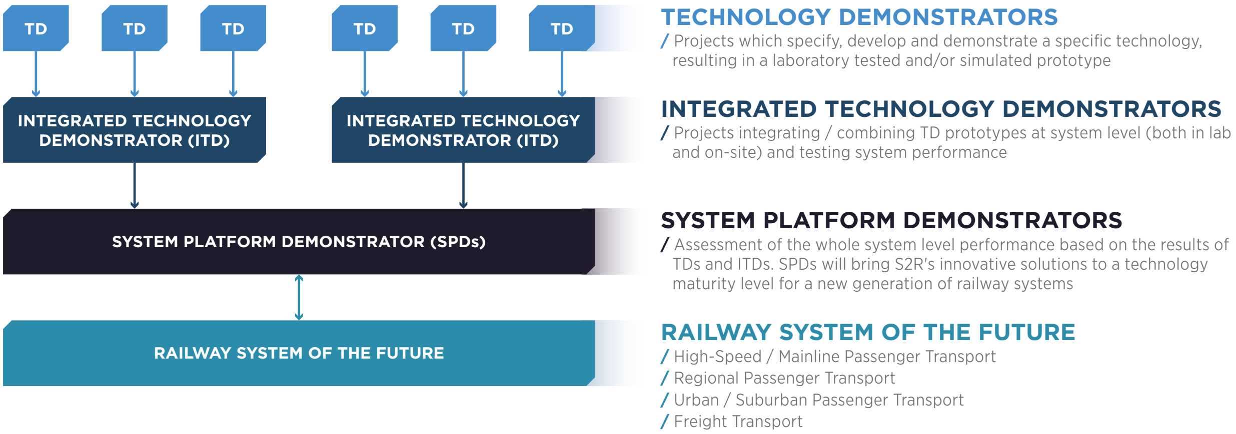


Figure 1 / ***Structure of demonstrators within Shift2Rail***

Technology demonstrators

TDs will focus on the development or adoption of innovative technologies and models within the rail subsystems identified in the Innovation Programmes (IPs). They will enable ground-breaking progress in key areas such as traction, automated train operation, and intelligent diagnosis and maintenance systems. They will seek inspiration from innovative technologies, materials and methods used or explored in other sectors. The innovations developed may consist of software or hardware systems, or systems combining the two.

Before being combined into ITDs, each TD will be tested (in labs on test benches, or in existing trains) in one or more prototypes (differentiated if different business segments are targeted) to assess the individual performance of the technologies developed and, where possible, to demonstrate conformity with the technical requirements that apply to the product developed.

Integrated technology demonstrators

ITDs will allow the testing of combinations of components and subsystems already verified and validated in TDs within virtual or physical railway environments to demonstrate the innovation potential of the components in different subsystems and systems, taking into account functional and operational specifications and the technical interfaces among the various TDs.

ITDs will also enable an analysis of compliance with regulatory requirements, and the validation of technologies will be followed up with a controlled approach to future authorisation and certification work.

System platform demonstrators

Ultimately, S2R will carry out proof and analysis of rail systems, designs and functions on fully representative innovative railway configurations in an integrated environment, simulating real operational conditions.

1.1. The system platform demonstrator scenarios

The SPDs will be created for the main rail market segments to simulate and test the interaction and impact of the various innovative systems resulting from S2R activities in the specific environments of each of the relevant market segments. The proposed SPDs will cover the following segments: high-speed passenger rail, regional passenger rail, urban/suburban passenger rail and rail freight. These SPDs will also be complemented by reflection on key transversal issues (megatrends) that are critical for the sector: safety, security, energy, digitalisation, etc.

The design of the SDPs will take into account the specificities of each market segment, its particular challenges and needs, and promising market opportunities. Based on this initial assessment, the SPDs will demonstrate how the correct aggregation of different innovations can greatly contribute to improving the performance of the sector. This will be based on an analysis of detailed key performance indicators (KPIs) on simulated models and measured against the S2R objectives as defined in the Master Plan.

In this respect, it is possible that the deliverables of a single TD might be relevant to more than one of the different railway transport segments. The results of one TD may therefore be demonstrated in more than one SPD if it is considered that these results correspond to the business needs of several rail market segments.

The exact design of each SPD is part of the work to be done in the S2R JU's System Integration Working Group, taking into account input from the broader stakeholder community (the S2R User Requirements Working Group and Implementation and Deployment Working Group), as well as, where relevant/available, the first results of the S2R lighthouse projects funded under the Horizon 2020 (H2020) first call. This work is also expected to be the subject of activities carried out as a result of the 2015 S2R call for projects.

There follows an overview of the key challenges for each of the SPDs identified in the S2R Master Plan.

High-speed passenger rail

This has been a very successful and innovative rail market segment for several decades, and high-speed passenger rail is often the preferred choice for long-distance national and international travel. The technical and technological challenges related to high-speed and mainline rail do not relate just to developing new types of rolling stock that provide comfortable transport capacity for increasing numbers of passengers but also to ensuring safe and efficient operation thanks to appropriate infrastructure design, enhanced traffic control and management systems, more efficient power systems, and shared track and corridor operations.

Regional passenger rail

Regional rail is already serving as the backbone of the European transport system, having expanded massively in recent years. However, this segment remains affected by competition with the private car and by the life-cycle cost (LCC) of operation compared with bus services. The core challenge for this market segment is to offer increased capacity to ever-increasing numbers of passengers, through improved system capacity with enhanced traffic management and automation concepts, and high-capacity rolling stock. These services are mostly operated under public service contracts and may or may not share infrastructure with mainline traffic. What is really at stake is making these services more attractive to customers, through increased reliability, frequency and speed, and by cutting costs, as well as through improved coordination with other public transport services and better integration into regional mobility strategies.

Solutions with a low overall LCC are also needed for regional networks with low traffic volumes to become or remain attractive.

Urban/suburban passenger rail

Railway networks in urban and suburban areas play a prominent role in major cities and high-density areas, serving the daily needs of urban populations and offering an attractive alternative to the use of a private car in more and more congested and polluted areas. This market segment is also experiencing growth, which it will be important to manage through innovative solutions. It is also one for which existing rail infrastructure is not used to the full extent of its potential for supporting more sustainable land use and transport policies. Cost-effectiveness and increased attractiveness are also important challenges, requiring higher levels of proven, affordable technology, improved accessibility, comfort and security, and innovative services based on ITS. Improvements through technical harmonisation of interfaces are also required.

Rail freight

Rail freight is a key element in the establishment of a sustainable transport system. An efficient and reliable, high-quality rail freight system in Europe is indispensable for the competitiveness of the European economy, its industries, businesses and society, which all make use of and rely on freight services. The low level of external costs generated by rail freight should make it the mode of choice for freight customers looking to reduce their environmental impact. However, the key challenge for rail freight to become a core link in intermodal transport is for it to be able to offer an attractive, reliable, rapid and cost-efficient alternative to road. The main objectives of this SPD should be to offer visible and viable solutions that increase productivity, reduce cost, optimises network capacity, and enable a better quality of services through optimised logistics services and rail technology, and that realise the full potential of digitisation to meet customers' requirements.

1.2. Integrated railway system architecture and conceptual data model

S2R innovations will challenge the current system's functioning or provide opportunities for overall system optimisation.

The rail sector needs to develop an encompassing new railway functional system architecture that integrates the different railway subsystems – starting with control, command and signalling (CCS) – following a modular approach and using standard interfaces and conceptual links between components or services, while preserving know-how and competitiveness.

The integrated railway functional system architecture will also need to be future-proof; solutions need to be not only modular but also scalable in time, with new technologies/features added in an agile manner. Technologies that can be expected to be introduced by 2022 and soon thereafter, with the introduction of related new Technical Specifications for Operability (TSIs), include the integration of S2R interoperable solutions for intelligent mobility management (with an enlarged traffic management system (TMS)); a wireless train control and monitoring system (TCMS); smart, connected radio object controllers; condition-based maintenance for all kind of assets; etc. In this context, activities related to the development of a conceptual data model (CDM) will contribute to overcoming data and systems fragmentation with a view to taking a system-of-systems approach.

The overall objective is to specify a future-proofed interoperable system to be shared across the sector, creating functional and conceptual links and offering opportunities for modular evolution, compatible with different subsystems, with CCS at its heart, and preserving know-how and competitiveness.

This activity will contribute to achieving a major railway system transformation, without deciding on a single target system – which could create legacy problems – but instead offering opportunities for modular evolution driven by end users' needs and ambitious R&I targets. R&I on a new integrated railway system architecture could contribute to redefining the way the railway operates and is managed, helping to achieve the new capabilities described in Part A of the MAAP.

In this respect, during the 2019 European Rail Traffic Management System (ERTMS) conference organised by ERA, the European Commission presented its vision of:

- one European CCS system;
- an adaptable CCS system;
- harmonisation of operations;
- optimised traffic management.

To this end, the S2R JU will:

- in the short term, provide a focus for coordination and programme management of wider CCS outputs through Innovation Programme X (IPx);
- in the long term – bringing together the manufacturing industry, railways operators and infrastructure managers (IMs) – provide, in particular, trackside modular architecture, including specification development, prototyping and demonstrations to create a railway functional system architecture.

On this, the S2R JU will work under the oversight of the European Commission together with ERA, in its role as the ERTMS system authority, and given its responsibilities for stewardship and maintenance of new specifications.

1.3. Deployment

Bringing about the technological and operational advances expected as a result of the S2R R&I activities will require active intervention. It will not happen by itself. Deployment of this complex array of innovations will involve a coordinated effort to guarantee an adequate level of consistency and achieve a Single European Rail Area (SERA). This requirement for active intervention implies a need for an understanding of the steps required in the process, of funding needs and of the essential system-of-systems interaction and complexity of the railway in all its segments and components. Those undertaking this active role should be as close as possible to the market, while retaining the necessary independence under joint governance.

Joint and coordinated deployment is predicated on a sound appreciation of the business case for change, at both corporate and societal levels, the requirements associated with standardisation and regulation, the timescales relating to opportunities for the insertion into the railway of new technical solutions, and a professional approach to risk management. As successful deployment will depend on interfaces with a range of organisations beyond the railway, a collaboration strategy at European level is also required.

The economic benefits of delivering the S2R Programme targets have been identified in the impact assessment of the S2R JU proposal ([2]):

- indirect leverage on industry R&I related to the development of industrial products exploiting H2020 innovations, worth up to EUR 9 billion in the period 2017–2023;
- the creation of additional gross domestic product at EU level of up to EUR 49 billion in the period 2015–2030, distributed among a large number of Member States;
- the creation of up to 140 000 additional jobs in the period 2015–2030;

([2]) Impact assessment accompanying the document *Proposal for a Council Regulation establishing the Shift2Rail Joint Undertaking*, SWD(2013) 535 final, Brussels, 16.12.2013

- additional exports worth up to EUR 20 billion in the period 2015–2030 thanks to the worldwide commercialisation of new rail technologies developed under H2020;

- LCC savings of around EUR 1 billion in the first 10 years and thereafter, with continued implementation, of around EUR 150 million per year.

Efforts towards coordinated deployment will build on the initiatives of the European Commission in this respect, such as the European deployment plan for ERTMS, as well as on experiences from other modes of transport (e.g. air traffic management) and sectors.

SECTION 2 – DETAILED TECHNICAL CONTENT

1. IP1 – Cost-efficient and reliable trains

Context and motivation

The ambitious objectives set out in the S2R Master Plan for the railway system of the future need to be supported by radical changes in the technologies applied in each of the components of the system, rolling stock being one of the key elements.

Traditionally, innovation in rolling stock has faced several obstacles, including the following.

- The long life cycle of railway vehicles, which can last for more than 30 years, tends to slow down the introduction of new developments.
- Owing to the variety of operational environments across segments and different standards and solutions in different countries, many innovations cannot be widely applied and it is not possible to benefit from economies of scale or to obtain an adequate return on investment (ROI) on new innovative developments.
- The complexity of the whole railway system and the fragmentation of responsibilities makes service-proven solutions preferable to new, innovative ones.
- High initial investment costs and long-term spending on maintenance lead to conservative approaches in the rail sector.

Commercial pressure and political long-term vision have pushed forward the evolution of rolling stock in the past few years, but the aforementioned limitations have prevented industrial innovation from achieving its full potential and have also often made it difficult for technically sound research developments to be transferred to real applications. In practice, innovation has generally been incremental and so have been the benefits gained from its implementation.

A sector-wide collaboration initiative such as S2R offers the right environment to overcome this situation by:

- incorporating the standardisation perspective from the beginning of activities, involving all stakeholders from the specification phase, to facilitate the penetration of new technologies;
- incorporating cutting-edge technologies already in use in other sectors into railway vehicles;
- identifying incipient technological opportunities that could bring considerable benefits if used in trains;
- bringing new technologies to a high TRL through longer-lasting actions

With this in mind, IP1 of S2R is dedicated to developing the technologies for a new generation of railway vehicles that fulfil the expectations set out in the S2R Master Plan.

Objectives of the IP and expected results

Taking the high-level objectives set out in the S2R Master Plan as a starting point, and considering the role that rolling stock plays within the whole railway system, the high-level objectives of IP1 can be summarised as follows.

1. Increase the physical capacity of vehicles and support the enhancement of transport capacity of railway lines.
2. Reduce travel disruptions for passengers by increasing the operational reliability and availability of vehicles, through the use of either fundamentally more reliable components or system/subsystem architectures.
3. Reduce the LCC of vehicle fleets (through reduced initial investment, maintenance, energy consumption, etc.) and of other subsystems of the railways interacting with vehicle fleets (e.g. through reduced track damage).
4. Increase the energy efficiency of vehicles through more efficient components and vehicle mass reduction.
5. Promote modal shift through more attractive and comfortable vehicles, more punctual services and cheaper tickets.

Fulfilling these objectives will help to guarantee that the S2R global objectives are achieved.

The high-level objectives need to be achieved through specific actions. The following technological developments can be expected to result from the work on IP1.

1. More efficient and lighter traction drives using the new generation of electronic material will be developed. With new power electronics able to control motors at a higher frequency, combined with the development of new generation permanent magnet motors based on a buried magnet architecture, a step change in energy efficiency will be achieved compared with existing permanent magnet synchronous motors and asynchronous induction motors.
2. The new drive-by-data concept for train control, along with wireless information transmission, will make new control functions possible, involving interaction between vehicles, consists and trains, with high safety and reliability levels achieved through very simple physical architectures. The targeted full connectivity of rail vehicles will enable the awaited digital railway. A new function-centric approach, together with higher standardisation levels, will lead to cost-efficient solutions and improved interoperability. A new generation TCMS will allow bottlenecks currently caused by physically coupled trains to be overcome. Concepts made by different companies and with different interfaces could be virtually coupled and driven together, sharing the same traffic slot.
3. The new generation of body shells will use composite or other lightweight materials. No rail vehicles are currently built from such materials, and this step change will lead to significantly lighter vehicles, carrying more passengers within the same axle load constraint, using less energy and having a reduced impact on the rail infrastructure.
4. Mechatronic running gear able to steer through points and crossings will open up huge possibilities for a new design philosophy in collaboration with IP3. The main possible innovations in running gear lie in combinations of new architectural concepts and new actuators in new lighter materials leading to new functionalities and significantly improved performance levels.
5. New braking systems with higher brake rates and lower noise emissions could create major capacity gains in terms of mass and volume in running gear, paving the way

for fresh running gear design. When these are combined with traction innovations, the next generation of passenger rolling stock will be able to offer improvements in acceleration and deceleration rates, leading to greater overall line capacity for trains.

6 Innovative doors will move away from current access solutions, based on honeycomb and aluminium or steel sheets, which still have drawbacks regarding energy consumption, and noise and thermal transmission. New lightweight composite structures could be made to react faster at existing safety and reliability levels, reducing platform dwell times and increasing overall line capacity. Customer-friendly information systems and improved access for people with reduced mobility (PRM) using sensitive edges and light curtains are part of this new development.

7 New modular concepts for train interiors will allow operators to adapt vehicle layout to the actual use conditions and will improve flow of passengers, thus optimising both the capacity of the vehicle and dwell times.

8 Heating, ventilation, air conditioning and cooling (HVAC) units with natural refrigerants will be developed to reduce the climate impact caused by artificial refrigerants.

Although the activities of this TD concerning traction power focus on the enhancement of electrically driven systems, the S2R JU also undertook exploratory research into alternative-fuel green technologies, as not all the network is electrified. This led to a collaboration with the JU on fuel cells and hydrogen, with train manufacturers, operating companies, infrastructure managers and fuel cell and hydrogen providers working together.

Table 1 summarises the main objectives of IP1 and provides an overview of some of the concrete deliverables that can be expected to result from the activities undertaken in the IP.

Table 1 / ***Objectives and challenges of IP1***

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
Line capacity increase	More space and weight available for passengers in each vehicle	Smaller and lighter power electronics and traction architecture concepts, along with simpler communications and electronics, lighter and wider carbody structures with an optimal architecture, and lighter running gear and brakes will allow new vehicle designs with more space for passengers
	Better control of the vehicles on the line (in terms of passengers/hour)	Fully connected vehicles will improve the efficiency of traffic management. Flexible coupling between trains will allow flexibility in the capacity of the line at peak times. The factors that increase operational reliability mentioned below will also moderately increase the capacity of the line
Increased operational reliability	Fundamentally more reliable technologies and components	Key elements and systems that are known to be more prone to operational failure (TCMS, traction, etc.) improved based on novel technologies that have greater fundamental reliability, combined with extensive tests done through the virtual certification platform
	Fundamentally simplified architectures, or architectures more suited to maintaining operation in case of failure	Train communications and control architecture, linking the functioning of all vehicle subsystems, based on new technologies allowing a much lower degree of physical complexity, leading to much higher reliability. Similar concept to be applied to brakes and others

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
Railway system LCC reduction	Reduction in the capital cost of vehicle fleets	New vehicle subsystems and components with better overall performance, without any increase in cost; better authorisation processes relying on virtual methods rather than on-track tests; reduced number of vehicles required per fleet thanks to greater reliability, shorter repair times and coupling flexibility between fleets
	Reduction in the number of vehicles needed for a given capacity'	Vehicles with increased availability, directly related to the deliverables shown in 'Increased operational reliability'
	Reduction in the cost of maintaining vehicles	Intrinsically more reliable system architectures and component technologies; simplified repair processes; better and more standard sensoring to detect condition; vehicles with lower axle loads, lower unsprung mass and better curving performance
	Reduction in the cost of maintaining other parts of the railway system	Track friendly vehicles with lower axle loads, lower unsprung mass, and better curving performance and ability to run through switches and crossings
	Reduction in the consumption of energy	See 'Mass reduction and energy efficiency'
Mass reduction and energy efficiency	Reduction in the mass of the vehicle	Reduced weight of most bulky elements (carbody, running gear, traction, etc.) combined with new, intrinsically lighter, architectures
	Reduction in energy use for heating	HVAC units with natural gases will allow the introduction of heat pumps with reduced energy consumption
	Increase in energy efficiency and reduction in energy losses	Increased energy efficiency in traction/braking; reduction in thermal losses (i.e. through doors); fully connected vehicles will allow energy-optimised real-time train operation
Noise reduction	Better calculation and design methods	Better techniques for assessment and prediction; theoretical criteria to guide design
	Noise reduction-oriented design	New innovative design features for traction, brakes, running gear, carbody shell and doors

Past and ongoing European and national research projects

IP1 of S2R will be supported to a great extent by many of the projects funded by EU research programmes in the past few years. S2R will be an efficient tool to bring the results of these projects closer to the market, thus maximising the real benefits from the investment that European society has made in railway research in recent years. Details of the projects are presented in the sections devoted to individual TDs, but some of those most relevant to S2R activities are briefly introduced here.

The outcomes from the European research projects **ModTrain** (on innovative modular vehicle concepts, and in particular knowledge developed on auxiliary power systems, interface with traction and standardisation) and **ModUrban** (dealing with common specifications and common architecture for urban rail systems) will be taken into account and used at the beginning of the development of the Traction Systems TD in IP1. The **RailEnergy** and **Osiris** projects on the energy efficiency of trains offer the first building blocks to develop the major technologies (new semiconductors, motors, etc.) that will be used to build the traction systems of the future in S2R.

In the same way, the TCMS TD will also take into account outputs from **ModTrain** as well as **Integrail** (addressing railway information systems and their integration into the major railway subsystems – important also for S2R data management system integration activities). Moreover, important knowledge and innovative practices on virtual coupling coming from European aerospace research projects (**RESET**, **SOFIA**, **INOUI** and **Asstar**) will be used in the development of the TCMS TD.

The future composite carbody shell to be developed in S2R will rely heavily on the results achieved in the seventh EU framework programme for research (FP7) project **Refresco**, the aim of which was to develop suitable technical standards to allow the use of new composite materials in structural applications in trains. These will also be useful for the work to be carried out in the area of doors.

The **Mechatronic Train** project results (dealing with running gear architectures, sensors, actuators and processing to increase safety, reliability and maintainability) will be taken into account and used at the beginning of the development of the Running Gear TD.

The results of the **ModBrake** project, which was designed to develop modular brake system architectures, will provide input to the development of new generation brakes in S2R.

The **Roll2Rail** IP1 H2020 lighthouse project, which was successfully finalised in 2017, was designed to kick-start many of the work streams of S2R and to mitigate potential risks at an early stage. The results of **Roll2Rail** have been incorporated into IP1 and constitute an essential element for the success of the programme.

Finally, the IP1 projects, and related complementary actions, represent the next steps in technological development. The outcomes of the projects will create a solid basis for the IP1 activities included in future Annual Work Plans (AWPs).

Set-up and structure of IP1

Technologically speaking, trains are very much structured in subsystems, each of which is usually responsible for a different function in the vehicle. Each function tends to be related to a specific type of technology that is able to provide a given level of performance at subsystem level. This functional division of the vehicle is presented in Figure 2 and has been used as a basis for the division of the TDs in S2R. Thanks to this strong function/subsystem/technology relationship, specialist teams will be able to develop the specific technologies to achieve the highest performance levels.

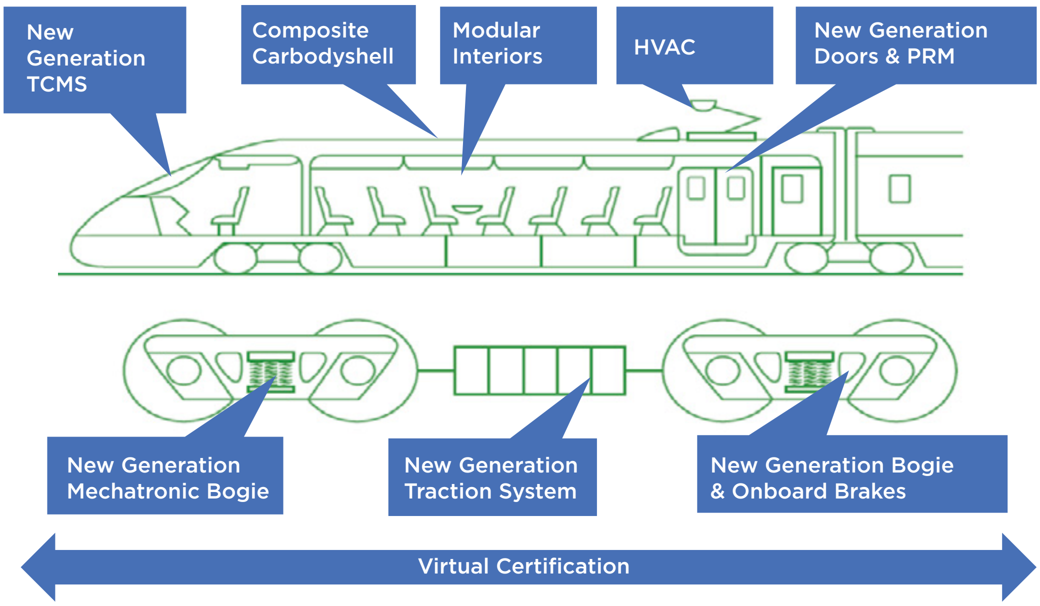


Figure 2 / ***Functional breakdown of a train into subsystems***

The choice of topics for the work in IP1 has been made taking into account the following.

1. Technological opportunities applicable to rolling stock subsystems: progress on fundamental technologies (e.g. new communications technologies, new power electronics components, innovative materials) has been analysed and potential transfer to railways of the most promising ones considered.

2. Relevance to performance and integration possibilities at vehicle and/or railway system level: developments need to be useful when integrated with other components of systems and have a meaningful impact at system level.

This approach leads to parallel developments covering the different functions to be provided by the vehicle, which converge at a later stage, with an integrated assessment (IA) constituting the final quantitative measure of the success of S2R.

As the technologies proposed are in general function-oriented, they generally refer to a specific piece of equipment. However, in some cases, they can apply to different TDs. A few examples of inter-related technological developments are:

- drive-by-wire TCMS (TD1.2) and fail-to-safe electronic controls for brakes (TD1.5), both relying on innovative safety-critical electronics and software technologies;
- wireless TCMS (TD1.2) and standard running gear sensoring (TD1.4), both relying on wireless communications solutions;
- composite material technologies, used in carbodies (TD1.3), doors (TD1.6) and running gear (TD 1.4);
- the virtual certification simulation framework and train virtualisation (TD1.2), which create the vehicle-level platform to be used by other subsystems (TD1.1, TD1.4, TD1.5, TD1.6) to carry out their virtual certification processes.

Even though a large part of the development effort is to be made within the TDs, this work will be coordinated with other relevant activities within S2R, exploiting synergies when possible, and in all cases working together towards the achievement of the same system-level performance objectives for the railway.

A more global view on functional interactions existing between TDs is provided by Figure 3, which highlights not only the technological but also the functional interdependencies between TDs and IPs.

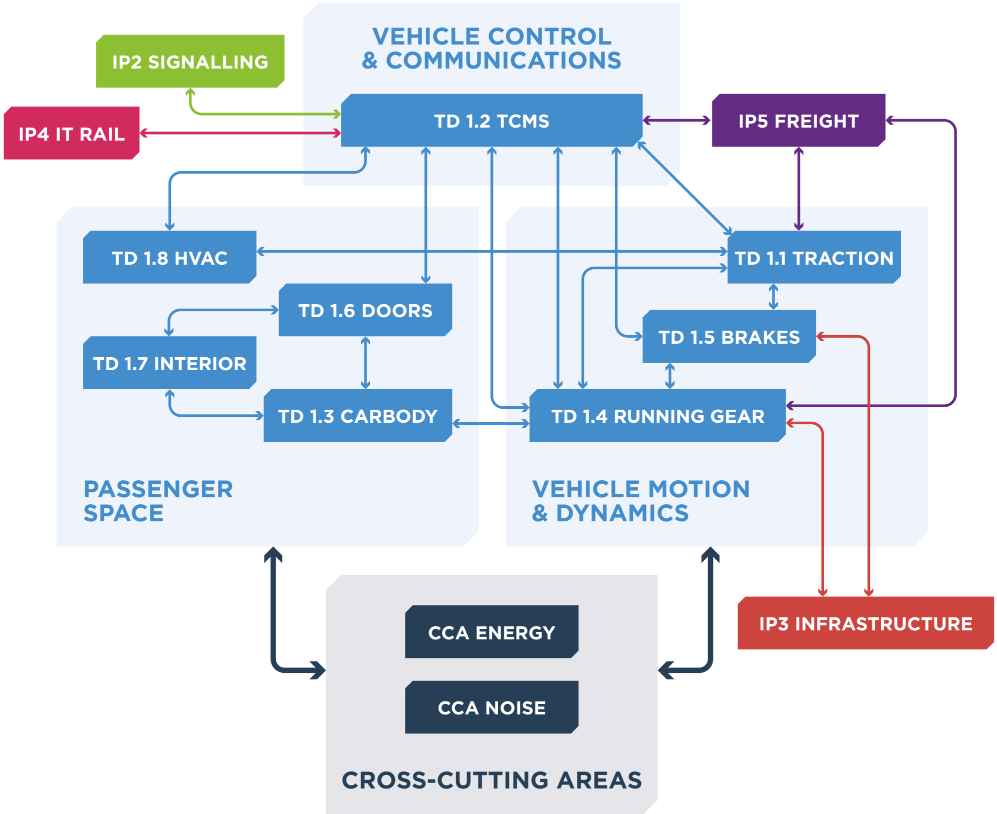


Figure 3 / ***IP1 TDs – map of inter-relationships***

In addition, the existing interactions with other IPs and within relevant TDs of IP1 take into account the work on the S2R system architecture performed in IPx.

1.1. TD1.1 Traction Systems

1.1.1. Concept

The traction drive subsystem is one of the main subsystems of a train, as it moves the train, converting energy from an electrical source (directly or via a chemical source) into mechanical energy.

In electric trains, the physical scope of such a subsystem starts from the pantograph and ends with the motorised wheels. The main components are the main transformer, power bus, traction inverters, motors, gearbox and, finally, wheels. All those components are controlled by electronic hardware and software (HW and SW).

Current electronic technology used in traction drives is based on silicon material such as the insulated-gate bipolar transistor (IGBT) power semiconductor devices used as an electronic switch. However, this technology has major limitations leading, for example, to high losses, too many failures, and heavy and large equipment. The emerging silicon carbide (SiC) technology provides high-speed switching capabilities with low on-resistance.

The Traction Systems TD will carry out the necessary work in five major phases to bring to the market a new generation of traction drive equipment.

1. **Capture** the necessary know-how in SiC technology, energy storage and wheel motors.
2. **Progress and implement** new methodologies, tools, norms and standards on reliability, noise, virtual certification and smart maintenance.
3. **Develop** new traction components and subsystems, including using the SiC technologies. Develop new traction architectures enabled by the new technologies. Develop a traction system based on independently rotating wheels.
4. **Demonstrate** key achievements through four rolling stock demonstrators and finally implement physically the new equipment on a tram, metro, regional train and high-speed train (HST).
5. **Conclude** on technical benefits.

1.1.2. Technical objectives

The high-level objective of this TD is to develop a new generation of traction drives using the new electronics materials becoming available. This TD will in particular bring to the railway market SiC technology. The following are the main technical objectives of this TD:

1. increased reliability and fewer service disruptions;
2. reduction of the weight and volume of large equipment and increased space for passengers or more space for energy storage systems on board;
3. reduction of noise emitted by traction drive equipment;
4. reduction of energy consumption, resulting also in reduction of maintenance costs;
5. development of harmonised rules for certification.

1.1.3. Technical vision

Our vision is as follows:

- an SiC-based traction system aligned with urban markets;
- an SiC-based traction system aligned with regional markets;
- a traction system based on independently rotating wheels for HSTs;
- a breakthrough on aero-acoustic, electromagnetic and electromagnetic interference noise reduction methodologies and prediction tools;
- a breakthrough on high-reliability design methodology, simulation and test tools for life-cycle estimation of critical power traction electronics components in real operational conditions and condition-based maintenance, to be applied to traction TD development;
- a breakthrough on validation and virtual certification methodologies, updated regulations, simulation tools and a test bench to reduce test ring certification tests, costs and duration.

The following table presents the progress targeted within the traction TD work.

STATE OF THE ART	NEW GENERATION TRACTION VISION
Heavy and very large traction equipment	High-speed motors and natural cooling systems thanks to new SiC semiconductor technology
Good, energy-efficient traction systems based on silicon IGBT semiconductors	Very highly energy-efficient traction systems thanks to new SiC semiconductors; very low-loss technology
Current traction systems based on silicon technology leads to too much noise emission (electromagnetic interference and cooling). Noise problems are discovered too late during the development cycle	Early-stage low-noise traction system and component design, thanks to predicted calculated noise signature; low noise prototype developed and tested within the traction TD
Reliability is too low and there is no ability to predict the lifetime of semiconductors and traction components in real train operational conditions	New methodology to predict lifetime, improved design and validation processes to progress on reliability during exploitation
Long and costly validation and certification process	New methodology and tools to implement more virtual validation and certification of the full traction systems and components; transfer of tests from train to static test bench and simulators
No standards on SiC semiconductors	European and worldwide standardisation, especially on packaging of semiconductor chips
Complicated and non-harmonised (at European level) certification standards. No standards on traction system virtual certification	Simplified framework for traction certification, recommendations for more virtual certification
No technology available for the combination of the independent wheel and the distribution traction concepts	New developments for more efficient (in terms of operation and energy consumption) and higher capacity trains by combining these two concepts

Interaction with other TDs (in the same IP and/or in other IPs)

- IP1: the Traction Systems TD has links with:
  - TD1.2 TCMS
  - TD1.4 Running Gear
  - TD1.5 Brake Systems
  - TD1.8 HVAC
- Other IPs: links with:
  - TD5.4 New Freight Propulsion Concepts
  - TD5.1 Fleet Digitalisation and Automation
- CCAs: links with and regular exchange on:
  - WA2 KPIs
  - WA3.2 Standardisation
  - WA3.3 Smart Maintenance
  - WA3.5 Virtual Certification
  - WA5.1 Energy
  - WA5.2 Noise

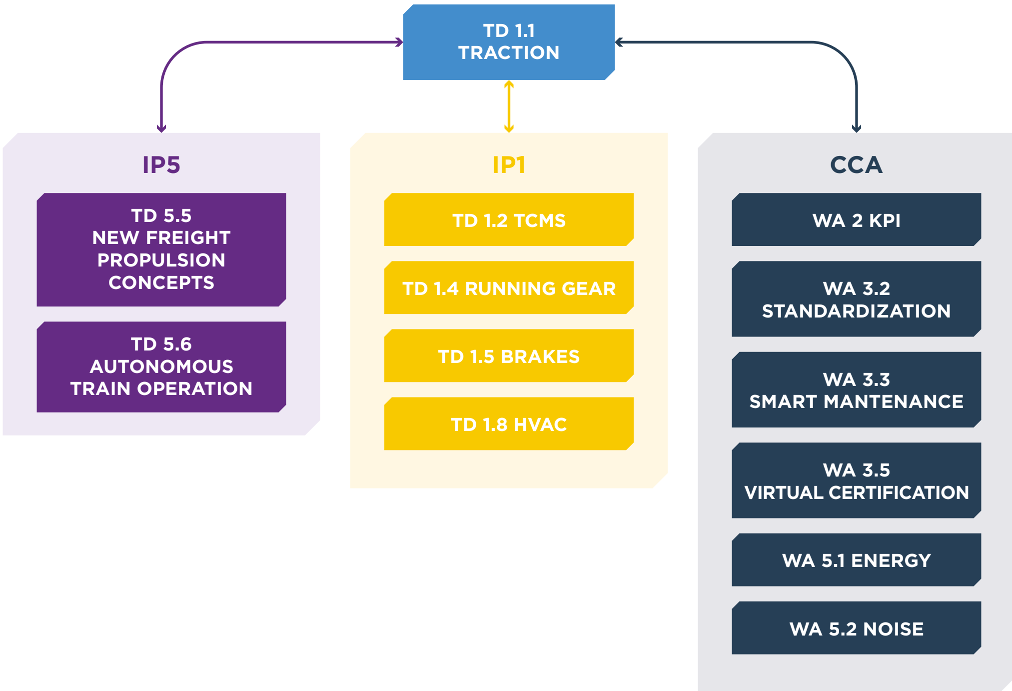


Figure 4 / ***TD 1.1 relationships***

1.1.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Keep the European traction industry in the technology race alongside Japan, which has made some advances in SiC technology and applications • Develop high added value and competitiveness in the traction industry, including new design methodologies and tools (noise, reliability, virtual certification tasks), and validation of traction components and systems • Develop and promote European/worldwide standards on new SiC semiconductor technology • Harmonise and simplify the traction certification process to decrease cost and duration via virtual certification drastic progress • Provide technological leadership supported by a combination of radical innovation (high-speed motors, independently rotating wheel distributed traction systems) • Provide proof of tangible benefits for the end user: / increase in operational reliability (fewer service disruptions) through more robust and better validated traction systems / support train capacity increase resulting from lighter and smaller traction equipment, new traction solution for low-floor HSTs / LCC reduction (through virtual certification, higher reliability, lower energy consumption and less maintenance) / additional advanced maintenance services through high added value functionalities such as traction system and component remote failure diagnostics and health monitoring

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Compliance with EU objectives	• Promotion of modal shift: a big impact brought about by the implementation of these new technologies towards better train punctuality and adding new accessibility to trains with station platforms and train floors at the same level • Support to capacity increase: as mentioned above, this will be enabled by more flexible traction component implementation in the train and fewer service disruptions • Greening of transport through energy consumption reduction thanks to high-efficiency components such as e-transformers and SiC-based traction inverters
Degree of maturity of the envisaged solutions	Currently, most of the proposed technologies are at low TRL levels. At the end of S2R it is expected that the successful concepts will have been brought to TRL 7 (prototype demonstration in real operational environment). In parallel with technical developments, marketing studies and norms and regulation work will prepare a favourable environment for economically viable new solutions for the industry and operators

This TD will contribute to enabling the following seven innovation capabilities.

INNOVATION CAPABILITY	TD1.1 TRACTION
4 – More value from data	*BB1.3: High reliability and availability of traction* The Traction Systems TD could provide digital services via traction smart maintenance
5. Optimum energy use	*BB1.1.1: New power electronics* *BB1.1.2: Independent wheel traction* The Traction Systems TD is focused on energy savings thanks to intrinsic traction technologies (e.g. SiC-based semiconductors) and weight savings
7 – Low-cost railway	*BB1.1.1: New power electronics* *BB1.1.2: Independent wheel traction* *BB1.1.3: High reliability and availability of traction* *BB1.1.5: Virtual certification of traction* *BB1.1.6: Standardisation of key traction components* The Traction Systems TD is not specifically oriented towards low cost; rather, it targets high KPI performances (weight, volume, physical energy savings, low noise, high reliability and availability) at optimised LCC (minimisation of capital costs, maintenance costs and energy costs on a 30-year basis) Moreover the Traction Systems TD works on pre-standardisation and virtual certification, leading to lower costs as soon as common approaches are agreed between railway stakeholders
8 – Guaranteed asset health and availability	*BB1.1.3: High reliability and availability of traction* The Traction Systems TD directly provides optimised maintenance via its smart maintenance work stream and thus provides indirectly minimised disruption of train operation via higher reliability and availability
9 – Intelligent trains	*BB1.1.3: High reliability and availability of traction* The Traction Systems TD is preparing better-communicating trains, including work on smart maintenance and data for energy management

INNOVATION CAPABILITY	TD1.1 TRACTION
11 – Environmental and social sustainability	*BB1.1.4: Traction electromagnetic interference and acoustic noise reduction* The Traction Systems TD works on energy savings and lower CO_2 emissions through various solutions such as higher intrinsic efficiency and higher energy
12 – Rapid and reliable R&I delivery	*BB1.1.5: Virtual certification of traction* *BB1.1.6: Standardisation of key traction components* Virtual testing and efficient implementation processes speed up production and deployment of new products; virtual certification methodologies using simulation and validation processes reduce costs for stakeholders There is close cooperation within the sector on standardisation and testing

1.1.5. Demonstration activities and deployment

Demonstration activities

The objective of the demonstration activities is to generate physical demonstrators, integrated in rolling stock, suitable for performing track tests, either in commercial lines or test rings (TRL 7 demonstrators).

The work is done in three steps: integration of traction equipment into four different rolling stock trains, assessments and, finally, demonstration conclusion.

In particular, the demonstrators will focus on obtaining experimental results that demonstrate:

- the new traction components' performances and behaviour;
- the new control strategies' performances and behaviour;
- traction local performance – acoustic noise level, reliability/availability (failure rates, ageing, etc.), energy, etc.;
- traction electromagnetic interference levels.

In addition, the real experimental results will be compared with the results obtained previously in virtual certification platforms (virtual certification software, simulation tools and hardware-in-the-loop platforms) to validate and assess the accuracy of those platforms.

All the prototypes will be tested on test tracks or commercial lines in different segment applications, as outlined below.

New SiC-based traction converter for metro application (TRL 7)

The objective is to generate a physical demonstrator of a metro train integrating a SiC-based traction system, suitable for performing tests in the field, in either commercial lines or test rings.

The scope includes all the required work to install fully functional prototypes of SiC-based traction converters in a real train.

During the project phase, a specific metro application will be selected. In order to minimise and rationalise the vehicle costs, it is intended to use the same train as ITD for the IP1 TD1, Traction Systems, and TD2, TCMS, for field validation tests on the metro application.

New SiC-based traction converter for regional application (TRL 7)

A fully functional prototype of an SiC-based traction converter for a regional train will be assessed.

Contributions from major operator members will be needed for this task to ensure all necessary support; these members will be needed to validate the test plan and participate in conclusions and KPI final quantification.

New Si- based traction converter for tramway application (TRL 4–5)

Demonstration of a traction converter prototype is planned.

New traction converter for HST application (TRL 7)

The final demonstration and assessment of a low-floor, independently rotating wheel distributed traction system TRL 7 prototype for an HST train will be carried out.

The table below summarises the expected demonstrators of TD1.1.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Traction	New-technology traction systems	Implementation of an SiC traction inverter on a tram	Tram	5	New power electronics: SiC TD
		Full demonstration on trains	Metro, regional	6/7	New power electronics, high reliability and availability of traction: new generation traction converter based on advanced semiconductor technologies; reduction in weight and size and increase in energy efficiency
	New traction architectures	Wheel motor demo on an HST to reach 360 km/h maintaining single axle and independent wheel configuration	High speed	6/7	Independent wheel traction: traction motor and traction drive architecture
	Reliability and availability increase	–	Generic	4/5	Concepts and architectures, knowledge of failure mechanisms of new devices, sensors, standardised methodology for reliability stress tests, remote diagnostics, health monitoring
	Virtual validation demo	Virtual validation of a power module or traction converter	Generic	5	Electromagnetic compatibility (EMC) state-of-the-art and gap analysis, and requirement and concept specification, including interfaces with simulators for virtual certification, and norms and regulation recommendations

Planning and budget

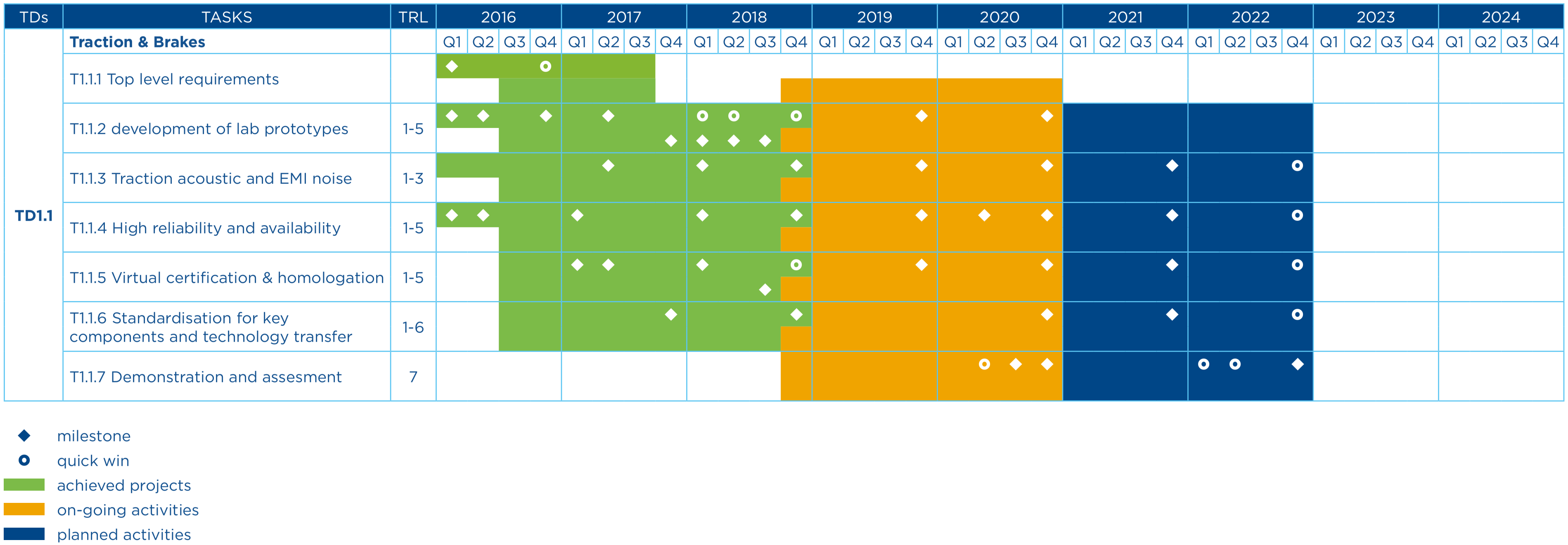


*Table 2 / **TD1.1 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q1 2018	Tramway converter based on SiC	Proof of technological feasibility
Q2 2018	Suburban lab Converter (prototype)	Proof of technological feasibility
Q4 2018	Prototype of an SiC-based converter for metro	Proof of technological feasibility: paves the way for high-TRL application in metro segment
Q4 2018	Final validation test report on power modules and final motor/wheel integration analysis and validation plan for independently rotating wheel traction system	Proof of technological feasibility: paves the way for high-TRL application in high-speed segment
Q4 2018	New methodologies for validation	Proof of technological feasibility
Q2 2020	TRL 4–5 Demonstrator on SiC traction for tramway	Proof of technological feasibility
Q1 2021	TRL 7 Demonstrator on wheel motor for HSTs	Proof of technological feasibility
Q1 2021	TRL 7 Demonstrator on SiC traction for regional trains	Proof of technological feasibility
Q2 2022	TRL 7 Demonstrator on SiC traction for metro	Proof of technological feasibility

Table 3 / ***TD1.1 milestones***

WHEN	WHAT
Q4 2019	WP4, Requirement specification for climatic conditions, contribution to the European Centre for Power Electronics guideline
Q2 2020	WP13, Validated microclimate data based on vehicle measurements and simulation
Q2 2020	WP14, Acceptance of design and virtual validation methodologies application by PINTA2 operators
Q3 2020	WP10, Prototypes demonstrated at InnoTrans 2021 S2R JU stand
Q4 2020	WP9, Final conference

The estimated total budget for the Traction Systems TD is around EUR 75 million.

1.2. TD1.2 Train Control and Monitoring System

1.2.1. Concept

The TCMS is the brain and the communications backbone of the train, critically affecting the vehicle's performance. In fact, it:

- integrates and manages all on-board information and makes train control decisions taking into account the overall situation;
- performs communication between equipment, vehicles and consists and between the train and the ground (except signalling-related communication);
- is the essential actor in the integration and interaction between different subsystems of the train.

Today, TCMS is still based on reliable standards and concepts, which, however, date back to the early 1990s, with embedded limitations in relation to transmission possibilities, technological bottlenecks, etc.

Through R&I activities, the next generation of TCMS will overcome current limitations through the introduction of **wireless** capabilities, full **driven-by-data** commands, **seamless coupling**, **enhanced throughput** and reliability, and new architecture based on **distributed functions** while supporting **safety** and **security** functionalities. This will further support easier **authorisation** and **self-configuration**.

The deployment of the next generation TCMS will contribute to achieving capacity targets and reducing the LCC of the assets while increasing performance.

The introduction of **complete interoperability** from the TCMS perspective, including the virtual coupling and functional open coupling concepts, will pave the way for a new way of operating trains by creating **chains of virtually coupled trains**.

Through the virtual coupling of trains (VCTS), where consists run together, coupled but without any physical connection, consists manufactured by different companies and with different interfaces can be virtually coupled, driven together by the leading cabin and sharing the same traffic slot. Pushing the concept to its limit, it would be possible to couple and uncouple consists on the fly (i.e. while both consists are moving or even cruising) and increase significantly the capacity of the line by making long chains of virtually coupled trains.

Although this concept will be developed in IP2 (TD2.8, Virtually Coupled Train Sets) the TCMS infrastructure required is targeted by this TD.

1.2.2. Technical objectives

The following are the main technical objectives of this TD.

- Reduce the amount and weight of cabling for train control by half (saving 10 km of cable for each 20 m of railcar). Reduce the space used by electronics hardware by 25 %.
- Gain the ability to implement Safety Integrity Level (SIL) 4 functions through the TCMS to perform additional safety-critical tasks.
- Reduce the operational unavailability of the TCMS by 50 %.
- Gain the ability to couple any pair of multiple units of different types, a feature currently totally non-existent and which can significantly increase line capacity (by 5 % more trains per hour).
- Support technologically the development of the virtual coupling concept, which can dramatically increase the capacity of lines.
- Reduce cost, time and effort spent on project engineering, integration and authorisation phases by 50 %.
- Reduce the maintenance and operation costs of the TCMS by 50 %.

1.2.3. Technical vision

The next generation of the TCMS is based on new architectural principles around a function-centric approach, supported by new technologies and well-proven concepts from other sectors where safety, security, performance, interoperability, connectivity, cost-efficiency and dependability are the key words.

Thus, the technical vision for the new generation of the TCMS proposed in S2R is based on the following:

- dependable wireless communications intra-consist (wireless consist network – WLCN), between consists (wireless train backbone – WLTB) and between trains (VCTS);
- standardised and secure train-to-ground link to make vehicles full players in the digital railway concept;
- less on-board electronics but with high levels of standardisation and compatibility (this reduced number of processors will handle any function from any system);
- architectures and communication technologies prepared for mixed-criticality data transmissions, and in any case supporting functions up to SIL 4;
- application (function) profile definition and standardisation;
- functional open coupling as the definitive way to achieve the full functional interoperability between consists;
- a virtual certification and testing platform with software in the loop, hardware in the loop, remote connectivity of subsystems and tooling, for time- and cost-efficient certification and authorisation.

STATE OF THE ART	NEW GENERATION TCMS
Wired TCMS entails a lot of cabling and connectors, and is a major source of failures; impaired data transmission through the auto-coupler	Wireless TCMS to reduce cabling and remove the need for physical contact in the auto-coupler, improving reliability and performance
TCMS up to SIL 2; safe trainlines still needed	Drive-by date concept – TCMS to provide SIL 4 capabilities that allow the integration of safety-critical functions; wired logics replaced by processors and/or field-programmable gate array
Architecture based on numerous central processing units (one or more per subsystem), distributed along the train; any software change in one of the subsystems requires recommissioning, as applications interface directly with the communication buses	Architecture based on a functional distribution among a reduced number of central processing units, where each function interfaces with the TCMS through a standardised framework; recommissioning only towards the framework is needed
Long and costly online debugging and commissioning processes; integration tests require the physical presence of subsystem suppliers	Use of a standardised simulation framework to virtually test and certify the TCMS and its applications, including train virtualisation, remote connection through the internet and hardware in the loop
Interoperability is impaired by incompatible coupling vehicles; they require not only identical physical interfaces but also compatible TCMS application software (i.e. the same on-board services, software versions and functions)	The deployment of the wireless TCMS and the standardised functional distribution architecture and the definition of standardised application profiles allow seamless coupling of vehicles
The train-to-ground link is not standardised, so no interoperability is possible for functions requiring such a connection (e.g. energy metering); Roll2Rail will propose a standard that will require further implementation and validation	Standardised train-to-ground communication will ensure interoperability and pave the way for the deployment of new functions, transforming the train into an extension of the railway undertaking’s network

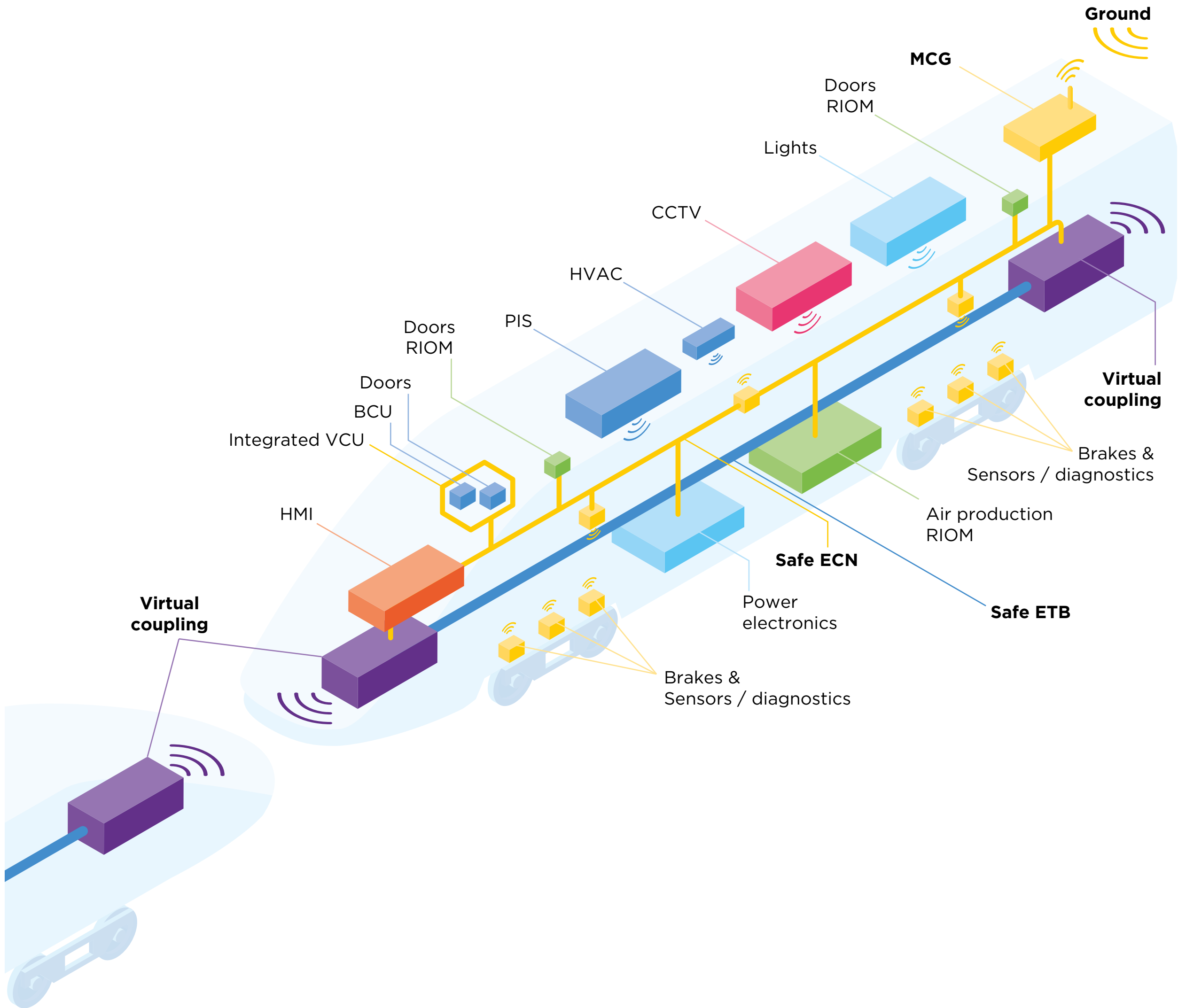


Figure 5 / ***Future TCMS architecture***

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs (see Figure 6), both from the point of view of technologies employed and of interaction in performance and objectives are:

- TD1.4, Running Gear – to support data transmission for new sensor concepts and the safe management of new mechatronics;
- TD1.5, Brake Systems – providing safety-critical architectures and protocols interfacing with the brake system to support the brake-by-wire concept;
- TD1.8, HVAC – standardisation of data interfaces of HVAC units;
- TD2.1, Adaptable Communications – clear synergies between TD1.2 and TD2.1, as the communication system for signalling should be complementary to that for TCMS, sharing most of the infrastructure, concepts and protocols, and coordination and cross-feeding of these TDs will be crucial for success;
- TD2.2, Railway Capacity Increase (ATO up to grade of automation (GoA) 4) – TD2.2 goal supported by the specification of the defined interfaces for the automated train operation (ATO) system;

- TD2.8, Virtual Coupling – TD1.2 expects to receive requirements from the Virtual Coupling TD, to be taken into account in the development of technologies, devices and software, and wireless components developed as part of TD1.2 will then be delivered, once tested, to TD2.8 for possible integration and demonstration, if required;

- TD2.11, Cybersecurity – having a single approach to railway telecommunications seems to be a wise option, and the starting point for both TDs will be the findings of Roll2Rail (GA 636032).

- TD2.5, Train Integrity – TD1.2 will involve developing a safe train inauguration with the creation of a safe train topology database (TTDB), to be straightforwardly reused in T2.5, as the TTDB contains the required information for train integrity in a safe way (SIL 4);

- TD5.5, New Freight Propulsion Concepts – providing support to wireless communication along long freight trains;

- CCAs – during the life of the TD, values concerning KPIs and proposals for standards will be delivered to CCAs (WA2 and WA3). In addition, the TCMS simulation platform and train virtualisations should be used as common platform for integrating all subsystem models and hardware in the loop used for virtual certification (WA3.5).

Moreover, the TCMS system being the central system for processing and communications within the train, some level of interaction will take place with all new developments related to on-board equipment, which should be fully compliant with the newly generated train control network (TCN) standards.

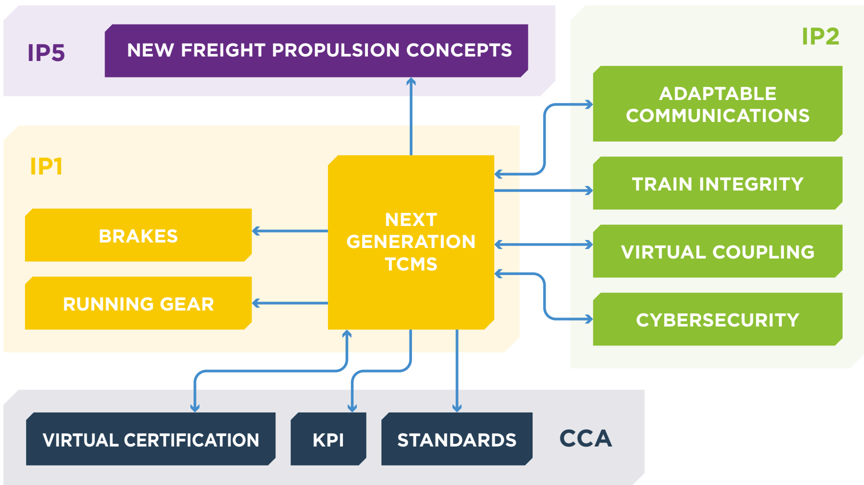


Figure 6 / ***Interaction with other TDs and IPs***

In addition, the existing interactions with other IPs and within relevant TDs of IP1 take into account the work on the S2R system architecture performed in IPX.

1.2.4. Impact and enabling innovation capabilities

The specific benefits of the new TCMS will have a major impact on the S2R system-level KPIs. The relative weights of the benefits provided by this work (in relation to a total of 100 %) are estimated in the table below, which provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Technological leadership supported by a combination of radical innovation (wireless TCMS, drive-by-data, distributed processing for higher reliability, etc.) and technical standards, establishing an effective advantage for the European industry • Tangible benefits for the end user: / increase in capacity (potentially up to 20 %) owing to flexible coupling between units and also to a reduction in service disruptions causing line blockages and delays / increase in operational reliability (potentially up to 50 %) owing to new, more robust TCMS architectures based on integrated electronics, less cabling and connectors, enhanced validation and debugging concepts, and more flexible processing of information specifically aimed at reliability and a reduction in the number of components / reduced LCC (potentially up to 30 %) owing to reduced engineering, testing and authorisation efforts, integration of multiple functions (including safety-critical ones), reduced weight and improved maintenance / additional performance and service through TCMS covering fail-safe functions, flexible coupling of trains, and train-to-train and train-to-ground communications
Compliance with EU objectives	• Promotion of modal shift: a big impact brought about by the implementation of these new technologies aimed at avoiding service disruptions and adding new innovation capabilities • Support for capacity increase: as mentioned above, this will be enabled by flexible unit coupling and fewer service disruptions due to lack of operational availability • Greening of transport through energy reduction can be achieved by better integration between subsystems and communications out of the train, as well as optimised consists with flexible coupling
Degree of maturity of the envisaged solutions	Currently, most of the proposed technologies are at TRL 1 or 2 (principles observed and the possibilities for using them formulated). At the end of S2R it is expected that the successful concepts will have been brought to TRL 6 or 7

This TD will contribute to enabling the following five innovation capabilities.

INNOVATION CAPABILITY	TD1.2 TCMS
1– Automated train operation	*BB1.2.1: Wireless TCMS, BB1.2.2: Drive-by-data* Support virtual coupling and platooning through wireless and safe communications, and functional open coupling
2 – Mobility as a service	*BB1.2.1: Wireless TCMS* Provides on-board infrastructure for digital services, as well as the link between train and ground
4 – More value from data	*BB1.2.1: Wireless TCMS, BB1.2.2: Drive-by-data, BB1.2.3: Functional distribution architecture* Provide on-board infrastructure for data acquisition, local management and transmission
5 – Optimum energy use	*BB1.2.1: Wireless TCMS* Supports energy-efficient train management

INNOVATION CAPABILITY	TD1.2 TCMS
6 – Service operation timed to the second	*BB1.2.1: Wireless TCMS* Allows and supports advanced health-monitoring systems, provides on-board infrastructure for condition-based maintenance
7- Low-cost railway	*BB1.2.2: Drive-by data, BB1.2.3: Functional distribution architecture, BB1.2.4: Virtual placing on the market of TCMS* Simplification of electronics and cabling; seamless integration of functions through standardised application profiles, interfaces and hardware components; greater interoperability between trains and fleets, fewer failures and shorter repair times, leading to smaller fleets; quicker and more cost-effective virtual certification
8 – Guaranteed asset health and availability	*BB1.2.1: Wireless TCMS* Provides higher TCMS availability and on-board infrastructure for condition-based maintenance
9 – Intelligent trains	*BB1.2.1: Wireless TCMS* Infrastructure to support train intelligence
10 – Station and smart city mobility	*BB1.2.1: Wireless TCMS* Infrastructure to support enhanced train-to-ground capabilities

1.2.5. Demonstration activities and deployment

The following table summarises the contribution of TD1.2, TCMS, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
TCMS	Wireless TCMS	Radio technology, architecture and protocols	Metro	6/7	Incorporate wireless technologies into train communication network solutions (i.e. train backbone, consist network and train-to-ground communication)
			Regional	6	
	Drive-by data	Architecture, protocols	Metro	6/7	Provide a train-wide communication network for full TCMS support, including the replacement of trainlines, connecting safety functions up to SIL 4 (including signalling)
			Regional	6	
	Functional distribution architecture	Specification, architecture and interface definition	Metro	6/7	New architectural concept based on standard framework and application profiles, distributed computing to allow execution of compliant functions on end devices distributed along the vehicle, meeting different safety and integrity requirements
			Regional	6	
				5	Support functional open coupling
	Virtual placing on the market	Technology definition, protocols and procedures	Generic	5/6	Standardised simulation framework in which all subsystems of the train will be simulated, allowing remote and distributed testing, including hardware in the loop, through heterogeneous communication networks

Two ITDs are anticipated for the TCMS: one regional ITD involving different members to check interoperability, and one metro ITD to test innovations under the most severe conditions (e.g. multiple radio signals, tight tunnels).

The new TCMS will be deployed for full-scale demonstration on a metro vehicle, including wireless features (train-to-ground communication and WLTB), SIL 4 capability and the new functional distribution architecture, and integrating innovations from other TDs (e.g. running gear monitoring and traction).

Two wireless communication networks will be deployed on two regional consists by different members in order to allow for additional interoperability tests when they are coupled together. Technical solutions to demonstrate train-to-ground communication in a regional ITD will be developed. The regional demonstrator will test the coupling of units in a laboratory, and wireless train-to-ground communication and WLCN in a real unit.

Members will be requested to provide at least a regional consist each for the integration of the new TCMS components. The other regional consist may be provided by a train operating company outside the JU membership if necessary.

All the principal elements required for rapid market uptake of this R&I output have been taken into account.

These are:

- demonstration of technologies in a real operational environment to give credibility and show the benefits clearly;
- common standard architectures based on interoperable black-box concepts;
- development supported by technical standards, which will increase the confidence of future clients and facilitate quick deployment in new projects.

The standardisation groups and committees concerned – such as the IEC TC9 Working Group 43, in charge of the International Electrotechnical Commission (IEC) 61375 series of standards; the European Telecommunications Standards Institute; and the 3rd Generation Partnership Project – will be provided with the results of TD1.2, making it possible, among other things, to fulfil the mandate from ERA to finalise the standard in order to refer to it from the Locomotive and Passenger Rolling Stock Technical Specification for Interoperability (Loc&Pas TSI).

It can be expected that between 3 and 5 years after S2R the new developments will be implemented in a high percentage of all new vehicles (estimated to be implemented in 40–80 % of all new projects in Europe and 30–60 % of all new projects worldwide).

Planning and budget

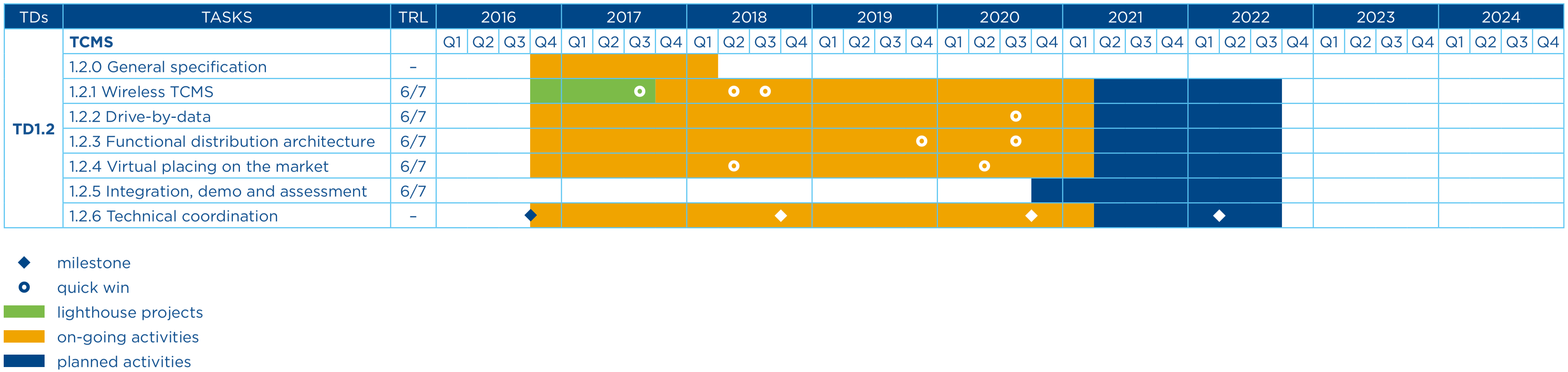


Table 4 / ***TD1.2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2017	Wireless communications evaluated in the laboratory	Main outcome of Roll2Rail (GA 636032) allows the selection of technology to be tested later on a real vehicle
Q2 2018	Interoperability tests of the new train-to-ground communication based on IEC 61375-2-6	Opens the door to implementing further applications using the train-to-ground link and assures interoperability; this quick win is key to integrating the vehicle into the digital railway world.
Q2 2018	Implementation of ECN/ ETB conformance testing	As ECN/ETB are the base for the other technologies developed within S2R, having conformance testing ready broadens the range of potential suppliers, improves competition and reduces costs
Q2 2018	Wireless ETB (WLTB) tested on a real vehicle	A fundamental step before prototyping equipment can be deployed in the ITDs; final validation of the technologies
Q3 2018	Connected trams at InnoTrans 2018	Full-train connectivity (train-to-ground and train-to-train); first steps towards virtual coupling
Q4 2019	Functional open coupling proof of concept	To achieve complete interoperability, increase line capacity and flexibility; a key technology for the virtual coupling concept
Q2 2020	Validation of the TCMS simulation framework	This is the starting point for the virtual certification of TCMS, which should dramatically reduce the costs of commissioning
Q3 2020	Prototype of SIL 4-capable ECN/ETB	An important intermediate step towards enabling the removal of cabling, reducing weight and complexity, and integrating new safety electronics for brakes
Q3 2020	Prototype of a vehicle control unit implementing the functional distribution middleware	Functions of different natures and safety levels can then be integrated into the control unit to reduce the number of on-board electronics and facilitate exchangeability and recommissioning

Table 5 / ***TD1.2 milestones***

WHEN	WHAT
Q3 2016	Start of S2R TD1.2 activities with the 2016 call for projects Connecta (GA 730539) and Safe4Rail (GA 730830), with the specification- and architecture-related activities (left side of the V-model)
Q3 2018	Start of prototype implementation phase (bottom part of the V-model)
Q3 2020	Start of the refactoring and integration into the ITD (e.g. modification of vehicles) phases (lower right side of the V-model)
Q1 2021	Start of the on-track testing and assessment phases (upper right side of the V-model)

The estimated total budget for the TCMS TD is around EUR 48.8 million.

1.3. TD1.3 Carbody Shell

1.3.1. Concept

The function of a carbody is to be the passenger transport container and also the physical link between all the elements of the vehicle.

Historically, passenger coaches were formed of a frame normally made of steel, which received the loads coming from the track and the other coaches, and of a cover, which incorporated the doors, windows and gangways.

Recent years have seen the progressive incorporation of non-metal parts into carbodies, such as in front cabs, rear ends, fairings, floors (floating or fixed) and under-frame coverings. All those parts are made of composite materials, which may include metal parts but in a lower proportion than in the past.

In the aeronautical industry, there has been an increase in the use of non-metal materials for structural components. There has also been a corresponding increase in knowledge of composite material behaviour and all issues relating to the safety of composite materials.

Therefore, it seems logical that such developments could take place in the rail industry, and this project specifically focuses on the primary structure of the carbody.

The main innovation of this TD is the use of composite materials in a hybrid carbody, in relation to which technical and commercial issues will be investigated. The current performance of the metal primary structures in terms of safety, durability and maintainability will be maintained or improved with the technologies developed and evaluated with this demonstrator.

1.3.2. Technical objectives

The following are the main technical objectives of this TD:

- a weight reduction of between 15 % and 30 %.
- energy savings in operation of 2–12 %, resulting from the weight reduction;
- improved maintainability, as a result of new concepts;
- the introduction of a specific health-monitoring system for the structures.

1.3.3. Technical vision

Aluminium carbodies were first single-walled and then double-walled extrusions, to increase stiffness and also to avoid the need for extra reinforcement.

Progress has also been made on steel carbodies, with continual reductions in steel-sheet thicknesses and ever smarter designs.

Therefore, non-supporting, partially supporting and self-supporting superstructures have been developed.

Composite parts have started to be used in secondary structures such as driver cabs, rear ends, fairings, floors and under-frame structures; however, there is little use of them in primary structures.

The current state of the art includes composite parts in secondary structures and assembly methods other than welding, such as riveting and bolting, to reduce costs and manufacturing time.

Although steel and aluminium cope well with the loads applied and also with carbody functions, weight reductions can be made by using materials other than metals. This has been proved in the aeronautical industry, where composites are increasingly being used in structural parts after having passed all tests regarding safety.

In addition, manufacturing processes for composite materials have evolved from completely manual manufacturing to more automatic processes. New processes allow greater repeatability and thus more control over quality.

In conclusion, lighter carbodies could be made using industrial processes, provided that adequate joining methods are used and there is compliance with rail safety standards.

The following table summarises how this TD will progress the state of the art and overcome today's limitations and difficulties.

STATE OF THE ART	NEW GENERATION CARBODY SHELLS
Full-steel carbodies, made of thin steel sheets, cast parts, extrusions or formed sheets; no proportionality between density and strength of base material	New carbodies with reduced weight
Full aluminium carbodies, made of extrusions, sheets, and/or reinforcements; more effective in manufacturing but with similar final weights to steel; a loss of interior space owing to the need for high inertia in the aluminium	New carbodies with significant reductions in weight that can also have a high proportion of the insulating material in their interiors
Carbodies with a primary structure of steel and aluminium, as mentioned above, to which metal or composite secondary structures are joined; the design of those joints requires significant reinforcement in some cases	As composite materials are created in the manufacturing process, the possibility opens up of better integrated and less heavily reinforced structures

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and of interaction in performance and objectives are as follows.

- TD1.4, Running Gear – there are activities in the TDs that have commonalities, such as the development of running gear subsystems made of advanced new materials. The validation processes employed to allow the use of carbody and running gear structures will have many points in common.
- CCAs: throughout the duration of the TD, values concerning KPIs and proposals for standards will be delivered to CCAs.

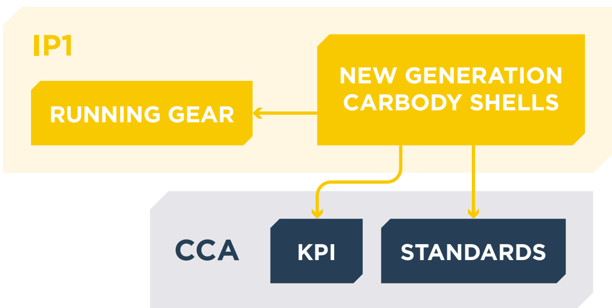


Figure 7 / ***Interaction with other TDs and IPs***

1.3.4. Impact and enabling innovation capabilities

The new carbody shells' specific benefits will have a major impact on the S2R system-level KPIs. The relative weights of the benefits provided by this work (in relation to a total of 100 %) are estimated in the table below, which provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Weight reduction	A lighter structure will allow an increase in the payload or technical equipment weight up to the TSI limits. Increased train capacity will make it possible to divide the maintenance cost among more passengers per train while keeping the price of maintenance steady
Improvements in manufacturing technologies	It is also expected that replacing some composite parts in the carbody may be quicker and less costly than replacing welded metal parts (repairing certain metal structures can be somewhat complex). Depending on the raw materials chosen, it is expected that the processes used for forming composite parts will be able to compete with those used for metals
Integrating functions into the parts made of new materials	Train functions such as the thermal insulation can be integrated into a carbody made of several materials, mainly composites, thus saving space and weight. In addition, integrating functions such as air conduction, piping, etc., can make the whole carbody system less prone to needing corrective maintenance
More attractive products	Vehicle structures made with these new materials will benefit from more space within the vehicle and therefore greater passenger comfort. In addition, a reduction in the time-to-market in both manufacturing and operational (repairs) periods is expected
Development of new skills in the railway industry	These technologies will have an impact on the way in which railway vehicles are produced and maintained, keeping the value added by the conventional metal constructions and adding new value from industries that are already producing systems for the aerospace and automotive sectors
Positive side effects for suppliers and research institutes	The need to decide on the physical characteristics of composite material systems will create activity in industries and research centres specialising in composite materials that are already working for other sectors, and will now gain experience in railway structural applications for composite materials

This TD will contribute to enabling the following two innovation capabilities.

INNOVATION CAPABILITY	TD1.3 CARBODY SHELL ENABLERS
5 – Optimum energy use	*BB1.3.1: Composite hybrid carbody shell* Increased space available within the vehicle through reduction in the size of the structure sections thanks to the new materials, together with mass reduction allowing more passengers or equipment within the axle load limit
7 – Low-cost railway	*BB1.3.1: Composite hybrid carbody shell* Integrating functions such as air conduction, pipes, etc., can make the whole carbody system less prone to needing corrective maintenance, and thus modularity involves less inspection and time for replacing parts. It is also expected that replacing some composite parts in the carbody may be quicker and less costly than replacing welded metal parts.

1.3.5. Demonstration activities and deployment

The following table summarises the contribution of TD 1.3, Carbody Shell, to the different ITDs of S2R.

<table>
<tr><th rowspan="2">RESEARCH AREA</th><th rowspan="2">SPECIFIC TECHNICAL OBJECTIVE</th><th rowspan="2">SPECIFICATION ACTIVITIES</th><th colspan="2">DEMONSTRATOR</th><th rowspan="2">FOCUS OF ACTIVITY</th></tr>
<tr><th>MARKET</th><th>TRL</th></tr>
<tr><td rowspan="3">Carbody shell</td><td rowspan="3">New materials in train carbody structures, to reduce weight and/or improve manufacturing process cost-effectiveness</td><td>Full high-speed intermediate coach of a Talgo 350 type train</td><td rowspan="2">High speed</td><td>5/6</td><td rowspan="3">The demonstration activities will have the following objectives for all the TD1.3 demonstrators:
• demonstration of the new materials' adaptability for the functions intended in the carbody structure
• demonstration of the joining techniques between the new materials (composites) and also between composites and metals
• demonstration of the achievability of the objective of weight reduction (between 15 % and 30 % forecast)
• explanation of the manufacturing, maintainability and repairability concepts for the railway environment
• proposal of standardisation and certification approaches (design, calculation, manufacturing, repair, etc.), and the common specifications for future composite material-based architectures</td></tr>
<tr><td>Coupler end of a Siemens Velaro HST made of carbon-fibre reinforced plastic</td><td>3/4</td></tr>
<tr><td>End structure of an under-frame area (called the headstock) for the end car of a Bombardier metro train</td><td>Metro</td><td>3/4</td></tr>
</table>

One of the main purposes of the demonstrators is to validate methods (design, calculation, manufacturing and testing) leading to the creation of standards that allow the easy and economical certification of the vehicles.

All the principal elements required for rapid market uptake of this R&I have been taken into account.

These are the use of:

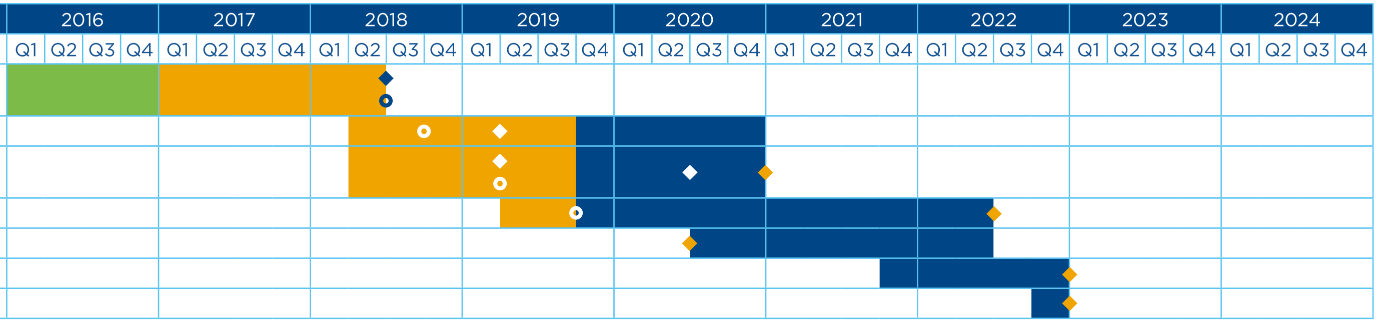
- manufacturing and testing techniques that have long been used in the aerospace industry and other industries in relation to composite materials, especially those that could match the costs targets typical of the railway industry;

- hi-tech materials that have proven to have excellent fatigue-resistance and serviceability properties in other sectors.

It can be expected that between 3 and 5 years after S2R, new standards will be in place that will simplify the implementation of these new structures.

Planning and budget

TDs	TASKS	TRL
TD1.3	**Carbody Shell**	
	1.3.1 Specifications	2
	1.3.2 Conceptual design	2
	1.3.3 Characterization activities	2
	1.3.4 Detail design	3
	1.3.5 Manufacturing	4/7
	1.3.6 Assembly	4/7
	1.3.7 Testing	–



◆ milestone
○ quick win
lighthouse projects
contracted activities
planned activities

Table 6 / ***TD1.3 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Technical specification of all the physical demonstrators	First tangible objective, which establishes the procedure for continuing work in the coming years
Q3 2018	Demonstration of all the material alternatives found for each part of the carbodies (zones that will be metal, zones that will contain composite type A, zones that will contain composite type B, etc., for the different demonstrators	A key activity within the project, this involves assigning the right material to the right place within each carbody, and should provide first estimations of mass reduction and information on the manufacturing technique to be used
Q1 2019	Conceptual design of the carbody or parts	This is the starting point for the detailing engineering and subpart design; at this point, all the manufacturing processes and joining methods will be chosen
Q3 2019	Safety assessment of the carbody or parts	Another key activity, in which the safety levels of the composite or hybrid assemblies have to be assessed, to maintain or improve on the safety levels of the current state-of-the-art metal assemblies

Table 7 / ***TD1.3 milestones***

WHEN	WHAT
Q2 2018	Demonstrator specifications
Q1 2019	Studies on material and manufacturing alternatives for demonstrators
Q1 2019	Conceptual design of demonstrators
Q2 2020	Structural and non-structural assessments, and noise and vibration harshness measurements
Q4 2020	Completion of design for manufacturing (drawings and specifications)
Q2 2020	Start of demonstrator manufacturing
Q4 2022	End of validation tests
Q4 2022	Final report

The estimated total budget for the Carbody Shell TD is around EUR 26.7 million.

1.4. TD1.4 Running Gear

1.4.1. Concept

Running gear systems are required to deliver safety, reliability, comfort and performance. The scope for improvements in performance and reduction in wear using conventional systems and without compromising safety and comfort is small.

The work to be carried out in this TD includes:

- development of new sensor architectures and functionality to monitor both running gear and track;

- validation and certification of lightweight and optimised materials for the running gear environment;
- specification and validation of actuator technology to control running gear and wheelsets;
- development of a new noise and vibration assessment methodology.

The next generation of running gear solutions needs to deliver reduced infrastructure/wheel wear and damage, while providing greater reliability and availability, with lower maintenance costs. This challenge is made greater by the need for increased high-speed stability, excellent curving performance, improved comfort and optimised systems for both airborne and structure-borne noise.

Train operators are also increasingly focusing on reducing energy usage, so innovative solutions are needed to reduce energy loss through rolling resistance, as well as aerodynamic drag, and to reduce vehicle and running gear mass.

All these requirements have to be met without compromising safety. The solutions will also provide enablers for far-reaching technology advances in the long term, and this will be taken into account from the specification stage.

New innovative running gear solutions support improved capacity, reduced LCC and improved performance.

1.4.2. Technical objectives

The following are the main technical objectives of this TD:

- weight reduction, which will facilitate a reduction in the engineering and integration efforts and generate energy savings through the whole life cycle;
- lower unsprung mass, which will help to reduce track damage, wear and vibrations, contributing to a reduction in system cost of up to 20 %;
- a reduction in wheel and rail wear (especially rolling contact fatigue) through improved (controlled) performance on straight as well as curved tracks, including wear-resistant materials, which will contribute to a cost reduction of up to 20 %;
- improved ride conditions through the use of active/semi-active suspension systems;
- a reduction in running gear-associated inspection and maintenance through monitoring, which will contribute to a maintenance cost reduction of up to 20 %;
- a reduction in the costs of running gear sensor equipment of up to 20 %;
- standards that support the introduction of advanced materials, sensors and monitoring, and active control systems;
- recommendations for validation methods for reduced noise and vibration from running gear;
- more efficient authorisation, with a reduction of up to 30 % in cost, time and effort.

1.4.3. Technical vision

The next generation of running gear solutions needs to deliver reduced infrastructure/wheel wear and damage, while providing higher reliability and availability, with lower maintenance costs.

The work to be carried out in this TD includes:

- development of new sensor and health-monitoring architectures and functionality to monitor both running gear and track;
- validation and certification of lightweight and LCC-optimised materials for the running gear environment;
- specification and validation of actuator technology to control running gear and wheelsets;
- development of a new noise and vibration assessment methodology;
- creation of a breakthrough in the performance of the authorisation process.

The approach begins with a thorough review of the specifications and requirements of the running gear of the future. In the second phase, technologies are individually developed; this covers the whole development process including basic research, lower level specifications, technology development, prototypes and laboratory tests, confirming performance and gaining a more comprehensive understanding of these technologies. Next, specifications and architectures at a whole-system level are reassessed and the most appropriate solutions for the different types of services and operational conditions are proposed. The final tasks are twofold.

1. A number of different running gear solutions bringing clear contributions to the S2R global KPIs are verified using demonstration scenarios.
2. Technical standards based on the technologies proposed are developed to promote future deployment.

In addition, the authorisation process needs attention to enable the innovations to be introduced into the operational environment.

STATE OF THE ART	NEW GENERATION RUNNING GEAR
Trailer bogies designed for a 20-tonne axle load are approximately 6.5–7 tonnes in weight and contain around 90 % steel	Future trailer bogies are around 5–5.5 tonnes in weight, with functional integration of suspension, frames, wheelsets and brake equipment, and using lightweight materials; further reduction will be introduced with new running gear concepts
Various requirements implicitly/historically consider steel the preferred material (e.g. fire regulations, and maintenance, inspectability and fatigue-resistance standards)	Harmonised requirements and design principles applicable to materials other than steel, allowing new, lightweight components and/or concepts to be applied to running gear
Architecture based on steel material capabilities	New materials allowing functional integration and new running gear concepts/architectures, including mechatronics
Traditional breakdown of components of functions with established (sometimes not very innovative) suppliers	New concepts and materials allowing new types of components and different integration to achieve new solutions, allowing new suppliers from other sectors to enter the market
Lightweight perceived as costly	Cost-efficient/cost-neutral lightweight solutions

STATE OF THE ART	NEW GENERATION RUNNING GEAR
Uncertainty about the benefits of lightweight design and materials for running gear	Clarity about the 'which, where and how' of light solutions and their benefits (technology roadmap)
Sensors specially developed or customised for running gear applications, produced in small volumes and at a high cost	New standardised sensors fit for purpose for running gear applications that can be produced in large volumes at a lower cost
Expensive cabling in running gear because of the mechanical protection required for the cables	Wireless sensor networks in running gear
Energy supply to sensors via cables from the carbody, leading to complex cabling inside the running gear and the carbody.	Sensors with efficient energy management and energy harvesting inside the running gear or even the sensors
Specific and different solutions for communication and integration into train-level systems exist	Clear standards for interfaces with train-level systems and maintenance systems enable compatible running gear sensors
Self-guiding: owing to wheel conicity, solid axles automatically steer themselves on curves. For independently guided wheels, the guiding mechanism changes the angle of attack to try to keep wheels parallel to the rails. In service, this simple principle involves some guiding errors that increase noise and wear both in wheels and in rails	Optimised methods to guide axles and wheels, taking into account actual track geometry
Lateral suspension: passive oil dampers that decrease the amplitude of carbody lateral oscillations	Semi-active and/or active dampers that react to lateral oscillations, taking into account the frequency and actual velocity and displacement of the carbody, to improve the comfort index
Vertical suspension: passive oil dampers that decrease the amplitude of vertical oscillations of carbody and/or running gear frame	Semi-active and/or active dampers that react to vertical oscillations, taking into account the frequency and actual velocity and displacement of the carbody and running gear frame, to improve the ride quality index
Virtual certification: today, the authorisation process for putting new rolling stock into service is largely based on full-scale field and line tests, which is expensive and time- and capacity-consuming. Moreover, it can be performed only at the end of the design process. There is therefore a clear need for a reduction in the duration and cost of the process.	The main target is to practically validate an overall industrial virtual certification process and to use it on real cases, demonstrating the approach (TRL 6/7)

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and of interaction in performance and objectives are the following.

- TD1.3, Carbody Shell – there are activities in the TDs that present commonalities in relation to developing carbody shells made or partly made of advanced new materials. The validation processes employed to enable the use of new carbodies and running gear structures will have many points in common.
- TD1.2, TCMS – the system architecture for any running gear and infrastructure monitoring will be based on standardised interfaces with the TCMS.
- Infrastructure – next generation passive/active suspension and curving control designs enable radical new thinking on wheel/rail conditions for reduced wear and damage (including rolling contact fatigue) on curved and straight tracks, as well as other high-cost infrastructure components such as switches and crossings. It is very important to consider

cost savings on infrastructure when seeking to demonstrate the benefits of developing new running gear.

- CCAs – throughout the duration of the TD, values concerning KPIs and proposals for standards will be delivered to CCAs.

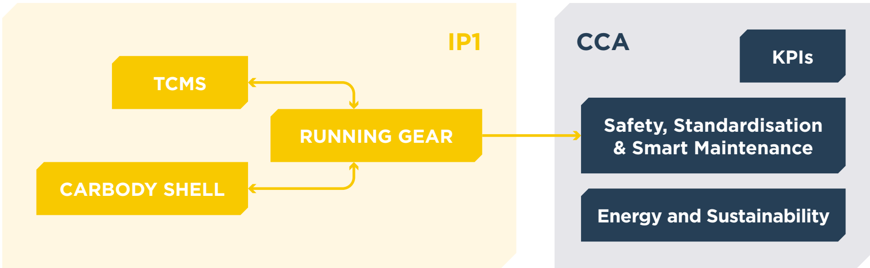


Figure 8 / ***Interaction with other TDs and IPs***

1.4.4. Impact and enabling innovation capabilities

The following table shows how the activities will contribute to the achievement of the S2R objectives.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Improved services and customer quality	Improved passenger comfort and increased availability
Reduced system costs	Enhanced overall curving and ride performance of new generation running gear; reduced running gear maintenance costs and reduced wheel and track LCC
Simplified business processes	Reduction in time and cost for the validation of lightweight materials, sensors and active control systems
Enhanced interoperability	Enhanced standardisation of sensor architecture and interfaces; standardised HW and SW communications protocols

This TD will contribute to enabling the following 10 innovation capabilities.

INNOVATION CAPABILITY	TD1.4 RUNNING GEAR
1 – Automated train operation	Autonomous trains can monitor themselves. Communication is possible between train, running gear and infrastructure. In-train signalling capability can be used to resolve infrastructure conflicts *BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance Development of new health-monitoring systems and innovative algorithms that allow condition-based maintenance of the track

INNOVATION CAPABILITY	TD1.4 RUNNING GEAR
2 – Mobility as a service	*BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance Development of new health-monitoring systems and innovative algorithms that allow condition-based maintenance of the track
4 – More value from data	*BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance Development of new health-monitoring systems and innovative algorithms that allow condition-based maintenance of the track
5 – Optimum energy use	*BB1.4.2: New materials for bogies* Lightweight and optimised materials validated and certified for the running gear environment
6 – Service operation timed to the second	*BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance Development of new health-monitoring systems and innovative algorithms that allow condition-based maintenance of the track

INNOVATION CAPABILITY	TD1.4 RUNNING GEAR
7 – Low-cost railway	*BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance *BB1.4.2: New materials for bogies* Lightweight and optimised materials validated and certified for the running gear environment *BB1.4.4: Virtual certification of bogies* Virtual testing and efficient implementation processes speed up production and deployment of new products; virtual certification methodologies using simulation and validation processes reduce costs for stakeholders There is close cooperation within the sector on standardisation and testing.
8- Guaranteed asset health and availability	*BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems Development of a wireless, on-board, in-service monitoring system with access to external information that provides the required data for condition-based maintenance
9 – Intelligent trains	Autonomous trains can monitor themselves. Communication is possible between train, running gear and infrastructure. In-train signalling capability can be used to resolve infrastructure conflicts *BB1.4.1: Bogie sensors and mechatronics* Establish an accepted general framework for developing health-monitoring systems for condition-based maintenance and interface with the TCMS Focus on open standards for bogie sensoring and solutions for safety-critical and non-safety monitoring systems
11 – Environmental and social sustainability	Green technologies enable the railway to operate exhaust emissions free and with low noise and vibration levels *BB1.4.3: Noise and vibration* Validated and refined methods for prediction and evaluation of new/improved noise-control measures; development of noise-optimised wheels
12 – Rapid and reliable R&I delivery	*BB1.4.4: Virtual certification of bogies* Virtual testing and efficient implementation processes speed up production and deployment of new products; virtual certification methodologies using simulation and validation processes reduce costs for stakeholders There is close cooperation within the sector on standardisation and testing

1.4.5. Demonstration activities and deployment

The following table summarises the contribution of TD 1.4, Running Gear, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Running Gear	Sensor and health-monitoring functionality	Architecture for health-monitoring systems, innovative algorithms, certification process and interface with the TCMS	Regional, high speed, metro, freight (locomotive)	6/7	Open standards for running gear sensors; solutions for safety-critical and non-safety monitoring systems
	Active suspension and control technology	Development, certification and tests of new active suspensions and radial steering		6/7	Solutions for suspension and running gear control technologies and their validation
	Noise and vibration reduction	New designs and materials to reduce noise emission	Metro	4/5	Validated and refined methodology for prediction and evaluation of new and improved noise-control measures
	Optimised materials	New materials, methods and manufacturing of frame components and wheels	Regional, high speed	6/7	New materials for lighter running gear, lower levels of degradation and lower railway system LCC
	Virtual certification	Methodologies using simulation and validation processes	Generic	6/7	The progressive use of simulation will enable an improved certification process to reduce costs for stakeholders

A key contribution of S2R is to provide new or revised standards for these emerging innovations to ensure that they can be certified for future rail contracts, specifically addressing the following issues.

- **Technical specification.** Define the general specification for new running gear layouts (with optional active technology). Specify related high-level architecture and interface requirements.

- **Sensor and health monitoring functionality.** Address the requirements of the recent TSI connected with sensors in running gears. Identify necessary new standards.

- **Optimised materials.** There will be standards such as fire, fatigue and inspection standards that need to be adapted because of the new materials and their specific characteristics. New standards may be required. An example would be the material characteristics of fibre-reinforced polymer (ballast impact).

- **Active suspension and control technology.** Some requirements of the recent TSI connected with static/dynamic tests to be performed during authorisation of future trains would need to be updated or modified. Related standards, such as EN 14363, could also be revised accordingly.

- **Noise and vibration reduction.** This TD will provide valuable input to future revisions of the noise TSI, since the running gear is the major contributor to pass-by noise at most normal running speeds.

- **Virtual certification.** The progressive use of simulation in several cases to be specified (cross-acceptance, vehicles with small modifications, out-of-range modelling of physical tests, etc.) will enable an improved certification process. Reduced times to market, more interoperable rolling stock, and cost savings for stakeholders and end users can be expected.

To guarantee rapid market uptake after S2R, the following elements have been taken into consideration.

- High-TRL demonstrators will be set up to prove and test different running gear solutions.

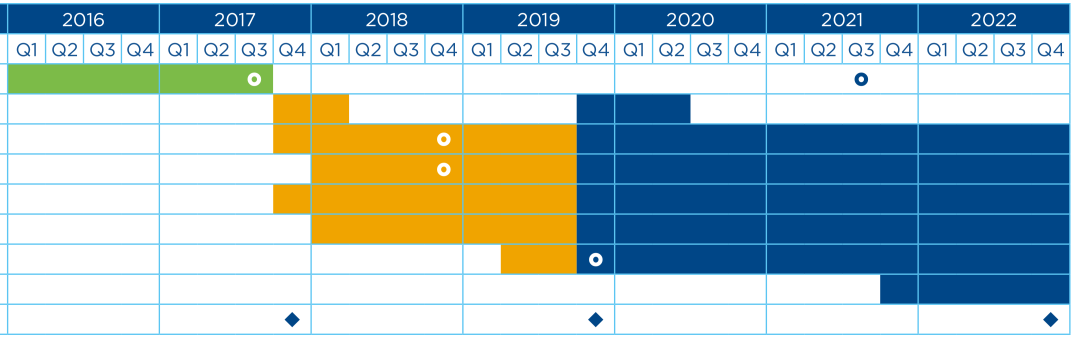
- Common technical standards for the technologies proposed will be developed.

- LCC modelling methodologies will be developed to evaluate benefits.

The adaptation of technical standards will have a major impact on the next generation running gear in terms of competitiveness and reliability. In addition, the adapted technical standards will contribute to swifter development of new running gear and faster market introduction.

Planning and budget

TDs	TASKS	TRL
TD1.4	**Running gear**	
	Roll2Rail – Universal Cost Model	–
	1.4.1 – Technical specification	3
	1.4.2 – Sensors and health monitoring	6/7
	1.4.3 – Optimised Materials	6/7
	1.4.4 – Suspension & Bogie control technology	3/7
	1.4.5 – Noise and Vibration	7
	1.4.6 – VIrtual Homologation	6/7
	1.4.7 – Reporting	–
		–



- ◆ milestone
- ○ quick win
- lighthouse projects
- contracted activities
- planned activities

Table 8 / ***TD1.4 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2017	Universal cost model	Main outcome of Roll2Rail (GA 636032) allows the validations running gear innovative equipment/solutions considering the energy, noise, infrastructure and vehicle costs/savings.
Q4 2018	Prototype of novel sensor system for health-monitoring systems	Specification and requirements for sensors and architecture for health-monitoring systems, innovative algorithms, certification process and interface with the TCMS
Q4 2018	New, non-conservative materials for wheels	The main advantages of such a wheel are reduced weight, less wheel wear, less tendency towards polygonisation and low noise emission
Q4 2018	Composite running gear frame components	New designs for frames components using lightweight materials; bench tests of the manufactured components
Q4 2019	Methodologies using simulation and validation processes	Establishment of an improved overall industrial virtual certification method for running gears, following the guidelines established by EN 14363:2016 to reduce on-track tests in favour of increasing simulations and bench tests
Q3 2021	Universal cost model 2.0	Building on the universal cost model results from Roll2Rail to create an open tool for the railway industry, making the model more user-friendly, more consistent and simpler

Table 9 / ***TD1.4 milestones***

WHEN	WHAT
Q4 2017	Start of S2R TD1.4 activities with the 2017 call for projects: PIVOT and the related Open Calls (OCs)
Q4 2019	PIVOT and OC ending. Start of PIVOT2. Manufactured prototypes of the running gear technical work streams are available or prototypes are ready for manufacturing
Q2 2023	PIVOT2 ending. S2R programme ending. Final report

The estimated total budget for the Running Gear TD is around EUR 23.9 million.

1.5. TD1.5 Brake Systems

1.5.1. Concept

The brake system of a train is a mission-critical system, which ensures the safe transport of passengers and goods and also the safety of humans in the train's environment.

The main tasks of a brake system in a rail vehicle are to:

- reduce the speed of a travelling train or vehicle in accordance with the operational conditions and to stop it completely if necessary;
- keep the speed of the travelling train or vehicle constant when travelling down gradients;
- secure standing (stopped) trains or vehicles against unintentional movement for a limited time;

- secure standing (parked) trains or vehicles against unintentional movement for an indefinite length of time (without any energy available on board).

Today, brake systems in the railway still rely on hardwired and/or pneumatic signals and on pneumatic brake controls to achieve the required level of safety (SIL 4 is required for the overall brake system). Today's brake system still ensures safety by dissipating kinetic energy into thermal energy using friction brakes.

As a result of R&I activities, next generation brake systems will overcome current limitations through the introduction of adhesion management solutions, brake energy recuperation technologies and brake control solutions embedded in TCMS solutions of the future; electromechanical brake systems will supersede pneumatic and/or hydraulic solutions.

Also relevant to R&I on future brake systems are ATO scenarios, support for virtual certification of brakes and efficient brake systems for freight trains.

Based on the requirements for safety (i.e. some brake functions will require higher safety levels in the future), the deployment of next generation brake systems will contribute to achieving capacity targets, reducing LCC, making diagnosis and maintenance easier and more efficient, and improving performance.

1.5.2. Technical objectives

The following are the main technical objectives of the Brake Systems TD:

1. ability to implement highly safety-relevant brake control functions in HW/SW architecture compliant with SIL 3 or 4;
2. ability to connect the brake control unit to the next generation TCN (as defined in TD1.2), supporting critical safety functions;
3. reduction in braking degradation in poor adhesion conditions, from the 25 % prescribed by the International Union of Railways (UIC) leaflet 541-05 to 15 %;
4. innovative friction pair solutions, lightweight (e.g. ceramic) brake discs, improved LCC;
5. enhanced, fail-safe electromechanical brake systems;
6. standardisation of the brake system assessment processes;
7. methods and tools for virtual certification of brake systems.

1.5.3. Technical vision

Pneumatic systems (or hydraulic systems) are mature technologies dominating the market, but future brake systems follow three megatrends:

- safe braking under all conditions (even low-adhesion situations);
- brake-by-wire (or brake-by-data) architectures;
- vision of an air-free train without a pneumatic system for brakes, doors and suspension.

Wheel-to-rail contact not only causes significant uncertainty when predicting braking distances but also is a general bottleneck with regard to the achievable braking performance of the train and, to a substantial degree, the traction effort as well. For environmental and technical reasons, the conditions for wheel-to-rail contact are highly variable and cannot be predicted exactly. They very much depend on different positions of the wheel on the track as well as on different travel times, seasons, etc. This negatively influences a large number of rail traffic characteristics, such as headway, punctuality and in particular safety.

Managing especially low or insufficient adhesion conditions can reduce braking distances. Thus it is important to minimise variation under comparable conditions. Future adhesion management will contribute significantly to a capacity increase in railway operation.

Ceramic brake discs weigh around 50 % less than conventional grey cast-iron brake discs, reducing the critical unsprung mass of wheelsets and contributing to reducing the rotating mass. Further advantages of ceramic disc brakes and other advanced friction pairing solutions are reduced fading and higher thermal stability, higher abrasion resistance and therefore a longer lifetime.

In addition to pneumatic solutions, electronic control functions and communication networks are necessary for in-service braking as well as for the exchange of diagnostic data. However, these double structures cause higher complexity. And, owing to intrinsic inaccuracies and to temperature- and ageing-related drift, pneumatic controls do not benefit from the accuracy offered by typical electronic controls. These disadvantages underline the immediate demand for improvements to close the gap with other industries that have finally managed to transfer safety-related functions to an electronic and software-based system architecture that is compliant with the required high SILs (SIL 3 or 4). This would not only enable greater accuracy and advanced emergency braking concepts but also make it possible to exploit the advantages of next generation TCMS, substituting the hardwired signals and brake control unit communication protocols of current railways custom networks (multifunction vehicle bus, TCN) for safe ethernet communication as defined in TD1.2, TCMS.

Today, pneumatic and hydraulic solutions dominate the market. Hydraulic solutions have the advantage of high force density, whereas pneumatic ones offer a relatively simple activation of braking power. In any case, the creation of concepts for pneumatic and hydraulic systems is necessary. With regard to ecological and maintenance issues, hydraulic systems are particularly demanding. A full drive-by-wire mechatronics brake system could overcome these drawbacks and offer the additional benefits of advanced control, diagnostic functions and ecologically friendly energy storage systems. By using such a system for light-rail vehicle (LRV) applications, the possibility of eliminating the oil management chain altogether would be opened up. A second application scenario in the scope of S2R is metro.

The certification and even virtual certification of the future need a process for the assessment of brake systems with standardised and distinct requirements as well as standardised test programmes defined on a common European basis. The goal is to reduce the time spent on and cost of authorisation processes.

STATE OF THE ART	NEW GENERATION TCMS
Safety braking-related functions (safety brake, safety-brake weighing) still assigned to traditional pneumatic systems. Owing to intrinsic inaccuracy and to temperature- and ageing-related drift, the pressure values provided can differ from the expected value, which can lead to increased braking distances or can cause sliding	Electronic HW/SW platforms designed to manage all braking functions (service, holding, emergency, safety brake, wheel-slide protection), compliant with the high safety levels SIL 3 and SIL 4, ensuring more accurate control
Brake control unit communication protocols based on current railway custom networks (multifunction vehicle bus, TCN), safety-related commands being hardwired	Next generation TCMS ethernet communication not as diagnostic media only but used as full operational communication system in accordance with the required SIL levels
Significantly changing conditions for wheel-to-rail contact, influencing many rail traffic characteristics, including safety and punctuality. Low adhesion causes slower acceleration and longer braking distances; high adhesion results in increased wear and tear and noise. Sanding and wheel-slide protection are far from the optimum considering the technical options available today	New technologies help to compensate for variation in adhesion characteristics and, combined with more sophisticated wheel-slide protection technology, make it possible to reduce braking distances in bad adhesion conditions and to improve overall train safety, finally reducing the wheel's LCC
Ceramic brake discs are used only at premium level in the automotive sector	Ceramic brake discs are introduced to the railway business, reducing LCC significantly by providing a lifetime design
LRVs use hydraulic friction brakes, while high-speed, regional, metro and freight trains use pneumatic technology. Electromagnetic brakes are not compatible with the space requirements of hydraulic LRV brake systems and are not competitive compared with pneumatic friction brakes	Electromechanical friction brakes are sufficiently compact to be substituted for the hydraulics in LRVs and competitive enough to be introduced to other vehicle types, allowing better control and diagnosis
Time-consuming and costly assessment as a result of the high degree of complexity of European and national regulations in combination, inconsistencies and/or divergences in interpretation	Specification of an assessment process with standardised and EU-wide accepted criteria, including a standardised test programme, to reduce the time spent on and cost of the authorisation processes

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions are as follows.

- TD1.1, Traction – there is a strong interdependence between acceleration and deceleration. Blended technologies and use of electro-dynamic (ED) brakes are examples of close interaction between traction and braking.

- TD1.2, TCMS – the TCMS is vital for the transmission of safety-relevant information in a train. Therefore, all relevant brake control information has to be exchanged in the TCMS, which is essential for advanced braking concepts. The development of an ethernet-based TCMS for high-safety-level brake functions can be applied to future brake control systems.

- TD3.10, Smart Metering for Railway Distributed Energy Resource Management System – this TD could determine the effect of brake energy recuperation on the energy flows of the entire railway system (energy returning from train to infrastructure) and, thus, significantly contribute to energy management strategies via the appropriate train-driving techniques.

- IP5, Brakes for Freight Scenarios – some of the technologies developed in TD1.5, Brake Systems, can be applied also to IP5 on freight. Examples are advanced friction brake technologies, electronic brake control applied through electropneumatic brake solutions for freight and brake functions such as automated brake tests.

- CCAs – during the life of the TD, values concerning KPIs and proposals for standards will be delivered to CCAs (WA2 and WA3).

1.5.4. Impact and enabling innovation capabilities

The new brake systems' specific benefits will have a major impact on the S2R system-level KPIs. The table below provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Technological leadership supported by a combination of: / radical innovation (high-safety-level electronic solutions, finally leaving behind the remains of legacy brake systems, quasi-elimination of the bottlenecks created by low adhesion) / exploiting technological enhancements in related systems (e.g. TD1.2, TCMS) • Tangible benefits for the end user: / increase in operational reliability through fewer operational restrictions under poor adhesion conditions and through better diagnostics for brake components / increase in support capacity through higher track throughput enabled by shorter and/or more reliable braking distances / LCC reduction as a result of better diagnostics, lower energy consumption and introduction of lifetime brake components
Compliance with EU objectives	• Promotion of modal shift by implementation of these new technologies to help avoid service disruptions and add new features • Support for an increase in capacity • Greening of rail transport through a reduction in energy consumption by reducing the rotating mass of brake discs • Elimination of oil in LRV brake systems
Degree of maturity of the envisaged solutions	• Highly safety-relevant brake control functions in HW/SW architecture • Brake distance degradation improvement • Development of a weight-reducing lifetime ceramic brake disc • Development of a drive-by-wire, mechatronic brake actuator • Reduction of time spent on and cost of brake system assessment

This TD will contribute to enabling the following six innovation capabilities.

INNOVATION CAPABILITY	TD1.5 BRAKE SYSTEMS
1 – Automated train operation	*BB1.5.1: Safe control and adhesion management* Support for safe braking under all conditions without driver surveillance; brake system electronics compatible with ATO and higher safety-level electronic solutions for brake control

INNOVATION CAPABILITY	TD1.5 BRAKE SYSTEMS
5 – Optimum energy use	*BB1.5.1: Safe control and adhesion management, BB1.5.2: Efficient force generation* Optimised energy-efficient brake system solutions owing to higher safety-level electronic solutions for brake control, innovative friction pair solutions and electromechanical brakes for railway applications
6 – Service operation timed to the second	*BB1.5.1: Safe control and adhesion management, BB1.5.2: Efficient force generation* Support for safe braking under all conditions without driver surveillance; brake system electronics compatible with ATO
7 – Low-cost railway	*BB1.5.3: Authorisation process* Reducing cost through air-free train solutions (getting rid of pneumatic components in a train): higher safety-level electronic solutions for brake control and electromechanical brakes for railway applications
9 – Intelligent trains	*BB1.5.1: Safe control and adhesion management, BB1.5.2: Efficient force generation* Support for safe braking without driver surveillance; brake system electronics compatible with ATO and higher safety-level electronic solutions for Brake Control
11 – Environmental and social sustainability	*BB1.5.1: Safe control and adhesion management, BB1.5.2: Efficient force generation* More efficient and silent braking through optimised use of technology (innovative friction pair solutions, electromechanical brakes)

1.5.5. Demonstration activities and deployment

The following table summarises the contribution of TD 1.5, Brake Systems, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Brake Systems	High safety-level electronic solutions for brake control	Specification, concept, demonstration, verification	Regional	7	An electronic HW/SW architecture, compliant with SIL 3 or 4, specially designed to be applied in brake control solutions, with safety functions transferred from traditional pneumatic components to electronic modules
			Urban	7	
	Adhesion manage-ment	Specification, concept, implementation verification	Generic and urban/ regional	5/6/7	Safe braking under all adhesion conditions, especially low-adhesion situations; demonstrate the function of a new adhesion management concept/function within a relevant environment on a test train
	Innovative friction pair solutions	Specification, concept, demonstration, verification	Urban/ regional	7	Development and design of a new generation of disk and friction materials; provide an innovative, high-power and eco-friendly friction pairing solution to be tested in a relevant environment
	Electro-mechanical brake for railway applications	Specification, concept, demonstration, verification	Urban/ regional	6	Development and testing of a mechatronic brake actuator for railway applications
	Certification process, including virtual certification	Specification, concept, demonstration, verification	Generic	4	Based on the results of the Roll2Rail project, the requirements, the standardised criteria and an implementation strategy for assessment of future brake systems will be determined; in addition, new methods and implementation strategies for the virtual certification of brake systems will be investigated and defined; certification processes for adhesion management testing environments will be developed

Planning and budget

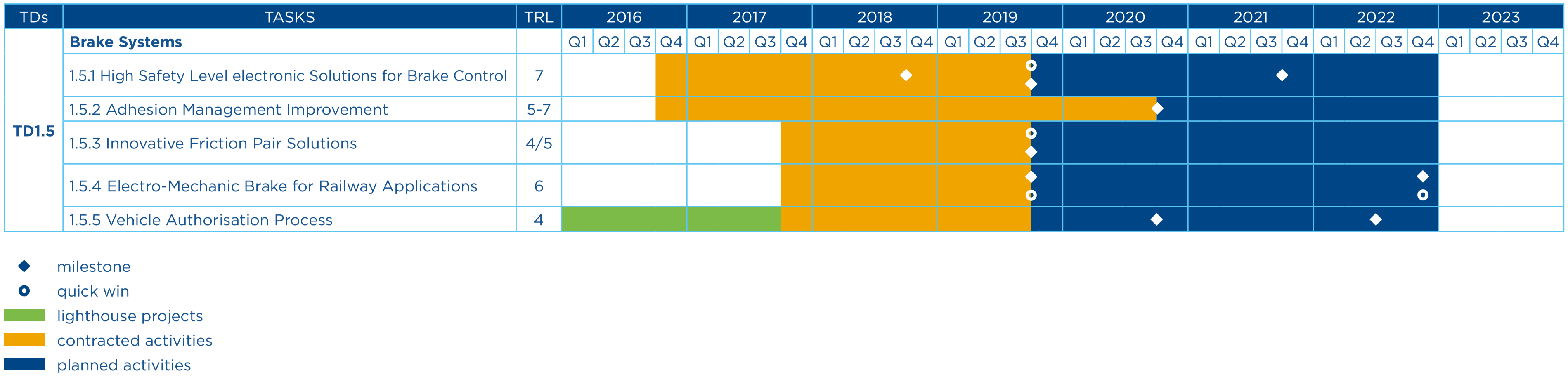


Table 10 / ***TD1.5 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
06/2018	Demonstrator wheel-slide protection test rig	Verification and validation of different adhesion situations in a repeatable, well-defined environment
09/2018	Future-proof brake system safety architecture	General specification and requirements for a brake system safety architecture integrated into the future TCMS
09/2019	Concept development actuator	Improvement of electromechanical brake actuators and expansion of the range of train applications
09/2019	Innovative friction pairing solution tested	Contribution to enhancing braking performance and reducing wear
09/2019	Demonstration of SIL 3/4 electronic hardware	Design and testing of future electronic hardware for the brake system taking into account the outcome of TD1.2, TCMS
12/2022	TRL 6 demonstrator for electromechanical brake	Demonstration and validation of a mechatronic brake actuator for railway applications

Table 11 / ***TD1.5 milestones***

WHEN	WHAT
09/2018	Adhesion data collection finalised
09/2019	Specification of materials, first specimen, first dynamometer tests
09/2019	TRL 4 demonstrator for SIL 3/4 brake system electronic hardware
09/2019	TRL 4 demonstrator for electromechanical brake
09/2020	As a first example, the virtual certification of a wheel-slide protection system to be performed
09/2020	Adhesion detection system installed
09/2021	SIl 3/4 electronics integrated in future TCMS
12/2022	TRL 6 demonstrator for electromechanical brake actuator

The estimated total budget for the Brake Systems TD is around EUR 30.8 million.

1.6. TD1.6 Doors and Access Systems

1.6.1. Concept

Train access systems such as doors but also steps and ramps are the key interfaces between station platforms, passenger trains and passengers. They enable passengers to board and exit the train and also have other functions, as they:

- contribute to comfort;
- optimise the dwell time resulting from passengers getting on and off the train;
- support the needs of PRM;
- guarantee passenger safety.

Today, access systems are still based on:

- for the leaves, two aluminium or stainless steel skins with aluminium pillars and beams in between as structural parts and with polyurethane foam or aluminium honeycomb as insulation materials;

- accessibility – moveable sliding steps (bridging plates) without height adjustment, often without horizontal stroke adjustment and with some accessibility barriers such as protrusions, upstands, etc.

Through R&I activities, the next generation of access systems will enhance **accessibility** while reducing disturbances to all passengers and operations, improve passenger **comfort** thanks to improved thermal and acoustic insulation, reduce **weight** with the introduction of an optimised metal solution or a plastic or **composite** solution, and introduce **new** functionalities thanks to new sensors and **modular design**, moving towards an **autonomous access system**.

The deployment of next generation access systems will contribute to achieving capacity targets, improved services, higher quality for customers and enhanced interoperability.

1.6.2. Technical objectives

The following are the main technical objectives of this TD.

1. Achieve a 3-W/m^{2}K thermal performance.

2. Increase door acoustic attenuation by 3 dB, with priority given to high-speed and regional trains on both thermal and acoustic behaviour.

3. Reduce vertical and horizontal offsets and gaps to 10 mm instead of 50 mm, as permitted today, and reduce all additional accessibility barriers such as protrusions at door sills.

4. Reduce the number of noise-producing PRM devices by approximately 10 % of the estimated number of current cases.

5. Reduce door weight by up to 10 %, depending on the train family.

1.6.3. Technical vision

The final target is providing new generation access systems with improved leaves in term of weight, thermal and acoustic insulation with adaptive gap fillers, and new functionalities.

The technical vision of the new generation access system proposed in S2R is based on the following:

- leaves based on composite technologies and/or on new architecture or new materials for metal solutions;

- gap fillers allowing level access to the train, ensuring easy and independent access;

- use of new sensors or different use of existing devices to upgrade access system functionalities, performance and safety to achieve an autonomous access system.

STATE OF THE ART	NEW GENERATION ACCESS SYSTEM
Door leaf consists of two skins bonded on an aluminium frame with a foam filling (one front and one rear pillar, one lower and one upper beam)	New composite, metal or plastic materials and new assembly processes that are presently not widely used in railway applications will be developed. The aim is to find a compromise between the highest possible performance, which is expensive, and the best cost ratio Targets to be achieved (in accordance with the S2R Master Plan and depending on market segments): • 3 W/m²K for thermal performance • increase sound reduction index by around 3 dB • reduce door weight by 10 %
At present, there is no solution for autonomous PRM boarding; the assistance of a crew member to activate a dedicated platform is needed	A horizontal gap filler with reduced protrusions and upstand at door sill for unassisted and easy PRM access will be developed, with an economically viable solution sought
Today, railway solutions for PRM such as specific buzzers, specific gap fillers or specific beacons, disturb other passengers	Non-disturbing solutions will be developed, following requirements in terms of safety
Very little visual or sound information for passengers at the doors	Interaction of doors and passengers, with doors displaying real-time visual or sound information to better guide passengers and improve passenger flow
Each time a new functionality such as passenger counting, displays, etc., has to be added to a door, the complete door leaf and/or door control unit has to be changed	A plug-and-play approach will provide a standard for device connectivity that results in: • a simplified validation process • more flexibility to change the functions of the door during the lifetime of the train
Automatic but not autonomous door: a crew member or driver is responsible for door opening and closing, because of low information levels and no direct view of the access system area	Automatic and autonomous doors that manages through information and sensors its own safe and rapid opening and closing, with little involvement of driver or crew

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and interaction in performance and objectives, is as follows.

- TD1.2, TCMS – the new TCMS architecture is likely to affect door control unit HW and SW.
- TD1.3, Carbody Shell – the carbody is one of the two main interfaces of the access system and both TDs will see the introduction of composite solutions.
- TD1.7, Train Modularity in Use:
  - add requirements to design a door to facilitate the loading of interior modules;
  - share technical watch about plug-and-play systems to design a modular leaf;
  - share new needs from cabin and access system points of view in line with the targets for autonomous trains and autonomous doors.

- TD11, Future Stations – the station (i.e. the platform) is one of the two main interfaces of the access system and future concepts for doors and stations will have to be compatible.
- CCAs:
  - / energy efficiency
  - / noise and vibration
  - / KPIs
  - / standards and regulation.

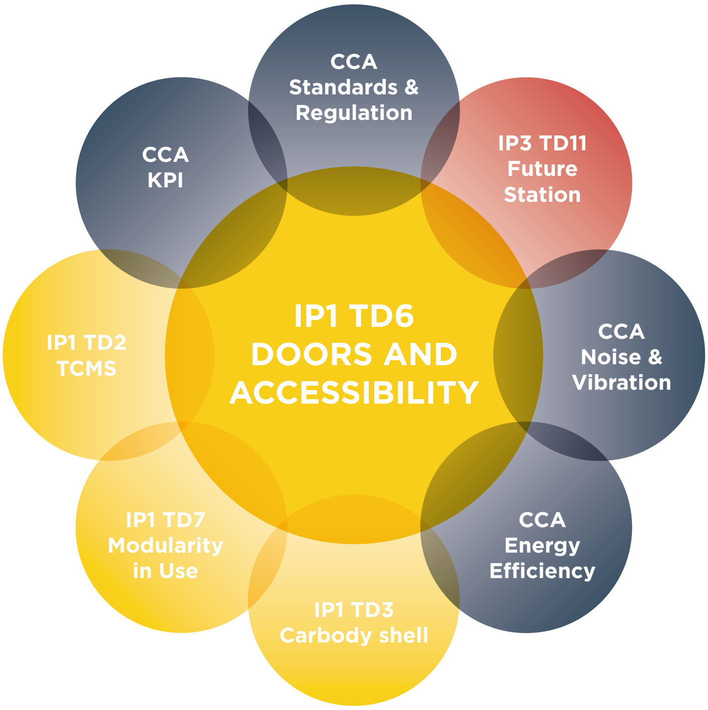


Figure 9 / ***Interaction with other TDs and IPs***

1.6.4. Impact and enabling innovation capabilities

The new generation access system's specific benefits will have an important impact on the S2R system-level KPIs. The benefits expected to be provided by this work are listed in the table below.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Competitive-ness of the EU industry	**Technological leadership in train access systems** • The use of advanced material technology gives the European rail industry the opportunity to become a trendsetter in new generation train access systems • Modular doors result in a significant reduction in LCC and also help to technically differentiate providers from competitors • Innovation becomes the key to competitive edge for the European rail industry. This allows a shift from the current mainly cost-related competition with Asian suppliers to technology-based competition **Tangible benefits for the end user** • A high level of comfort for passengers • Capacity increase supported through lighter train access solutions • Meets PRM-specific needs in terms of mobility and passenger flow • Combines visual and audio information taking into account sensory disabilities
Compliance with EU objectives	**Capacity increase** • Lighter door solutions will provide: / increased capacity / improved competitiveness (more passengers for the same cost) • Better PRM accessibility will provide: / an increase in PRM capacity • Autonomous doors will provide / better and safer flow management (increased capacity) **Greening of transport** • Energy savings can be achieved through lighter materials and improved performance of the entire door system
Degree of maturity of the envisaged solutions	Currently, most of the proposed technologies are at TRL 1 or 2, which means the features have been observed in principle and the possibilities for using them have been formulated. The target of the TD Doors and Access Systems is to bring successful concepts up to TRL 6 or 7 (i.e. demonstration of prototypes in a relevant environment or system prototype demonstration in an operational environment)

This TD will contribute to enabling the following eight innovation capabilities.

INNOVATION CAPABILITY	TD1.6 DOORS AND ACCESS SYSTEMS
1 – Automated train operation	*BB1.6.1: PRM access, safety and door entry surveillance solutions* Allowing smoother and safer access through autonomous doors and improving crowd management
2 – Mobility as a services	*BB1.6.1: PRM access, safety and door entry surveillance solutions* *BB1.6.2: Light doors and improved comfort (acoustic and thermal)* Ensuring good service conditions for all passengers and providing greater comfort inside the train
4 – More value from data	*BB1.6.1: PRM access, safety and door entry surveillance solutions* New vehicle data with new sensors to improve entry surveillance and foster the development of an autonomous door
5 – Optimum energy use	*BB1.6.2: Light doors and improved comfort (acoustic and thermal)* Lighter and better-insulated doors, improving energy efficiency
6 – Service operation timed to the second	*BB1.6.1: PRM access, safety and door entry surveillance solutions* Autonomous access and autonomous doors are key to ensuring rapid and predictable boarding/alighting
7 – Low-cost railway	*BB1.6.1: PRM access, safety and door entry surveillance solutions* *BB1.6.2: Light doors and improved comfort (acoustic and thermal)* Optimised solutions (cost versus function) for each market segment, including autonomous PRM access and lighter materials, leading to overall cost reductions in the railway system
9 – Intelligent trains	*BB1.6.1: PRM access, safety and door entry surveillance solutions* Communication with all passengers including PRM to facilitate boarding and egress
10 – Stations and smart city mobility	*BB1.6.1: PRM access, safety and door entry surveillance solutions* Optimising passenger flow and dwell time

1.6.5. Demonstration activities and deployment

The following table summarises the contribution of TD1.6, Doors and Access Systems, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Doors and Access Systems	PRM access and communi-cating doors	Mock-up representation of improved bridging plate concept	Regional	5	Measure improvements in easy and independent access and egress to the train (residual gaps, slopes, upstands, protrusions, etc.) Test the new door functionalities (platform detection, alert signals, security solutions, automatic opening and closing, etc.)
		On-line testing of new door functionalities Functions will be added to the existing functions of the doors, which will remain active during the tests		7	Testing of the new functions that will be implemented on the doors in an operational environment
	Light and comfortable doors	A new generation of door opening and closing mechanisms and leaves will be implemented on a static regional train Two types of door leaves: • based on metal solutions • based on composite solutions		6	Testing of the integrated door (operator and leaves): • weight • door operation (e.g. opening and closing times) Mechanical, acoustic and thermal performance will be tested in laboratories: • in representative mock-ups for mechanical tests • tested separately for acoustic and thermal comfort

One ITD is anticipated for the new generation access systems. The train will be a regional one, as it is the most appropriate type of train for on-track testing to validate the newly developed systems. However, other train families, such as metro trains and commuter trains (design study or calculation and even, in some cases, demonstrators/mock-ups), will be considered and results for all market segments will be assessed during the project.

The ITD will integrate all the systems developed, such as:

- new composite and/or metal leaves, to be integrated with a modern opening and closing door operator;
- gap filler;
- platform detection systems measuring platform height;
- devices for the new door functionalities;

- technologies for an autonomous door.

At the end of the project, the following improvements will be ready for market introduction:

- greater passenger comfort;
- better access to trains for PRM;
- reductions in train weight and energy consumption;
- safer access with little surveillance by crew or driver.

It is expected that the outcome will also affect TSIs and EN standards. Standardisation committees such as CEN TC256 SC3 Working Group 27, in charge of EN 14752, and other committees in charge of the EN 16584, EN 16585 and EN 16586 series, will be fed with the outputs and results of access system activities (introduction of composite materials, new functionalities, fully automatic doors, etc.).

Track tests as part of the TD will guarantee that new features can be considered proven. It can be expected that immediately or at least in the next 3 years the new developments will be implemented in a large range of new vehicles.

Planning and budget

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022
	Doors and Access Systems		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
TD1.6	1.6.1 Technical Development Prequesites	4	defi composite						
	1.62 People with Reduced Mobility, Safety and Door Entry Surveillance solutions	4	porte du futur						
	1.6.3 Improved passengers comfort and weight and energy optimisation	6	defi composite						
	1.6.4 Integration in technical demonstrator, Demonstration and Assessment	4							

- ◆ milestone
- ○ quick win
- finished projects
- contracted activities
- planned activities

Table 12 / **TD1.6 quick wins**

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2019	Concept for leaves	Concept for improved leaves (acoustic, thermal and weight comparison for metal leaves; new acoustic insulation concept, etc.), including test results on different configurations and concepts implemented on panels (1 m x 1 m) or leaves
Q4 2019	Concept for gap filler	Concept for footstep (three-dimensional (3D) model) virtual mock-up validated
Q4 2021	Laboratory validation of bridging plate prototype	Validation of bridging plate and systems for improved accessibility at laboratory level
Q3 2021	Laboratory validation of leaves prototypes	Validation of leaves at laboratory level

Table 13 / **TD1.6 milestones**

WHEN	WHAT
Q1 2018	Overall access system specification
Q2 2018	Specifications for improved accessibility
Q2 2018	Specifications for both metal-based and composite-based leaves
Q2 2021	Prototype of gap filler for laboratory testing
Q2 2021	Prototype of leaves for laboratory testing
Q1 2022	Entrance system implementation for track tests

The estimated total budget for the Doors and Access Systems TD is around EUR 9.8 million.

1.7. TD1.7 Train Modularity in Use

1.7.1. Concept

The TD Train Modularity in Use (TMIU) covers activities focused on the passenger saloon and the driver's cabin. The main objectives for passenger areas are to:

- modulate passenger capacity;
- optimise passenger flow;
- reduce the cost of interior design;
- increase attractiveness.

The main objectives for the driver's cabin are to:

- to prepare the autonomous train to be able to adapt the cabin during the life of the train;
- personalise the cabin to the user or operator;
- offer new functions;
- reduce the cost of operation.

The activities will aim to increase the modularity and flexibility of the passenger lounge areas and driver's cabin through the use of standardised features, new technologies and plug-and-play components in order to simplify maintenance, refurbishment and commercial operations. This innovative work will propose economic solutions handling conflicting requirements such as passenger capacity, comfort, weight, available volumes and organisation/competences to be developed to create train configurations meeting passenger and operator demands that evolve over time.

Generally, the concept of modularity can be separated into three categories, with each having a different purpose.

- Modularity in design: the train is made up of small, independent modules, which are connected to constitute the finished product.
- Modularity in production: this primarily relates to the manufacturing process and facilitates the implementation of equipment (for improved comfort and/or service).
- Modularity in use (MIU): this particularly relates to ease of use, handling or product evolution.

This TD will mainly work on MIU. The overall objective of the TMIU TD is to make railway transport more attractive to passengers and foster future modes of train operation making flexible use of the driver's cabin.

The interior design of current rolling stock is not adapted to the amount of flexibility required to meet passenger demand during the in-service operating life of a train (40 years). It is not possible to easily change the interior layout or add services (power outlets etc.). The driver's cabin currently stays the same during the lifespan of the train. It could be an obstacle to operating autonomous trains in the near future if the design of current cabins does not allow changes in technologies and uses. When initiating the process for a new train procurement, a railway operator has to make a final choice on the design 6 to 7 years before the first train enters service. There is a risk that the selected train will become quickly obsolete and not meet passenger and/or operator expectations.

MIU concepts must allow coaches to be refurbished more quickly than is the case with current coach design, and at a reasonable cost. This will allow more frequent configuration changes to meet passenger requirements.

Concepts based on the MIU approach will lead to genuinely innovative solutions, meeting market needs and enabling the configuration of the coach interior and driver's cabin to be modified at an affordable cost.

1.7.2. Technical objectives

The TMIU TD will cover the market for new trains and refurbishment. The aim is to reach TRL 6 with TRL 4 or 5 disruptive concepts. The objective is to have a blend of physical and virtual mock-ups of the disruptive concepts.

The following are the main technical objectives of this TD.

1. Adapt train interiors to increase **capacity**.
2. Reduce dwell time at stations by improving **passenger flow** in and out of trains and between vestibules and saloons.
3. Increase **attractiveness** and satisfaction.
4. Reduce the **cost** of design and refurbishment.

1.7.3. Technical vision

TD 1.7 proposes to explore fixation and plug-and-play systems to enable reconfiguration of the passengers' area inside a coach with regards to capacity as follows:

- a few times per year, depending on passenger capacity requirements or the passenger profile (e.g. commuter trains for workers) or destination (e.g. ski trains);
- every 5–6 years, on refurbishment (new design, new interior layout, etc.).

In addition, the atmosphere of the interior could be changed:

- a few times per year, depending on the seasons or the line travelled (lighting, decor);
- every 5–6 years, on refurbishment (completely new design).

Furthermore, work on this TD will make it possible to reconfigure passenger information support inside a coach more easily:

- a few times per year, depending on passenger capacity requirements or passenger profile (adapted to seat position or capacity);
- every 5–6 years, on refurbishment (new design, easy updates, new connectivity, etc.)

Ensuring comfortable indoor climatic conditions (i.e. thermal comfort) regardless of the interior layout chosen remains essential:

- minor changes – move interior partition walls, increase capacity or change the positions of the seat;
- major developments – new design of the roof, new luggage rack location or height or new closed spaces added.

STATE OF THE ART	NEW GENERATION INTERIORS
Roll2Rail interiors: improved methodologies to qualify comfort	Evolve interior design without degraded comfort or attractiveness for passengers; Roll2Rail results will provide the TD with limits to keep within and will be key in selecting ideas/concepts
ModTrain–EUPAX/PrEN design for PRM use: work on interior design (toilets, services, PRM requirements, etc.) but no result on MIU	These two European projects (research and standards) have determined the needs of PRM; the TD will work on solutions to offer flexibility for railway operators to increase PRM accessibility (e.g. by adding PRM seats or wheelchair user spaces quickly) and the project results will provide the working group with information on the limits of design available, thus helping to select ideas/concepts
A complex industrial operation is necessary to change layout during the in-service operating life	Research modularity to: • increase capacity by 15– 25 % in a given train • reduce the cost of layout change by 50 % • reduce the time taken for layout change by 50 %
There is limited evolution of the mechanical attachment units and electric connections	Set up a plug-and-play approach (mechanical and electrical connections) to: • offer the possibility to change interior design without involving important external equipment • reduce the cost of refurbishment by 25 % • simplify the validation process (standards)

STATE OF THE ART	NEW GENERATION INTERIORS
No clear definition of 'modularity': for who, to achieve what benefits, etc.	Library and semantic search to: • define common terminology in Europe • facilitate understanding of targets between operators and manufacturers
No standard of fixation (versus aeronautics with the quick change system)	Propose common standards for fixation systems
European flexible rolling stock: not enough experience to edit a European guide	Recommend new European standards, with input from studies and mock-up

Interaction with other TDs (of the same IP and/or of the other IPs)

TD1.6, Doors and Access Systems:

- add requirements to design a door that facilitates the loading of interior modules;
- share technical watch about plug-and-play systems to help in designing a modular leaf;
- share new needs for the cabin of the future that could influence command of doors.

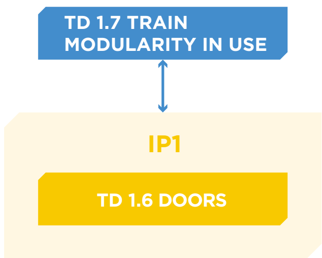


Figure 10 / ***Interaction with other TDs and IPs***

1.7.4. Impact and enabling innovation capabilities

The improvements resulting from the content of this R&I activity aim to contribute to the achievement of the KPIs of the S2R initiative by enabling the following benefits:

- increase easily and at low cost the capacity of an existing train by 20 % (regional and intercity trains are the main target);
- increase passenger flow into and off trains to reduce by 15–20 % dwell time in stations (regional and long-distance trains are the main target)
- carry out interior retrofit operations twice as often during the life of rolling stock at the same LCC, including the driver's cabin;
- ensure that thermal comfort meets customers' needs, and not only standards, especially when rebuilding a vehicle or changing a vehicle's use, e.g. from long distance to regional traffic.

The following table summarises the strategic impacts that will be produced by the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• An operator selects an interior design. Choices vary from one country to another and are also dependent on usage. • Tangible benefits for the end user: / increase the passenger lounge area's ability to meet needs / increase the ability to adapt the driver's cabin of a train to the profile of the line (from several driving assistant systems to automatic driving) / reduce the cost of refurbishment / increase capacity for new as well as existing trains
Compliance with EU objectives	• Increase capacity: the capacity of each coach can be changed • Increase attractiveness: the coach interior and services on board can be adapted more quickly to evolving passenger requirements and more economically than currently • Greening of transport can be achieved through optimisation of capacity
Degree of maturity of the envisaged solutions	• From TRL 3 or 4 (for new ideas) to TRL 5 or 6 • The first part of the work will explore available existing solutions, so a limited number of concepts will go from higher TRLs (TRL 5 or 6) to TRL 7 or 8

This TD will contribute to enabling the following five innovation capabilities.

INNOVATION CAPABILITY	TD1.7 TRAIN MODULARITY IN USE
1 – Automated train operation	*BB1.7.2: Driver's cab of the future* The driver's cab of the future will enable the space in the driver's cab to be used for passengers when on ATO; it will foster the transition to ATO through flexible solutions
2 – Mobility as a service	*BB1.7.1: Interiors modularities* It will be possible to reconfiguring passenger information support inside a coach more easily
6 – Service operation timed to second	*BB1.7.1: Interiors modularities* Will increase passenger flow into and off trains to reduce dwell time in stations and increase overall passenger capacity Higher availability through faster retrofitting
7 – Low-cost railway	*BB1.7.1: Interiors modularities* Easier refitting of interiors (standardised modules, faster procedures) will lead to decreased cost
10 – Stations and smart city mobility	*BB1.7.1: Interiors modularities* Optimised passenger flow into and off trains Enhanced and easily adaptable information systems for passengers

1.7.5. Demonstration activities and deployment

The following table summarises the contribution of TD 1.7, TMIU.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
TMIU	New passenger coach interiors	A physical mock-up of a piece of passenger space (real carbody of a vehicle) Virtual mock-up of a complete modular train and simulation of passenger flow for one new interior design InnoTrans 2020: physical demo only on flat panel (e.g. to demonstrate the technologies) InnoTrans 2022: specific representative environment to present product	Regional	6	Develop new quick-change and secure system (hard points) New user experiences on board thanks to modular interiors with several new diagrams to show the capabilities for adapting and developing the new quick-change systems (fast points) for interior finishes (lighting, decor, etc.) Study capabilities for influencing passenger flow through the new interior design
TMIU	New driver's cabin	Virtual mock-up of a complete modular train (3D model in virtual reality), including driver's cabin InnoTrans 2020: demo with prospective design pictures	Regional	4/5	Study the capabilities for new user experiences on board thanks to a modular driver's cabin with several new uses of the space for GoA2 to GoA3 and develop new driving human–machine interface

Planning and budget

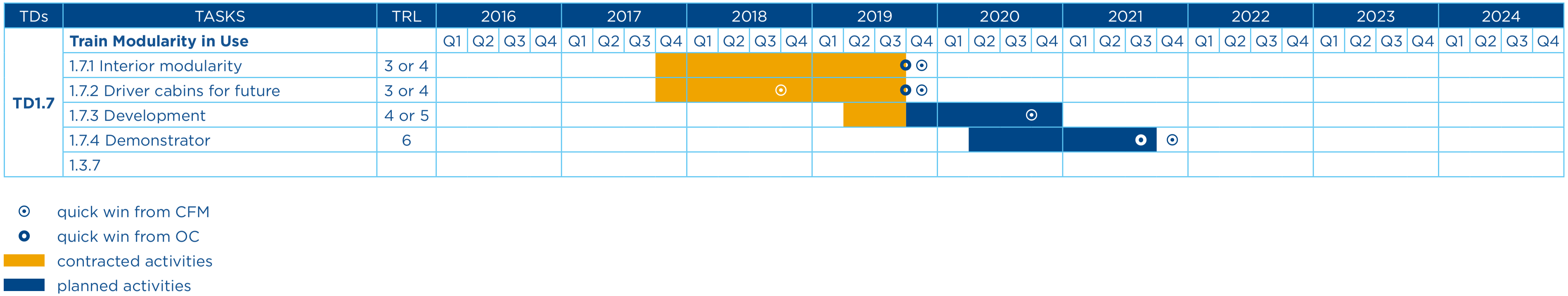


Table 14 / ***TD1.7 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2018	T1.7.1: video/design view regarding the needs of operator (which type of modularity is best for the future etc.) and the state of the art (what we do in railway now and what other industries do, technologies we can use to go further)	Faster adaption of interiors leads to less downtime Better user experiences and easy adaption to users' needs thanks to modular interiors Influencing passenger flow through the new interior design
Q3 2018	T1.7.2: video/design view: a video to explain the innovative approach to the cabin and several views or sketches of the results (depending on confidentiality at this stage)	Modular driver's cabin allows additional use cases for cabin/passenger space with regard to ATO New approach to the driving human–machine interface
Q3 2019	T1.7.1: video/design view/mock-up: new plug-and-play technologies	Faster adaption of interiors leads to less downtime Better user experiences and easy adaption to users' needs thanks to modular interiors Influencing passenger flow through the new interior design
Q3 2019	T1.7.2: design view/mock-up: illustrations of studies on the concepts	Modular driver's cabin allows additional use cases for cabin/passenger space with regard to ATO New approach to the driving human–machine interface.
Q1 2020	T1.7.3: book of concepts with illustrations and mock-ups	Further development of solutions to achieve the above
Q3 2020	T1.7.4: first mock-ups and/or prototypes	Setting up demonstrators to achieve the above

The estimated total budget for the TMIU TD is around EUR 3 million.

1.8. TD1.8 Heating, Ventilation, Air Conditioning and Cooling

1.8.1. Concept

Conventional HVAC systems within rail vehicles use artificial refrigerants that have a very high impact on global warming (e.g. R134a). In order to limit the climate impact from HVAC systems, the European Commission passed in 2014 Regulation No 517/2014, which aims to reduce the use of artificial refrigerants within the EU. According to the schedule, the amount of refrigerants allowed to be placed on the European market is to be reduced to 21 % (compared with the average consumption over the period 2009–2012) by 2030. Rail service operators have been forced to act quickly because of the long lifetime of rolling stock. Conventional refrigerants will become scarce and expensive in the near future. Therefore, new and redesigned trains have to be equipped with eco-friendly HVAC systems using natural gases such as air or CO_2.

In the past, a few systems using natural refrigerants have been available on the market (e.g. ICE-3 uses air as a coolant), but these systems are much more expensive and have not been proven to be reliable. ICE-4 uses conventional refrigerants.

Regional and urban railway vehicles have different requirements of HVAC systems, since they are not required to keep the same temperature year round but rather to deliver a comfortable environment for the passenger depending on the actual outside temperature. The increasing costs of such systems are even more critical for urban and regional trains. So far, only prototypes exist for these applications.

Therefore, there is a very strong need to develop HVAC systems with natural gases for new vehicles and redesign existing vehicles, as well as to provide suitable simulation and testing/ assessment tools.

Since HVAC systems are integrated into the vehicle, connected to the energy supply and control system, and to be maintained by railway operators, the development of new HVAC systems requires collaboration between vehicle integrators, HVAC suppliers and rail service operators. Since these stakeholders all take part in S2R IP1, this topic is well located in this programme.

1.8.2. Technical objectives

The main technical objectives of this TD are as follows.

1. Push forward the development of eco-friendly HVAC systems with natural gases to overcome the limitation on artificial refrigerants within the EU (40 %).
2. Gain an advantage for European HVAC suppliers in relation to developments outside of Europe (10 %).
3. Open up opportunities to develop new HVAC systems with low LCC that are optimally integrated into the vehicle (20 %).
4. Open up opportunities to standardise the interfaces to HVAC components (compressors, heat exchangers, etc.) at the beginning to development (20 %).
5. Reduce the energy consumption of vehicles by means of integration of a heat pump (10 %).

1.8.3. Technical vision

There are two different eco-friendly HVAC solutions under discussion, using natural gases or CO_2. In contrast to conventional HVAC solutions, HVACs using natural gases open up opportunities to integrate a heat pump to increase the efficiency of heating, operating in a larger temperature range (R134a up to – 5°C; CO_2 up to – 20°C; air no limit). This is very important for hybrid vehicles with batteries, where HVAC energy consumption further reduces the operating kilometre range of the vehicle.

STATE OF THE ART	ECO-FRIENDLY HVAC SYSTEMS
Use of artificial gases that have a very negative impact on global warming	Use of eco-friendly natural gases such as air or CO_2
Integration of a heat pump for energy saving is economically not easy to achieve	Easy to integrate a heat pump for energy saving

STATE OF THE ART	ECO-FRIENDLY HVAC SYSTEMS
No standardised interfaces of HVAC components such as air compressors, heat exchangers, etc.	Possibilities for standardised interfaces of HVAC components and connection to the energy supply and energy management system
Poor and time-consuming maintainability as a result of the need to collect the refrigerant before disassembling the HVAC system	Easy and fast maintainability; no environmental impact of leakages

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs (see Figure 11), from the point of view of both technologies employed and interaction in performance and objectives are as follows.

- TD1.1, Traction – increased HVAC efficiency impacts alternative traction systems (e.g. hybrid vehicles with batteries);
- TD1.2, TCMS – standardised interfaces for control and monitoring of the HVAC system;
- CCAs, WA5.1, Energy and sustainability – reduction in energy use.

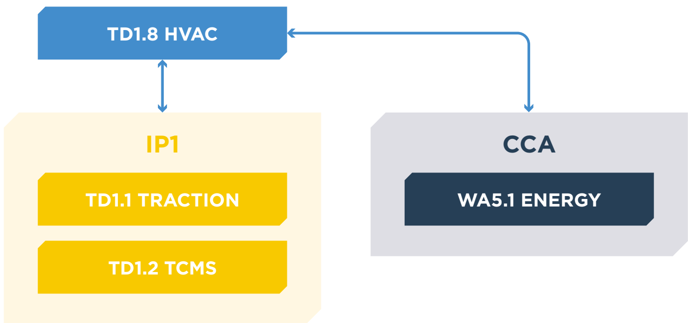


Figure 11 / ***Interaction with other TDs and IPs***

1.8.4. Impact and enabling innovation capabilities

This TD will have a major impact on the S2R KPIs, as shown below.

KPI	KEY CONTRIBUTION FROM THE TD
Life-cycle costs	Reduction in energy costs
Reliability	Increased availability as a result of shorter repair time
Support the competitiveness of the EU industry	Improved competitiveness of European HVAC suppliers in relation to Asian suppliers
Compliance with EU objectives	Fulfils European requirements for a reduction in artificial refrigerants

This TD will contribute to enabling the following four innovation capabilities.

INNOVATION CAPABILITY	TD1.8 HVAC
5 – Optimum energy usage	*B1.8.1: Eco-friendly HVAC* Reduced energy usage of HVAC systems by 20–45 % by means of integration of a heat pump
7 – Low-cost railway	*B1.8.1: Eco-friendly HVAC* LCC reduction as a result of reduced energy usage and standardised interfaces
8 – Guaranteed asset health and availability	*B1.8.1: Eco-friendly HVAC* Improved availability as a result of lower repair times and condition-based maintenance
9 – Intelligent trains	*B1.8.1: Eco-friendly HVAC* Standardised control interface for optimisation of energy management and diagnostic data for condition-based maintenance

1.8.5. Demonstration activities and deployment

The following table summarises the demonstration activities of TD1.8, HVAC. Based on the requirement specification, existing HVAC prototypes with CO_2-refrigerant will be analysed with respect to fulfilling the requirements. Using this input, the existing HVAC prototypes will be adopted or new ones built (TD). The prototypes will be integrated into vehicles and tested within a climatic chamber as well as in real operation. In addition, simulations and pre-standardisations of interfaces will be carried out, and an evaluation and migration strategy will be followed. The strategy looks also at alternative refrigerants and at the risks posed by different technologies.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
HVAC	HVAC technology with natural gases	Further development of (one or two) HVAC systems with natural gases Simulation of behaviour Standardisation of interfaces Integration into a regional electric multiple unit Test within a climatic chamber and in real operation	Regional	7	Further development, simulation and testing of operation Standardisation of interfaces Reduction in climate impact Reduction in energy consumption and costs

Planning and budget

TDs	TASKS	TRL	2019				2020				2021				2022			
TD1.8	**HVAC**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	1.8.1 Requirement specification	1																
	1.8.2 Analysis of prototypes	2																
	1.8.3 Simulation	3																
	1.8.4 Further development of prototypes	5																
	1.8.5 Test of prototypes	5																
	1.8.6 Pre-standardisation of interfaces	1																
	1.8.7 Evaluation and migration strategy	1																

◆ milestone
planned activities, AWP 2019
planned activities, AWP 2020

*Table 15 / **TD1.8 milestones***

WHEN	WHAT
Q1 2020	Requirement specification finalised
Q1 2020	Analysis of prototypes finished
Q2 2020	Simulation results
Q3 2020	Prototype development finalised
Q4 2020	Prototype test in climatic chamber finalised
Q1 2022	Prototype test in real operation finalised
Q1 2022	Pre-standardisation finalised

The estimated total budget for TD1.8 is around EUR 5 million.

2. IP2 – Advanced Traffic Management and Control Systems

Context and motivation

Control, command and communication systems should go beyond being only contributors to the control and safe separation of trains and become flexible, real-time, intelligent traffic management and decision support systems.

Although ERTMS has become a worldwide dominant solution for railway signalling and control systems, it has the potential to offer increased functionalities and become even more competitive. Current systems do not sufficiently take advantage of new technologies and practices, including use of satellite positioning technologies, high-speed, high-capacity data and voice communications systems (Wi-Fi, 4G/LTE, 5G), automation, and innovative real-time data collection, processing and communication systems, which have the potential to considerably enhance traffic management (including predictive and adaptive operational control of train movements), thereby delivering improved capacity, decreased traction energy consumption and carbon emissions, reduced operational costs, enhanced safety and security, and better customer information.

Furthermore, the ERTMS specifications do not cover all interfaces, or engineering and operational rules to the extent needed, meaning that different railways and suppliers continue to design their own solutions, thereby hampering interoperability and increasing costs. As ERTMS is further deployed, the overall goal is that the whole CCS system has a European market, not individual national markets.

Objectives of the IP and expected results

A key challenge for IP2 is to deliver the R&I input in order for game-changing ERTMS to become a reality. It will enhance the overall line capacity and contribute to LCC reductions and global reliability of the railway system, while maintaining the highest level of safety, thanks to better management of signalling and supervision systems on static infrastructure by supporting the development of an intelligent integrated mobility management (I2M) system.

IP2 will focus on innovative technologies, systems and applications in the fields of telecommunication, train separation, supervision, engineering, automation and security, and improving digitalisation as one of the key aspects to achieve in all the systems with a view to enhancing the overall performance of all railway market segments.

IP2 will support maintaining the dominance of ERTMS as a solution for railway signalling and control systems across the world.

Maintaining ERTMS as the basis of any evolution, IP2 developments will aim to go beyond mainline railway ERTMS applications, with a view to extending the new signalling and traffic management system to all railway transport segments (urban/suburban railways, overlay systems, high-speed lines, low-traffic lines and freight lines, mixed traffic lines, i.e. passenger (non-high-speed, e.g. up to 200 km/h) and freight trains), integrating both existing ERTMS interfaces and architecture and typical communications-based train control (CBTC) functionalities already applied to urban and mass transit lines.

IP2 will ensure continuity and backward compatibility with the current signalling and supervision systems through ERTMS standards but fostering the highest integration possible in terms of technology, operational rules, engineering processes, supervision and communication network.

IP2's main goals are to speed up the time to market, improve interoperability, offer improved functionalities and standardised interfaces, investigate modularity concepts, reduce costs (capital expenditure, CAPEX, and operating expenses, OPEX), and achieve an effective and reliable public rail transport network with the capability to interconnect and interpenetrate urban rail and mainline solutions.

In order to achieve these very challenging main targets within S2R, IP2 plans a strong integration of different technologies and systems not yet largely applied to the railway field (e.g. satellite positioning, today mainly used for non-vital functions; moving block, currently applied to mass transit).

IP2 works are at the heart of an integrated railway system having functional and conceptual links with innovative technologies coming from, among other sources, the implementation of a possible wireless TCMS or modular and scalable architecture approaches taking into account the work already started by some infrastructure managers (IMs) with railway reference CCS architecture (RCA) and by some railway undertakings (RUs – train owners and operators) with open CCS on-board reference architecture (OCORA). This activity will be further developed to integrate, in particular within IP2 activities, the results of the S2R Call 2019 dedicated to kick-starting the creation of an integrated railway system architecture.

The following table summarises the main objectives of IP2 and provides an overview of some of the concrete deliverables that can be expected to result from the activities undertaken in the IP.

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Line capacity increase	Better use of (existing or new) infrastructures by operating with more trains on the same line (less headway)	Introduce standardised moving block system (based on absolute braking distance) and ATO (up to GoA3/4) concepts in a wider range of rail transport segment markets (from freight to mass transit). For the longer term, investigate the application of the relative braking distance concept as well
	More flexible use of the vehicles on the line (in terms of covering different passengers/hour needs)	Introduction of train virtual coupling functionality to allow further flexible accommodation of the capacity of the line at peak times
Operational reliability increase	Fundamentally more reliable technologies and components	Introduction of formal methods and testing processes/tools to be applied – from specification up to commissioning phase – to key elements and systems the failure of which might have a major impact on line operation (e.g. signalling, telecoms)
	Fundamentally simplified architectures, or architectures more suited to continued operation in the event of failure	Train communications and control architecture based on new technologies allowing much lower physical complexity and enabling operational recovery in the event of degraded modes

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Railway system LCC reduction	Reduction in the capital cost of signalling and telecom infrastructures	Introduction of flexible architectures, general purpose networking technology and application of operational and engineering standards, allowing correct system design customisation to the requirements of different market segments (from freight to mass transit) and, therefore, a reduction of overall investment cost. Definition of business model that deals with the impact of shifting capital investment from trackside to on board, leveraging the new opportunities for tailored networks-as-a-service offerings on generic mobile networks. The definition of a better authorisation processes, relying on lab methods rather than on on-track tests, will also guarantee a consistent capital cost reduction
	Reduction in maintenance cost	Reducing as much as possible the number of electronic and mechanical components laid down along the line and concentrating them in a limited number of easily accessible areas. Wider introduction of auto-diagnostic functions to detect the status of more critical components will allow predictive (and optimised) maintenance
	Reduction in the consumption of energy	Introduction of appropriate ATO functionalities (with GoA 2 to 4) and intelligent traffic management in all rail transport market segments

Past and ongoing European and national research projects

IP2 will ensure strong continuity with several ongoing or past projects (e.g. Trans-European Transport Network (TEN-T) projects, NGTC, Union Industry of Signalling (Unisig) activities in the framework of the Baseline 3 development, GSA projects such as STARS and ERSAT-EAV, euLynX).

Relations with ERTMS working groups will be ensured, as many TDs of IP2 have common subjects.

Specifically, the following TDs have tight relationships with Unisig working groups and EUG (ERTMS Users Group). Possible areas for interaction are also indicated in the following table.

IP2 TDS	UNISIG WORKING GROUPS	AREAS FOR INTERACTION
TD2.1 Adaptable Communications for All Railways	Euroradio	Provide an adaptable train-to-ground IP communication system supporting backward compatibility for ERTMS, easy migration and capability to be resilient to radio technology developments
TD2.2 Railway Network Capacity Increase (ATO up to GoA 4 – UTO)	ATO over European Train Control System (ETCS)	The results of the TEN-T programme (GoA 2 concepts and requirements) will be implemented (prototypes) and validated in order to provide a GoA 2 solution for railway applications ready for deployment
TD2.4 Fail-Safe Train Positioning (including satellite technology)	Train localisation, e.g. with satellites	Interoperable and safe absolute positioning of the train, mainly obtained by applying the Global Navigation Satellite System (GNSS) technology to the current ERTMS/ ETCS core

IP2 TDS	UNISIG WORKING GROUPS	AREAS FOR INTERACTION
TD2.6 Zero On-site Testing (control–command in LAB demonstrators)	IOP	Unisig IOP standards taken as the baseline in order to improve testing in lab
TD2.11 Cyber Security	Key management	Input for TD2.11: cyber-risk assessment of the ETCS solution carried out by TEN-T working group, including security by design aspects

Set-up and structure of IP2

In order to address the challenges of IP2, 11 TDs have been identified. The interactions between these TDs will be strongly fostered and managed as an integrated and interrelated project in order to achieve a common and coherent new signalling and supervision system.

The work will be organised around the following research areas.

Smart, fail-safe communications and positioning systems

- The development of a **new communication system** (TD2.1 Adaptable Communications for All Railways) able to overcome the shortcomings in current ETCS and CBTC and deliver an adaptable train-to-ground communications system usable for train control applications in all market segments, using packet switching/IP technologies (GPRS, EDGE, LTE, Satellite, Wi-Fi, 5G, etc.), in accordance with the findings of the ongoing NGTC project. The system will enable easy migration from existing systems (e.g. the Global System for Mobile Communications – Railway (GSM-R)), provide enhanced throughput, safety and security functionalities to support the current and future needs of signalling systems, and be resilient to interference and open to radio technology evolution. The focus will be as well in supporting the shift from network as an asset to network as a service, considering also the vision of virtual network slices being developed and deployed by the 3rd Generation Partnership Project and the mobile operator community. Backward compatibility with ERTMS will be ensured.

- **Safe train positioning** (TD2.4 Fail-Safe Train Positioning (including satellite technology)) via the development of a fail-safe, multi-sensor train-positioning system, applying GNSS technology to the current ERTMS/ETCS core and introducing, as a possible add-on for fulfilling the scope, the use of other new technologies (e.g. inertial sensors, mobile network positioning) or of existing on-board sensors (e.g. accelerometers, odometer sensors), aims to boost the quality of train localisation and integrity information, while also reducing overall costs, in particular by enabling a significant reduction in all trackside conventional train detection systems (balises, track circuits, axle counters, etc.).

- The development of **smart object controllers** (TD2.10 Smart Radio-Connected All-in-All Wayside Objects), consisting of autonomous, complete, intelligent, self-sufficient smart equipment (boxes) able to connect by standardised interfaces not only with control centres (e.g. interlockings) or other wayside objects and communicating devices in the area (by radio or satellite), but also with, for example, on-board-units. Such intelligent objects – knowing and communicating about their status conditions – would not only provide opportunities in terms of cost reduction and asset management improvement but also open new ways of railway network information management and control.

Traffic management evolution

- An **optimised TMS** (TD2.9 Traffic Management Evolution) through improved traffic management operations with automated processes for data integration and exchange with other rail business services. The backbone of the new architecture will be a scalable, interoperable and standardised communication structure able to be applied within an integrated rail services management system. These features will be combined with new business service applications (e.g. advanced driver advisory system (DAS) on area level, intelligent, automated and flexible dispatching systems including conflict detection and resolution) to allow predictive and dynamic traffic management in regular and degraded situations. This TD will use and integrate real-time status and performance data from the network and from the train, using on-board train integrity solutions and network object control functions, supported by wireless network communication.

- **On-board ATO** (TD2.2 Railway Network Capacity Increase (ATO up to GoA 4 – UTO)) aims to develop and validate a standard ATO with form-fit functional interface specification (FFFIS) interfaces up to GoA 3/4 over ETCS, where applicable, for all railway market segments (mainline/high speed, urban/suburban, regional and freight lines).

Moving block (MB), train integrity and virtual coupling

- **Moving block** (TD2.3 Moving Block) aims to improve line capacity by decoupling the signalling from the physical infrastructure and by removing the constraints imposed by trackside train detection, thereby allowing more trains on a given main line, especially for high-density passenger services. The system will be backward compatible with existing ERTMS system specifications and enable developments towards CBTC functionalities for urban applications.

- **Safe train integrity** (TD2.5 On-board Train Integrity) aims to specify and prototype an innovative on-board train integrity solution, capable of autonomous train tail localisation, wireless communication between the tail and the front cab, safe detection (SIL-4) of train interruption and autonomous power supply functionality without the deployment of any fixed trackside equipment. This functionality will be developed particularly for those market segments (freight and passenger low-traffic lines) where such a function is not yet available using reliable existing on-board features.

- **Virtual coupling** (TD2.8 Virtually Coupled Train Sets) aims to enable virtually coupled trains to operate much closer to one another (within their absolute braking distance) and dynamically modify their own composition on the move (virtual coupling/uncoupling of train convoys), while ensuring at least the same level of safety as currently provided.

Smart procurement and testing

- The development of a set of **standardised engineering and operational rules** (TD2.7 Formal Methods and Standardisation for Smart Signalling Systems) will contribute to an **open standard interface** (if supported by positive business case) **and functional ETCS description model**, all based on formal methods, in order to ease verification and authorisation processes, eventually leading to improved interoperability, while reducing the need for extensive field tests in the future.

- The development of a **new laboratory test framework** (TD2.6 Zero on-site testing (control–command in lab demonstrators)), composed of simulation tools, testing procedures in order to carry out open test architecture with standardised interfaces (FFFIS), clear operational rules and simple certification of test results, aims to minimise on-site testing (with the objective of zero on-site testing) by performing full laboratory test processes even if the systems are composed of sub-components from different suppliers. The test framework will also allow remote connection of different components/subsystems located in various testing labs.

Communication network and security systems

- **Cybersecurity** (TD2.11 Cybersecurity) will aim to achieve the optimal level of protection against any significant threat to the signalling and telecom systems in the most economical way (e.g. protection from cyberattacks and advanced persistent threats coming from outside).

All the IP2 research areas and relevant TDs are closely linked to each other. Strong connections are already planned with other IPs and/or CCAs.

Figure 12 shows the expected links and interactions between TDs of IP2, as well as with other IPs. Table 16 also shows in detail the relationships for each TD and also reveals the major challenge of IP2, which is to foster the evolution of a whole and interactive signalling system.

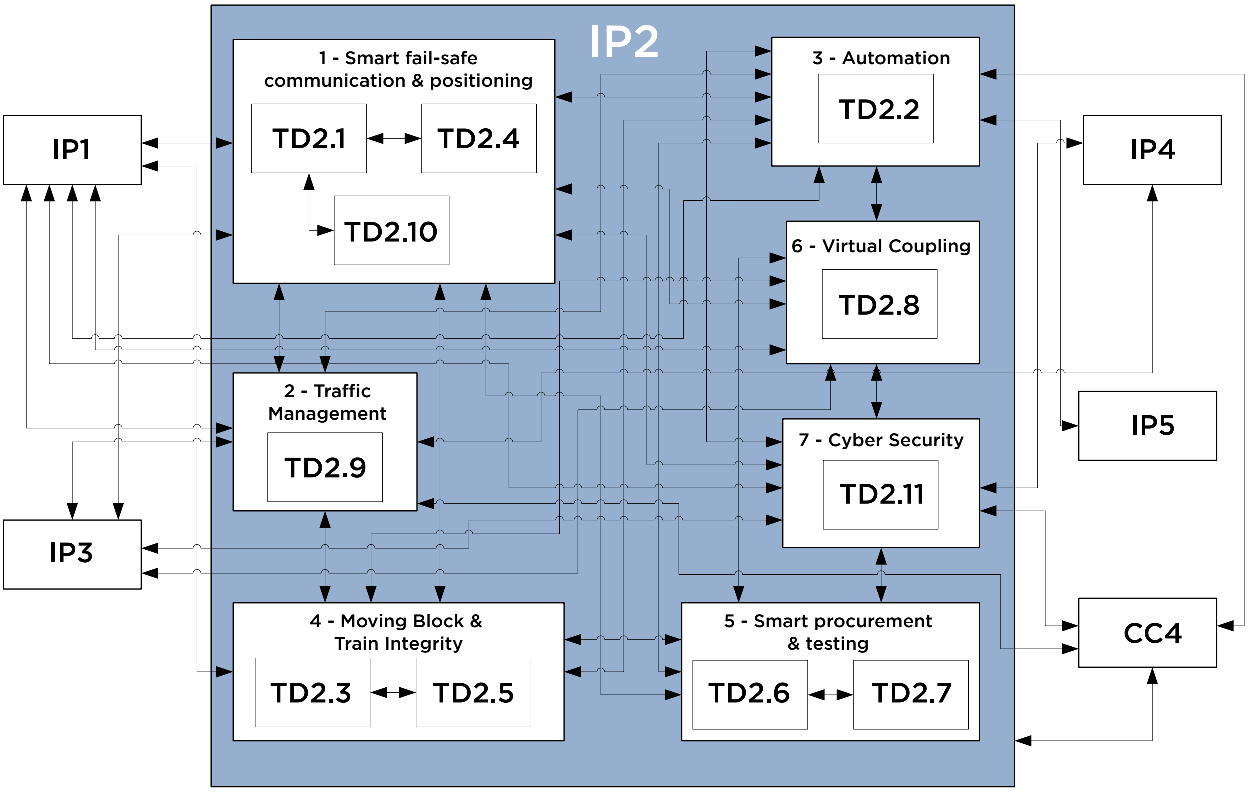


*Figure 12 / **IP2 research and innovation relationships***

The following tables show how close are the synergies within IP2 and with the other innovation programmes in S2R. The tables also identify the main direction of the information expected to be shared between TDs and other IPs.

In addition, the existing interactions with other IPs and within relevant TDs of IP2 take into account the work performed in IPx. This activity will be further developed in IPx to create an integrated railway system architecture.

Table 16 / ***Links and synergies between TDs within IP2***

FROM → TO

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
S2R IP2	TD2.1	*Adaptable Communication for all Railways*		←	←	←	←			←		←	←
	TD2.2	*Network capacity increase (ATO up to GoA4)*	←		←	←	←	←	←	←	←		←
	TD2.3	*Moving Block*	←			←	←		←	←	←		
	TD2.4	*Fail safe Train Positioning(satellite)*	←	←	←		←	←	←	←			←
	TD2.5	*Train Integrity*	←		←	←			←	←			
	TD2.6	*Zero on Site Testing*	←		←	←			←	←		←	←
	TD2.7	*Formal Methods*				←	←			←			
	TD2.8	*Virtual Coupling*	←		←	←	←	←	←				←
	TD2.9	*TMS evolution*		←	←								←
	TD2.10	*Smart Radio connected (wayside object)*	←					←	←				←
	TD2.11	*Cyber Security*	←			←			←	←	←	←	

In IP2 almost all TDs have links to each other and need to exchange deliverables and findings during the entire timeline of the project. This confirms that, particularly for IP2, the working and development approach have to be system oriented with the aim of achieving an integrated and consistent new signalling, automation and communication structure. Dependency is high, as often the result of a TD is one of the essential components or functions that allow the accomplishment of the target for other TDs. Synergies and coordinated project planning are among the most important key aspects for the achievement of the Master Plan objectives.

Table 17 / ***Links and synergies between IP2 TDs and IP1***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
S2R IP1	TD1.2	*Train Control and Monitoring System TCMS*	X	X		X	X			X	X		X

Many IP2 TDs also have **potential** links with TD1.2, TCMS. The purpose is to identify common requirements and solutions where on-board signalling and automation systems have to communicate with each other, with wayside systems and with the train. The approach is expected to foster standard solutions, which means integration and cost reduction.

Table 18 / ***Links and synergies between IP2 TDs and IP3***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
S2R IP3	TD3.1	*Enhanced Switch & Crossing*										↑	
	TD3.2	*Next Generation Switch & Crossing*								↑		↑	
	TD3.6	*Dynamic Railway Information Management*									X		←
	TD3.7	*Railway Integrated Measuring and Monitoring*										X	
	TD3.8	*Intelligent Asset Management Strategies*										X	

Some IP2 TDs are expected to have relationships with IP3 mainly for the aspects related to diagnostic and maintenance procedures and integration processes.

Table 19 / ***Links and synergies between IP2 TDs and IP4***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
S2R IP4	**TD4.1**	***Interoperability Framework***											←
	TD4.4	***Trip Tracker***									←		

Two main relationships are expected with IP4, one related to the interface of TMS with passenger information system and the other one for providing results of the cybersecurity assessment for the interoperability framework.

Table 20 / ***Links and synergies between IP2 TDs and IP5***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
S2R IP5	**TD5.6**	***Autonomous Train Operation***		X									

Cooperation is planned between TD2.2, Railway Network Capacity Increase (ATO up to GoA 4), and TD5.6, Autonomous Train Operation, in order to harmonise ATO overall development and functionalities for freight application as well.

Table 21 / ***Links and synergies between IP2 TDs and CCAs, In2Rail***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
IN2RAIL *(Subproject I²M)*	**WP7**	***System Engineering***									↑		
	WP8	***Integration Layer***									↑		
	WP9	***Now and Forcasting***									↑		

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
CCA	**Sub-WA2**	***KPI Monitoring***	X	X	X	X	X	X	X	X	X	X	X
	Sub-WA3.1	***Safety***											
	Sub-WA3.2	***Standardisation***	←										←
	Sub-WA3.3	***Smart Maintenance***											
	Sub-WA3.4	***Smart Materials***											
	Sub-WA3.5	***Virtual Certification***											
	Sub-WA4.2	***Integrated Mobility Management I2M***		X							←		X
	Sub-WA5.1	***Energy***		X								↑	

There are several links with CCAs and In2Rail that mainly affect supervision systems (wayside and on board) and cybersecurity. Sub-WA2, KPI monitoring, has also to interact with all IP2 TDs in order to manage and harmonise the KPI process.

Table 22 / ***Links and synergies between IP2 TDs and FP7 NGTC***

			S2R IP2										
			TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
FP7 NGTC	**WP2**	***ETCS/CBTC investig.***					↑						
	WP3	***Technical Coherence***		↑	↑								↑
	WP4	***Message Structure***		↑							↑		
	WP5	***Moving Block***			↑		↑			↑	↑		
	WP6	***Radio Based Comm***	↑				↑					↑	↑
	WP7	***Satellite Positioning***				↑	↑						

2.1. TD2.1 – Adaptable Communication System for All Railways

2.1.1. Concept

The Adaptable Communication System for All Railways provides the communication backbone for existing and emerging railway applications with a particular focus on train-to-ground communication for enabling the next level of digitisation of railways. The approach foresees the separation and decoupling of railway applications from the underlying radio systems and supporting generic communication services to overcome dependencies on the evolution of radio technology, as well as enabling new operating models that reduce capital investments and operational costs.

2.1.2. Technical objectives

The following are the main technical objectives of this TD.

1. Realise the potential of emerging railway applications with enhanced, flexible and superior communication services.

2. Design a technology-independent system by decoupling the railway applications from the underlying radio access systems and consequently introduce generic and flexible communication services. Allow future evolutions of the radio bearer technology with minimum dependencies or impact on the railway applications.

3. Support multi-access networks with the ability to aggregate and combine radio bearers for increased redundancy or improved throughput.

4. Become adaptable by intelligently selecting and using appropriate bearers based on the railway application requirements.

5. Support concurrent use of communication services by multiple railway applications combined with policy control and communication prioritisation to ensure proper handling of safety-critical applications.

6 Leverage existing and emerging radio technology to enable improved communication efficiency; higher throughput, lower latency, increased availability, and comprehensive security features.

7 Aim for a common and unified communication system for all railways and address the convergence of metro and main line, regional and high speed.

8 Reduce capital investment, operational costs and project complexity, together with the ability to support alternative operational and business models based on shared communication infrastructure up to network-as-a-service approaches.

2.1.3. Technical vision

Figure 13 shows a block diagram of the envisaged adaptable communications system for all railways. The focus is on the ground-to-train link, where several radio network options are shown, and an appropriate selection made according to the prevailing quality of service demands by the applications and available radio resources. Several on-board and trackside applications are depicted, including automatic train protection, ATO, train control and monitoring system (TCMS) and critical voice communication between driver and signalling teams. The dark blue blocks form integral parts of the ACS, whereas grey (existing wireless technology) and light blue (applications) blocks interface with the ACS.

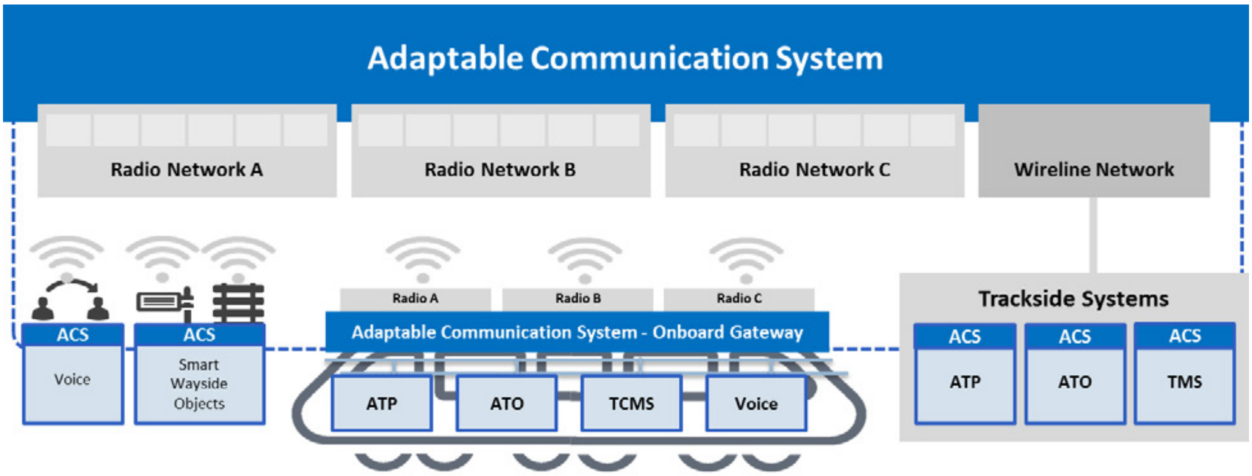


Figure 13 / ***Functional diagram of Adaptable Communication System for All Railways***

The following table shows five key differentiators between the current state of the art and the envisaged ACS. Thus it is clear that the ACS presents a step change in communication technology for servicing the current and emerging operational needs of railways.

STATE OF THE ART	ADAPTABLE COMMUNICATION SYSTEM
Monolithic communication system with direct interactions with railway applications	Decoupling of railway applications from the underlying radio systems using generic communication services leveraging IP-based transmission
Limited communication features and capabilities constraining railway communication functionality and limit application usage	Ability to transparently combine and aggregate multiple communication resources and leverage flexible routing capabilities, traffic flow prioritisation, seamless inter-radio access technology as well as inter-network handover, and ubiquitous redundancy
Changing or upgrading the communication system forcing costly changes or updates to the railway applications	Radio system and related upgrades of the radio technology completely independent from the railway applications
Communication infrastructure owned by the railway undertaking.	Support for different infrastructure-sharing flavours up to network-as-a-service models; the new system will plan flexible operational models that fit the needs of the railway undertaking.
Proprietary and niche market solutions driving communication system costs	Use of a standardised functionality and commercial-of-the-shelf components to leverage economies of scale and scope from general telecommunication market and a wide set of manufacturers supplying network equipment and terminals/mobile devices

Interaction with other TDs (in the same IP and/or in other IPs)

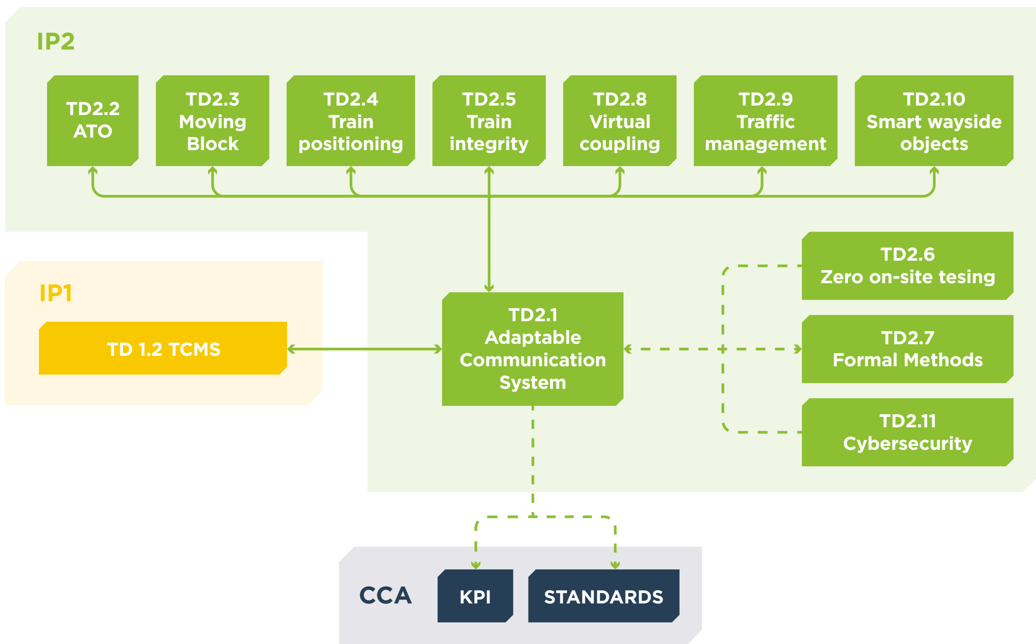


Figure 14 / ***Interaction with other TDs and IPs***

2.1.4. Impact and enabling innovation capabilities

The new adaptable communication system provides significant value and benefits to all of the proposed TDs of S2R. Benefits range from simplification of communication services to new and superior communication characteristics. With the introduction of the adaptable communication system, the railway applications become independent from the radio technology and rely on generic communication services, which provide higher throughput, increased availability and reliability, transparent support for multiple radio technologies and significant cost savings. The following table provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	The adaptable communication system acts a key enabler for the complete rail system and provides the following tangible benefits to maintain and enhance technology leadership: • separation and decoupling of the communication subsystem from the railway applications, which introduces generic communication services without dependencies or implications to the underlying technology or network systems • combination and bundling of various radio systems, including satellite communication, into generic services to improve communication performance and characteristics such as enhanced throughput, superior resiliency, transmission prioritisation and enlarged coverage, which enable new innovative railway applications • support for new business models to provide communication services based on infrastructure or resource sharing up to network-as-a-service models • LCC reduction (through sharing the communication network or the possibility of using public networks in some circumstances)
Compliance with EU objectives	• Communication technology is in constant evolution and the TD will take that situation into account: the modular architecture will allow the latest convenient technologies to be applied to emerging markets, while nevertheless ensuring backward compatibility with the already deployed ERTMS in Europe, allowing a migration phase. The radio bearer could be transparently selected and adapted to the specific conditions to keep the costs as low as possible (e.g. use of satellite communication in a large sparsely populated area, to save the cost of a wayside communication infrastructure) • It will enable a common communication system to address the requirements of all segments in the rail system with unified and cost-efficient communication services • It will help to advance railway applications to achieve the goals around capacity increase, modal shift and more efficient railways • It will leverage standardisation, interfaces and architecture to ease and improve interoperability between different subsystems and the communication system
Achieve the SERA	Interoperability will be provided, including with a solution suitable for the urban/suburban domain, answering the needs of current and enhanced CBTC and ETCS solutions
Degree of maturity of the envisaged solutions	Although the radio technology and system expected to be integrated into the adaptable communication system is either commercially available or currently emerging, the system to combine, manage and support generic communication services to railway applications is currently at TR1 or 2 (principles observed and the possibility of using them formulated). At the end of S2R it is expected that the concepts and functional prototypes will have been brought to TRL 6 or 7

The Adaptable Communication System for All Railways provides communication services and associated benefits to basically all innovation capabilities. Accordingly, the following building blocks can be added to the row for each innovation capability in the table below:

- BB2.1.1, Definition of a multi-bearer technology including satellite communication;
- BB2.1.2, System open to exploit the use of public land mobile networks;
- BB2.1.3, System resilient to the evolution and needs of the signalling system.

This TD will mainly contribute to enabling the following seven innovation capabilities.

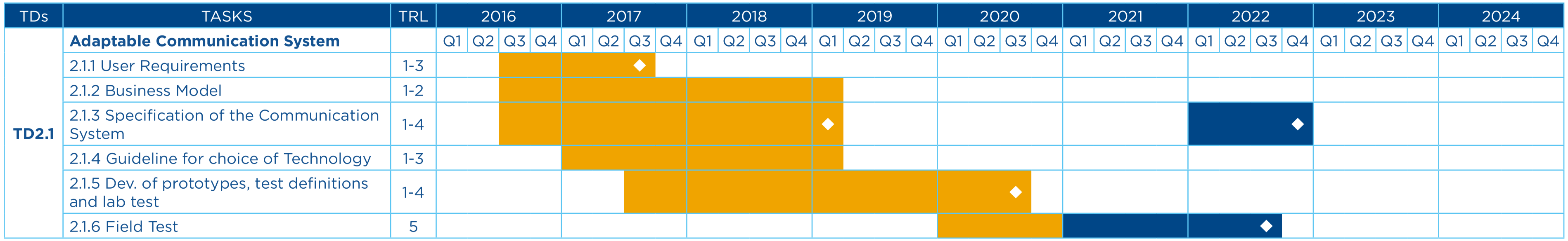
INNOVATION CAPABILITY	TD2.1 ADAPTABLE COMMUNICATION SYSTEM – TRL 5/6
1 – Automated train operation	Provide generic and enhanced communication services that are transparent and decoupled from the railway application, including ATO. Thus, the Adaptable Communication System is a key enabler for the ATO application
4 – More value from data	Act as communication backbone for the rail system and drive digitalisation in railways to the next level while supporting adaptable, secure, resilient and scalable communication services
6 – Service timed to the second	Provide flexible and efficient communication services to support the information exchange between vehicles and traffic management to enable consistent and real-time management of the rail system
7 – Low-cost railway	Rely on standardised system components and decouple application layer from communication system to reduce project implementation and certification costs. New business models based on infrastructure sharing as well as support for network-as-a-service models provide OPEX savings
8 – Guaranteed asset health and availability	Supporting generic and adaptable communications to the rail system supports the efficient exchange of information to ensure that asset health and availability are significantly improved
9 – Intelligent trains	Provide the communication backbone to enable trains to interact with the trackside applications and reliably exchange data without the constraints of existing communication solutions
10 – Stations and smart city mobility	A single shared train-to-ground communications system provides flexible, secure and improved connectivity for new railway applications, trains, passengers and other users of all rail systems, including high-speed, regional, urban and metro rail

The above list of contributions to innovation capabilities represents only the main areas for TD2.1. Further contributions to other capabilities are expected; for example, mobility as a service (MaaS) will be supported by the availability of new business and operating models for the communication system up to network-as-a-service models to leverage reductions in CAPEX, OPEX and total cost of ownership. Communication as a service becomes an integral part of the MaaS capability. Furthermore, the logistics on demand innovation capability is also supported by the adaptable communication system with flexible and multipurpose information exchange between freight applications and relevant transport units enabling new innovation for the freight transport domain. Finally, rapid and reliable R&I delivery is improved with the decoupling of railway applications from underlying radio systems, which removes the dependencies and complex interactions to introduce, upgrade or enhance existing applications independent from the standardised communication system.

2.1.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Adaptable Communication System for All Railways	Improve communication capabilities (throughput, quality of service (QoS), availability, coverage)	Technology guideline, business model analysis, system specification	Urban High speed Regional	4/6	Integrate multiple existing and emerging radio systems into a unified communication system providing generic services to the applications. It also includes infrastructure sharing or network-as-a-service models
	Support transparent and decoupled communication services	System specification	Urban High speed Regional	4/6	Combine, aggregate and manage different radio bearers or networks to provide a generic communication system decoupled from the railway application to avoid dependencies or implications if the underlying radio technology changes or evolves
	Enable common and unified communication for all railways	Business model analysis, system specification	Urban High speed Regional	4/6	Assess communication requirements from all railway segments and identify the common basis allowing specific options per segment
	Encompass new business models for the communication system	Technology guideline, business model analysis, system specification	Urban Regional High speed Freight	3	Analyse the different sharing options for the communication infrastructure and resources (e.g. spectrum), up to a network-as-a-service model. Develop a tool to compare business models and share options based on input parameters covering cost implications, technology options, etc.

Planning and budget



◆ milestone

contracted activites

planned activities

Table 23 / ***TD2.1 milestones***

WHEN	WHAT
Q3 2017	User and system requirements deliverable
Q1 2019	Specification document deliverable
Q3 2020	Lab test and validation of prototypes
Q3 2022	Field test and validation of TD
Q4 2022	Update of specification document

The estimated total budget for TD2.1 is around EUR 26.4 million.

2.2. TD2.2 Railway Network Capacity Increase (automated train operation up to grade of automation 4 – UTO)

2.2.1. Concept

Mainline ETCS applications (including suburban) are currently generally limited to non-automated train operation (GoA 1 present in both ERTMS level 1 and ERTMS level 2). The higher grade (GoA 2) is very rare on old systems and non-existent on ETCS ones.

The operation concepts formally defined by European railway operators (the European economic interest grouping) cover all GoAs:

- GoA 1, non-automated train operation (current situation) – the train is driven manually, but protected by ETCS;
- GoA 2, semi-automated train operation – the train is driven automatically, but the driver is still in the cab to check the absence of obstacles in the track;
- GoA 3, driverless train operation;
- GoA 4, unattended train operation.

Even though the highest GoA is a proven technology in urban operations, the operational constraints of the mainline transport system are significantly more complex than those of urban systems.

Compared with urban systems, the situation for mainline systems is more complex:

- the track layout is larger and more complex;
- the roll-out of any new system across the network takes many years, resulting in most journeys spanning lines with significantly different levels of fitment of infrastructure;
- there are many different train types (with different performance levels and door layouts);
- most trains are not all dedicated to a particular line; they may go anywhere in the country, with a few running anywhere in Europe;
- the absolute exclusion of people (as well as animals and other obstructions) from tracks is not practically achievable throughout a national network; that would mean vast lengths of

fencing to install and maintain, and a multiplicity of over-bridges, level crossings, footpath crossings, open station platforms, etc.;

- IMs and railway undertakings are often independent (at least in the EU), and sometimes other parties are also involved, such as train-leasing companies.

Despite the specificities of main lines, ATO (up to GoA 4) will be undoubtedly beneficial for the different kinds of railway operation:

- for high-speed trains, intercity lines and regional lines, semi-automated operation (at least GoA 2) will enhance timetable adherence and optimise energy consumption;
- for freight lines, on both heavy haul railways and low-density traffic lines, ATO (at least GoA 2) will provide smoother operation, bring energy savings and permit optimal efficiency, e.g. allowing 'meet and pass' operation whenever possible;
- for urban and suburban applications, driverless (GoA 3) and unattended (GoA 4) types of operation will allow high performance for lines carrying intensive inner suburban and cross-city services having the full advantage of ETCS (interconnections, diverse train types, interoperability, etc.).

2.2.2. Technical objectives

The aim of this programme is to investigate, develop and validate ATO over ETCS up to GoA 4. The actual objectives are:

1. To increase the transport capacity on existing lines while limiting investment in new infrastructure.
2. To reduce the operating costs, save energy and make more efficient use of resources (e.g. staff).
3. To make an important contribution to the vision of a fully automated rail freight system (TD5.6).

2.2.3. Technical vision

The state of the art is based on proprietary solutions that are not interoperable. The existing systems consider simple lines and operation schemes.

The progress will be to provide an interoperable solution based on ETCS and able to manage the delivery of varied service patterns on a mixed-traffic network taking into account the complexity of mainline operation (large interconnected network, different level of infrastructure fitment, many different train types not dedicated to a given line, etc.).

Compared with the current state of the art in railways, the following benefits are expected from TD2.2.

Table 24 / ***Benefits expected***

	HIGH-SPEED LINES	LOW-TRAFFIC LINES/ REGIONAL LINES	URBAN/SUBURBAN LINES
Punctuality	Journey times less variable and closer to timetables	Journey times less variable and closer to timetables	Journey times less variable and closer to timetables
Operational headway	Less variability in actual journey time permits the infrastructure operator to allow less reserve time in the theoretical timetables. This leads to lower operational headway and will increase the line capacity	Less variability in actual journey time permits the infrastructure operator to allow less reserve time in the theoretical timetables. This leads to lower operational headway and will increase the line capacity	Less variability in actual journey time permits the infrastructure operator to allow less reserve time in the theoretical timetables. This leads to lower operational headway and will increase the line capacity
Mean journey times	Less variability in actual journey time permits the operator to reduce the journey times planned in the theoretical timetable	Less variability in actual journey time permits the operator to reduce the journey times planned in the theoretical timetable	Less variability in actual journey time permits the operator to reduce the journey times planned in the theoretical timetable
Energy consumption	The trains are driven according to optimum speed profiles that minimise the energy consumption	The trains are driven according to optimum speed profiles that minimise the energy consumption	The trains are driven according to optimum speed profiles that minimise the energy consumption
Staffing costs	Driverless and unattended operations allow reduction in the required operational staff, thus contributing to enhancing railway transport productivity	Not an issue	Driverless and unattended operations allow reduction in the required operational staff, thus contributing to enhancing railway transport productivity

Interaction with other TDs (in the same IP and/or in other IPs)

TD2.2 is linked with the following TDs:

- TD2.1, Adaptable Communication System for All Railways – for achieving common telecommunication infrastructure for ATO data exchange;
- TD2.3, Moving Block – for common influence;
- TD2.4, Fail-safe Train Positioning – for managing absolute positioning to be used for ATO functions;
- TD2.5, On-board Train Integrity – to manage automatic coupling and uncoupling;
- TD2.6, Zero On-site Testing – to have the benefits of the results from this work package (WP) for ATO trackside system (ATO-TS) and on-board ATO system (ATO-OB) testing;
- TD2.7, Formal Methods and Standardisation for Smart Signalling Systems – including to have the benefits of the results from this WP for ATO-TS and ATO-OB development;
- TD2.8, Virtually Coupled Train Sets – to increase operation performances with ATO managing virtually coupled trains;
- TD2.9, Traffic Management Evolution – to consider standard interface with TMS; trackside ATO management is considered to be a subsystem separated from TMS and connected to TMS via a standard interface of the integration layer that will be developed under TD2.9;

- TD2.11, Cybersecurity – to cover communication between ATO on board and at wayside;
- TD5.1, Fleet Digitalisation and Automation – in order to get ATO specification for freight and to provide ATO prototypes to be tested on a pilot line dedicated to freight.

TD2.2 will also interact with IP1 (Connecta) in order to envisage standard interfaces with TCMS and rolling stock.

Finally, TD2.2 will have links with CCA Sub-WA5.1 Energy and Sub-WA4.2 I2M in order to identify information to be exchanged in addition to that provided by the TMS developed in TD2.9.

2.2.4. Impact and enabling innovation capabilities

Thanks to the operational headway reduction, it is expected that TD2.2 developments will bring 10–50 % (or even more) line capacity increases. The final figures will depend on several parameters: the existing line or network characteristics, the available or possible extensions and adaptations of the infrastructure, and the characteristics of existing and new rolling stock are among the parameters that will have to be considered.

The consequence of the operational margin improvement is that the number of trains per hour may be increased without changing the infrastructure or the signalling.

Energy savings depend on the type of operation and type of trains. Recent studies have demonstrated that automatic driving can lead to savings of between 12 % and 20 %.

The benefits associated with staff reduction also depend on the type of operation.

For example, the use of automatic unsupervised turn back would allow a reduction in staff numbers.

In GoA 3/4, the staff reduction is, by definition, much larger, even if, in these grades of automation, the operator must still have people on site in order to manage the degraded modes.

ATO over ETCS (up to GoA 3/4) will completely change the way future railway lines are operated.

Without imposing heavy investment to create additional infrastructure, it will:

- improve services and customer perception of quality by improving punctuality and by increasing transport capacity in order to face the growing demand for public transport over the coming decades;
- reduce operational costs by saving energy and reducing staff;
- enhance interoperability by producing ATO over ETCS interoperable requirement that will be used to modify the current ETCS TSI.

TD2.2 provides interoperable solutions for automatic driving (up to GoA 4). Given this, the following building blocks can be added to the different rows for each innovation capability:

- BB2.2.1, Definition of the architecture for application of ATO (GoA 2 up to GoA 4);
- BB2.2.2, Definition of the model for improving punctuality and quality of service, reducing energy consumption.

This TD will mainly contribute to enabling the following six innovation capabilities.

INNOVATION CAPABILITY	TD2.2 ATO (UP TO GOA 4) – TRL 6
1 – Automated train operation	TD2.2 provides the following for GoA 2 and GoA 3/4: • interoperable specification (including interface specification) • prototype development • factory interoperability tests mixing solutions from different suppliers • on-site pilot tests With these activities, TD2.2 is a key enabler for the ATO application
3 – Logistics on demand	ATO in GoA 4 increases flexibility of railway operation in all market segments, improving transport capacity in real time based on the actual situation. It also reduce the recovery time after disruption
5 – Optimum energy use	ATO in GoA 2, GoA 3 and GoA 4 is based on optimised speed profile computation, which guarantees on-time arrival and minimises energy consumption
6 – Service timed to the second	ATO in GoA 2, GoA 3 and GoA 4 is based on optimised speed profile computation, which guarantees on-time arrival and minimises energy consumption
7 – Low-cost railway	ATO in GoA 3/4 reduces operational costs with better use of operational staff. In addition, ATO in GoA 2, GoA 3 and GoA 4 minimises energy consumption, reducing drastically the associated operational costs
9 – Intelligent trains	TD2.2 provides the specification for the entire GoA 4 solution based on intelligent unattended trains

2.2.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
ATO up to GoA 3/4	Demonstrate the interoperability of GoA 2 solution in factory	System requirement specification for GoA 2 Test bench Interoperability	Urban High speed Regional Freight	6	Two reference test bench platforms will be used (one from Siemens and one from Alstom). These reference test bench platforms will be used to interface ATO trackside and on-board solutions delivered by different suppliers in order to demonstrate the interoperability of the solution
	Demonstrate the feasibility of GoA 2 solution on actual pilot train and line	System requirement specification for GoA 2 Test bench Interoperability	Urban High speed Regional	6	The tests will be hosted by Network Rail on Hitchin test facilities (the pilot line) and on the Class 180 train (Alstom train with Alstom ETCS)
	Demonstrate the interoperability of GoA 3/4 solution in factory	System requirement specification for GoA 3/4 Test bench Interoperability	Urban High speed Regional Freight	6	Two reference test bench platforms will be used (one from Anslado and one from Alstom). These reference test bench platforms will be used to interface ATO trackside and on-board solutions delivered by different suppliers in order to demonstrate the interoperability of the solution
	Demonstrate the feasibility of GoA 3/4 solution on actual pilot train and line	System requirement specification for GoA 3/4 Test bench Interoperability	Urban High speed Regional Freight	6	Pilot train and pilot line will be equipped. Pilot test will include obstacle and track intrusion detection devices

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Railway network capacity increase (ATO up to GoA4-UTO)		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.2.1 ATO over ETCS - GOA2 Specification	3-4								◆																				
	2.2.2 ATO over ETCS - GOA2 Product Development	5-6																												
	2.2.3 GOA2 Reference Test Bench Demonstration	6												◆																
	2.2.4 GOA2 Pilot Line Demonstration	7																	○											
TD2.2	2.2.5 ATO over ETCS - GOA3/4 Feasibility Study	3																												
	2.2.6 ATO over ETCS - GOA3/4 Specification	3-4																				◆								
	2.2.7 ATO over ETCS - GOA3/4 Product Development	5																												
	2.2.8 GOA3/4 Reference Test Bench Demonstration	6																								◆				
	2.2.9 GOA3/4 Pilot Line Demonstration	7																												◆

◆ milestone
○ quick win
contracted activities
planned activities

Table 25 / ***TD2.2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2018	Semi-automated operation (GoA 2)	The main outcome of this quick win is the availability of GoA 2 products making it possible: • to increase operational performance, reducing the operational headway by up to 30 % • to reduce operational cost, saving on energy consumption by at least 15 % • to enhance punctuality and to reduce the mean journey time

Table 26 / ***TD2.2 milestones***

WHEN	WHAT
Q1 2018	ATO over ETCS GoA 2 specification available
Q4 2018	ATO over ETCS GoA 2 reference test bench results available
Q2 2019	ATO over ETCS GoA 2 pilot test results
Q4 2020	ATO over ETCS GoA 3/4 specification available
Q4 2021	ATO over ETCS GoA 3/4 reference test bench results available
Q4 2022	ATO over ETCS GoA 3/4 pilot test results

The estimated total budget for TD2.2 is around EUR 22.48 million.

2.3. TD2.3 Moving Block

2.3.1. Concept

The concept of a moving block signalling system is to use moving block principles to localise the trains, and to determine movement authorities.

Moving block is seen by a large number of IMs and RUs as a way to increase significantly the capacity of railway lines that are already saturated or will become saturated in the near future. The moving block techniques can not only improve the transport capacity of the lines, but also reduce the cost of the signalling installations and increase the reliability of railway transport.

Moving block signalling has already been implemented by various suppliers for urban railways, typically within vertically integrated organisations, with captive rolling stock. It is not yet implemented to any large degree across other railway categories, where there can be many operators, with many train types, requiring full interoperability.

2.3.2. Technical objectives

The objective of the TD for Moving Block is to define, develop and test a high-capacity, low-cost, high-reliability signalling system, based on moving block principles, applicable across all railway categories:

- high capacity is based on the use of moving block principles, which permit decoupling of the infrastructure from train performance parameters;
- low cost is achieved by the reduction in the use of trackside train detection;
- high reliability is achieved as a consequence of the reduction in trackside equipment associated with trackside train detection.

These are all contributions towards overall S2R objectives.

Each of these areas can have an impact on services for customers:

- higher capacity enables an increase in the number of train services that can be run over given infrastructure;
- lower cost is of interest to all, and potentially enables upgrading of railways that would not otherwise be upgraded, especially in the low-traffic market segment;
- higher reliability can have a direct impact on services provided to customers.

It is also an objective of this TD to enhance interoperability. This will be achieved by working collaboratively on the specifications for the moving block signalling system. Collaboratively agreed specifications will enable interoperability at several overlapping levels:

- between equipment from different vendors;
- between trackside and on-board equipment;
- between equipment owned and operated by different RUs.

2.3.3. Technical vision

Within mass transit systems, CBTC or similar systems can approach close to theoretical maximum capacities. However, this is achieved in vertically integrated railway systems, which in general do not interact with other railways, and which have one or a very limited number of different types of trains, with fixed train consists.

Within mainline systems, traditional signalling systems have fixed blocks (Figure 15).

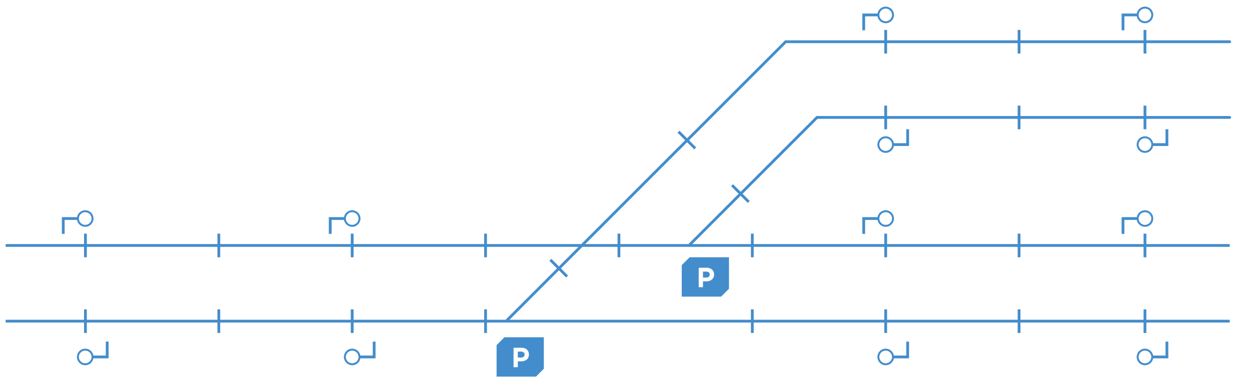


Figure 15 / ***Fixed block layout***

The blocks are fixed during the design of the infrastructure, and then hard-coded into the infrastructure, for example by the application of track circuits or axle counters.

There are also limitations based on signal-sighting rules, cable routing and power supplies.

The ambition of the moving block signalling system is to remove the constraints imposed by hard-coding the train detection blocks into the infrastructure (Figure 16).

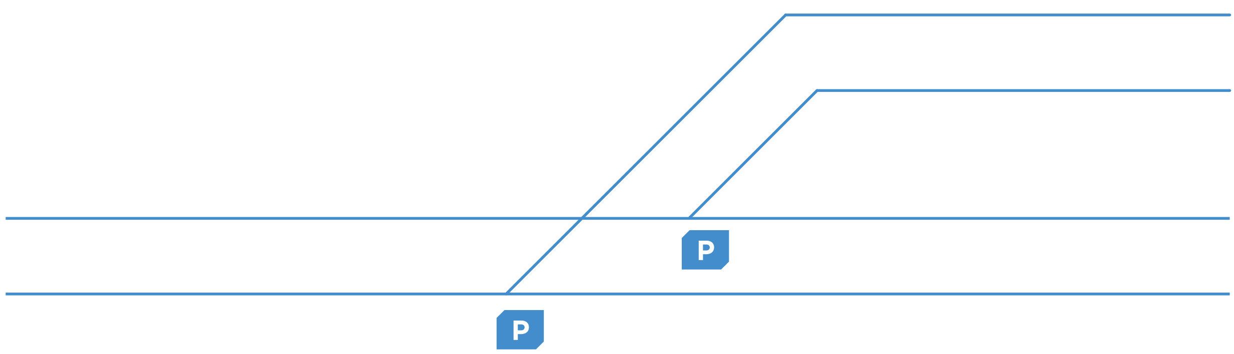


Figure 16 / ***Fixed block removal***

Once the constraint of the hard-coded blocks is removed, the signalling system, and hence the TMS, can determine the best use of the infrastructure in terms of capacity for different types of trains, or under different traffic conditions. Initial work in TD2.3 will be based on absolute braking. Later phases, in the task Future Moving Block Systems, will explore how to include relative braking concepts.

In order for such a system to be accepted as safe in the absence of trackside train detection, it is important that train integrity is provided (TD2.5).

As stated previously, such a moving block signalling system without trackside train detection also has the ambition to reduce costs and increase reliability – both of these based on the overall reduction in trackside equipment.

Interaction with other TDs (in the same IP and/or in other IPs)

*Table 27 / **Interaction with other TDs and IPs***

OTHER TD	MAIN OUTPUTS FROM TD2.3	MAIN INPUTS TO TD2.3
TD2.1 Adaptable Communication System for All Railways	Communication requirements for moving block signalling system, for example latency, frequency of messages	Communication capabilities resulting from the work of TD2.1
TD2.4 Fail-safe Train Positioning	Train location requirements for moving block signalling system – likely to be similar to present ETCS level 2 requirements	Train location capabilities resulting from the work of TD2.4
TD2.5 On-board Train Integrity	Train integrity requirements for moving block signalling system – new for moving block	Train integrity capabilities resulting from the work of TD2.5
TD2.6 Zero On-site Testing	Interface specifications to enable development of test environment	No specific input to TD2.3
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	No specific output from TD2.3	Understanding of how formal methods could be applied to the specification of moving block signalling systems
TD2.11 Cybersecurity	No specific output from TD2.3	Understanding of the impact of cybersecurity measures on train–trackside communications. It is likely that the impact of TD2.11 on TD2.3 will be via TD2.1

The Moving Block Signalling System will provide the safety critical layer of the signalling. Full usage of the increased capacity will then require the train regulation and traffic management systems. Therefore the moving block signalling system will interact with the train regulation and traffic management TDs within IP2:

- TD2.2 Railway Network Capacity Increase,
- TD2.9 Traffic Management Evolution.

The interaction with these TDs is summarised in the following table.

OTHER TD	INTERACTION WITH TD2.3
TD2.2 Railway Network Capacity Increase	Collaboration with TD2.2 to understand how to build combined ITD showing ATO operation over moving block signalling system
TD2.9 Traffic Management Evolution	Collaboration with TD2.9 to understand how to build combined ITD showing traffic management over moving block signalling system

2.3.4. Impact and enabling innovation capabilities

This TD will contribute to progress on the following strategic aspects.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Increased capacity	Moving Block signalling will enable increased capacity by removing the hard coding for specific trains from the railway, thus permitting optimised usage of the railway infrastructure
Reduced costs	Moving Block signalling will enable a reduction in cost by removing some of the equipment fitted to the railway in traditional signalling systems, such as trackside train detection
Increased reliability	Moving Block signalling will enable an increase in the reliability of railway signalling, based on the reduction in equipment fitted to the railway

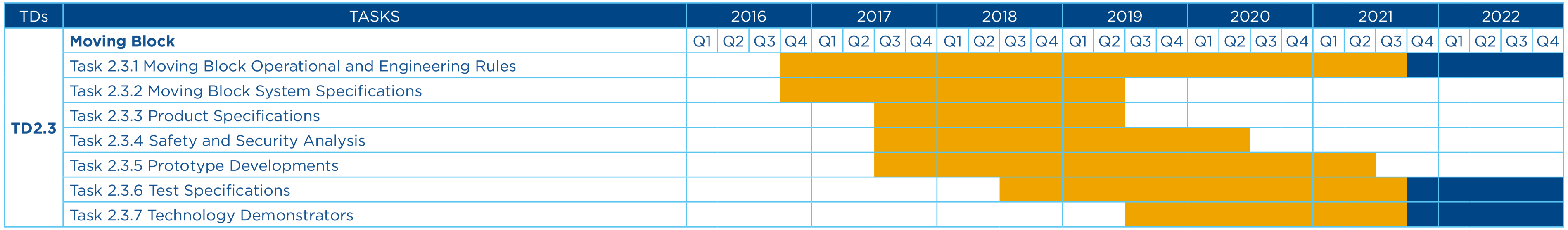
This TD will contribute to enabling the following innovation capabilities.

INNOVATION CAPABILITY	TD2.3 MOVING BLOCK ENABLERS – TRL6
1 – Automated train operation	It is expected that Moving Block will be integrated with ATO. • BB2.3.1: MB prototypes able to be applied and customised to each railway market segment • BB2.3.2: Operational procedures due to the application of MB
6 – Service timed to the second	Moving Block will permit services to be timed to the second, provided sufficient communication bandwidth is provided. • BB2.3.1: MB prototypes able to be applied and customised to each railway market segment • BB2.3.2: Operational procedures due to the application of MB
7 – Low-cost railway	Moving Block contributes towards lower cost railways by a reduction in the equipment fitted to the railway. • BB2.3.1: MB prototypes able to be applied and customised to each railway market segment • BB2.3.2: Operational procedures due to the application of MB
9 – Intelligent trains	Moving Block contributes towards Intelligent Trains, as within ETCS each train manages its own movement within the overall movement authority. • BB2.3.1: MB prototypes able to be applied and customised to each railway market segment • BB2.3.2: Operational procedures due to the application of MB

2.3.5. Demonstration activities and deployment

<table>
<tr><th rowspan="2">RESEARCH AREA</th><th rowspan="2">SPECIFIC TECHNICAL OBJECTIVE</th><th rowspan="2">SPECIFICATION ACTIVITIES</th><th colspan="2">DEMONSTRATOR</th><th rowspan="2">FOCUS OF ACTIVITY</th></tr>
<tr><th>MARKET</th><th>TRL</th></tr>
<tr><td rowspan="4">Moving Block</td><td rowspan="2">Higher capacity</td><td rowspan="2">Moving block system specification</td><td>Urban/ suburban</td><td>6</td><td>Create TD for urban/suburban and high-speed railway environments. Links with TD2.1, TD2.2, TD2.5.</td></tr>
<tr><td>High-speed lines</td><td>6</td><td>Enable maximum use of available infrastructure on capacity-constrained railways</td></tr>
<tr><td>Lower cost</td><td>Moving block system specification</td><td>Low traffic/ freight</td><td>6</td><td>Create TD for high-speed railway environment. Links with TD2.1, TD2.2, TD2.5.
Enable maximum use of available infrastructure on capacity-constrained railways</td></tr>
<tr><td>Migration</td><td>Moving block system specification</td><td>Main line</td><td>6</td><td>Create TD of an overlay moving block signalling system, focused on enabling migration from traditional signalling systems</td></tr>
</table>

Planning and budget



contracted activities

planned activities

The estimated total budget for TD2.3 is around EUR 25.06 million.

2.4. TD2.4 Fail-safe Train Positioning (including satellite technology)

2.4.1. Concept

The TD Fail-safe Train Positioning (including satellite technology) is intended to become an absolute positioning system, significantly reducing the number of traditional train detection systems. The solution will be based on a safe multi-sensor positioning concept, where GNSS is the preferred technology. The approach taken to apply the GNSS-based localisation functionality to ERTMS will guarantee the ERTMS interoperability concept and will allow the introduction of the state-of-the-art technologies in the use of absolute position technologies (e.g. GNSS and different augmentation subsystems) and of kinematic sensor technologies (e.g. inertial sensors, gyroscope sensors, microelectromechanical systems). To reduce the modifications to the existing ERTMS standard and, thus, the impact on existing ERTMS solutions and on the development of the planned ERTMS specifications roadmap, the concept of virtual balise and the same ERTMS location and train position principles (i.e. last relevant balise group and measured distance from that group) will be adopted. Moreover, enhancements related to the odometry, based on multi-sensor technologies, will also be investigated and implemented (if needed) to improve the performance of the ERTMS system without any changes to ERTMS functions.

During the TD2.4 development (a framework of 5 years), incremental functional enhancements will be identified based on the technology trends (e.g. from mono-constellation and mono-frequency GNSS positioning to dual-constellation and dual-frequency GNSS positioning, inertial sensor developments, digital map developments).

The TD2.4 Fail-safe Train Positioning functional block will be defined and developed so as to ensure (1) backward compatibility at ERTMS subsystem level and at ERTMS constituent level and (2) interoperability at the ERTMS constituent level (i.e. on-board and trackside level) by the specification of the required FFFIS.

Demonstrators will be developed to verify this TD in the context of high-speed, conventional, regional and freight lines.

2.4.2. Technical objectives

The following are the main technical objectives of this TD.

1. Significant reduction in the number of physical balises and possibly of traditional train detection systems (e.g. track circuits, axle counters), using a multi-sensor positioning concept, where GNSS is the preferred technology. When required, IP communication networks might be explored for supporting innovative signalling systems based on GNSS positioning, virtual balises and no track detection systems.

2. Interoperable and safe absolute positioning of the train by preserving the ERTMS location and train position principles, mainly obtained by applying the GNSS technology to the current ERTMS/ETCS core. To cope with GNSS degraded situations, complementary kinematic sensor technologies will be explored and used.

3. Scalable and modular Fail-Safe Train Positioning functional architecture that also allows the integration of future sensor technologies that are not available today and the benefits coming from the GNSS technology trend.

4 Based on the public results of the GSA STARS Project (i.e. WP2, Preparation of campaign; WP3, Field measurement, data collection; WP4, Data post-processing), execution of complementary test campaigns, both in lab and on field, to characterise and assess the new technologies foreseen in TD2.4 but not used in STARS with respect to the highly demanding rail environments.

5 Based on the public results of the GSA ERSAT-GGC project, design and development of enhancements of the process and related tools for classifying railway track areas as suitable or not suitable for the placement of Virtual Balises.

6 Definition and development of (a) models (suitable for railway environments) describing the local effects on the positioning's accuracy, (b) simulators for supporting lab tests and (c) appropriate test suite for laboratory and field tests. The models will also take into account the public results of important and representative projects such as STARS and ERSAT-GGC.

7 Study of different solutions to achieve train position functionality in railway environments, such as single-constellation and multi-constellation approaches, GNSS algorithm improvement, mono- and multi-frequency receivers, and improvements obtained by using alternative augmentation systems and additional kinematic sensors.

8 Define guidelines for performing GNSS signal in space survey, track surveys and the EMC environmental characterisation. Analysis of local effects and modelling (obstruction, multi-path, non-line-of-sight) and observables levels including contribution to Minimum Operational Performance Standards (MOPS) error models.

9 Investigation of the use of real-time kinematic method or alternative solutions in railway applications to build a ground truth reference system.

10 Investigation of digital map and digital track database technologies and related development environments to support the on-board detection of virtual balises.

11 Conception and integration of a digital track database or digital track geometry into the on-board ETCS. Procedures for safe dynamic uploading will be defined and described. The description of possible requirements on the radio communication network for limiting the upload transfer time will also be analysed and provided.

2.4.3. Technical vision

Table 28 / ***The technical vision***

STATE OF THE ART	FAIL-SAFE TRAIN POSITIONING
Train localisation by means of physical balises and the relative distances from the reference balises (last relevant balise groups)	The main measurable advantage, in areas where satellite positioning is applicable, is represented by the significant reduction in the physical balises for the position referencing and, in combination with train integrity/ETCS level 3, in the trackside traditional train detection systems (track circuits, axle counters, etc.). In addition, the replacement of physical balises with virtual balises will also lead to an increase in the operational performances (e.g. no delays caused by the application of brake commands due to vandalism, failure of physical balises, EMC interferences in the eurobalise airgap)
Train detection through trackside signalling devices (track circuits, axle counters)	When the technology enables track discrimination, fail-safe train positioning based on GNSS and multi-sensor technology opens up the possibility of signalling systems that do not need the deployment of trackside devices

Train separation based on ETCS/ ERTMS	Fail-safe localisation of the train through satellite navigation systems and the concept of virtual balises, which would keep the ERTMS core largely unchanged, is expected to significantly reduce the need for traditional train detection systems on the track, with advantages with regard to cost, maintenance and vandalism protection
ETCS/ERTMS interoperability and backward compatibility	The fail-safe train positioning functional block will be designed and developed to guarantee ERTMS backward compatibility and interoperability. The interfaces of the fail-safe train positioning functional block, to be integrated as a functional block of ERTMS/ETCS constituents, with impact of the interoperability requirements will be defined as FFFIS

Interaction with other TDs (in the same IP and/or in other IPs)

Interactions are expected with IP1 (rolling stock) and IP3 (infrastructure) projects, for the integration of the new module(s) on board and for the trackside technology to support the new functionalities and interfaces.

IP2 interactions are foreseen as in the following table.

Table 29 / ***Interaction with other TDs and IPs***

OTHER TD	MAIN OUTPUTS FROM TD2.4	MAIN INPUTS TO TD2.4
TD2.1 Adaptable Communication for All Railways	Provide requirements and system behaviour to define (1) the trackside-to-train communication (and vice versa) needs, and (2) the train-to-train (T2T) communication (and vice versa) needs (if required for new signalling positioning functions)	Cooperate to understand how new communication technologies and services can facilitate and suggest solutions for trackside-to-train communication (and vice versa)
TD2.2 Railway Network Capacity Increase (ATO up to GoA 4 – UTO)	Provide requirements and system behaviour (1) to identify possible synergies about track database management and (2) to provide continuous train position information when the ETCS kernel is still not available. When the ETCS kernel is not available, the SIL associated with the continuous train position is expected to be less than SIL 4	If a common and shared solution can be defined so as to also take the SIL 4 requirement into account, cooperate to define (1) specifications and procedures for track database survey and constructions, (2) methods and tools for track database construction and verification, (3) methods and tools for dynamically updating the track database
TD2.3 Moving Block	Provide requirements and system behaviour to identify/define the needs for signalling defensive checks on train positioning	Cooperate to understand if signalling defensive checks for train positioning can be identified/implemented
TD2.5 On-board Train Integrity	Provide requirements and system behaviour to exploit the advantages of the new train position system	Cooperate to understand how localisation also based on new sensors and/or GNSS information can contribute to the train integrity function

TD2.6 Zero On-site Testing	Provide requirements and system behaviour to identify the needs for the laboratory verification infrastructure based both on ERTMS and GNSS technologies and on a combined use of multi-sensor technologies. Investigate the possible integration of the modelling tools and the simulators, developed in the context of TD2.4, into the TD2.6 verification infrastructure	Understand the use of TD2.6 outcomes for reducing the need to carry out test activities on site and to inject faults for verifying critical system properties
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	Evaluate the identified formal and semi-formal methods and the related recommended environments to analyse their possible applications in the recommended life-cycle phases	Cooperate to follow common methodology in writing documents – functional requirement specification (FRS), software requirement specification (SRS) – and/or modelling and verifying some system properties
TD2.8 Virtual Coupling	Provide requirements and system behaviour to identify impacts on the virtual coupling concept	Cooperate to understand possible impacts on the new train position system as well as on the virtual coupling system
TD2.11 Cybersecurity	Provide requirements and system behaviour to identify security needs in the context of the GNSS signal in space and the new data (with respect to those already set out in ERTMS standard BL2 R2) exchanged through the new open networks (e.g. the network for exchanging the on-board track geometry information or on-board track database, augmentation information)	Cooperate to quantitatively evaluate the risks of intentional radio frequency interference with GNSS signal in space and, if needed, the possible mitigations from the components point of view (e.g. GNSS antenna, GNSS receivers) up to the system level

2.4.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Increased capacity	The expected possibility of resetting the train confidence interval frequently due to the use of virtual balises should contribute to fostering the application of new train separation systems such as moving block that will enable increased capacity, permitting optimised usage of the railway infrastructure. An accurate analysis at the system level should be carried out
Reduced costs	Fail-safe Train Positioning will enable a reduction in cost by removing a great percentage of physical balises and, when the technology enables it, also the trackside train detection subsystems (e.g. track circuits, axle counters)
Increased reliability	Fail-safe Train Positioning will enable an increase in the availability and reliability of railway signalling, based on the reduction in equipment fitted to the railway, the effects of their failures and the consequence of acts of vandalism on physical balises

This TD will contribute to enabling the following four innovation capabilities.

INNOVATION CAPABILITY	TD2.4 FAIL-SAFE TRAIN POSITIONING ENABLERS TRL 5–6
1 – Automated train operation	• BB2.4.1: GNSS application in railway for safe train localisation • BB2.4.2: Reduction in trackside train detection systems • BB2.4.3: Interoperability with ERTMS/ETCS core

6 – Service timed to the second	• BB2.4.1: GNSS application in railway for safe train localisation • BB2.4.2: Reduction in trackside train detection systems • BB2.4.3: Interoperability with ERTMS/ETCS core
7 – Low-cost railway	• BB2.4.1: GNSS application in railway for safe train localisation • BB2.4.2: Reduction in trackside train detection systems • BB2.4.3: Interoperability with ERTMS/ETCS core
9 – Intelligent trains	• BB2.4.1: GNSS application in railway for safe train localisation • BB2.4.2: Reduction in trackside train detection systems • BB2.4.3: Interoperability with ERTMS/ETCS core

2.4.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Fail-safe Train Positioning	Demonstrator for Fail-Safe Train Positioning functional block integrated in a complete ERTMS-based solution for regional low-traffic lines	A complete SIL 4 system prototype of the Fail-Safe Train Positioning subsystem integrated with an ERTMS-based system in the context of the regional low-traffic Sardinia line will be installed and commissioned as a trial site. A Mermec virtual balise reader/transmission system prototype, based on multi-sensor technologies, will also be verified in the laboratory	Regional low-traffic lines and freight lines	5/6	Within X2Rail-2 the concepts of the lab and field demonstrators will be defined. Within X2Rail-5 the development of the field demonstrator will be completed and verified in lab and field
	Demonstrator for Fail-safe Train Positioning module	A full SIL 4 prototype for the train positioning system will be developed. It will be targeted for its application on regional low-density traffic lines where good satellite coverage could be achieved. An important part of the development will be the definition and implementation of a communication interface between the on-board ETCS/EVC device and the odometry subsystem. This prototype will have a modular design that could allow, if requested, its integration with the on-board EVC system	Low-density traffic lines	4/6	Within X2Rail-2, the Fail-safe Train Positioning requirement, safety analysis and simulated testing environment are identified. The demonstrator at X2Rail-5 has the aim of proving what simulated testing has shown as valid Fail-safe Train Positioning
	Demonstrator of a virtual balise reader/ transmission system for high-speed/mainline, freight and regional lines	A location determination system/virtual balise transmission module prototype demonstrator with emphasis on application to freight and regional lines will also be developed. This demonstrator will be finally verified in a real railway environment on a selected regional line in Czechia	High-speed/ mainline, freight and regional lines	4/6	Within X2Rail-2 the concepts of the lab and field demonstrators will be defined. Within X2Rail-5 the development of the field demonstrator will be completed and verified in lab and field

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Fail-Safe Train Positioning (including satellite technology)		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD2.4	2.4.1 – General Specification	NA																												
	2.4.2 – On site GNSS performance tests																													
	2.4.3 – Analysis of the results of the GNSS Performance test activities																													
	2.4.4 – Analysis of the technical solutions for optimizing the GNSS performances in railway environment and proposal for the demonstrators																													
	2.4.5 – Proof of concept GNSS based localisation devices																													
	2.4.6 – Process for validation in lab and on field																													
	2.4.7 – Lab tests	4																												
	2.4.8 – Update of the technical specifications according to the full test campaign results	4-5																												
	2.4.9 – Development of Prototypes	4-5																												
	2.4.10 – Field activities: integration and commissioning tests, validation and certification of the prototypes	4-7																												

contracted activities

planned activities

*Table 30 / **TD2.4 milestones***

WHEN	WHAT
Q4 2018	System requirement specification of the Fail-safe Train Positioning functional block of the on-board constituent
Q4 2018	System architecture specification and system functional hazard analysis of the Fail-safe Train Positioning subsystem
Q3 2020	Minimum operational performance requirements of the multi-sensor devices required for the Fail-safe Train Positioning subsystem

The estimated total budget for TD2.4 is around EUR 24.29 million.

2.5. TD2.5 On-board Train Integrity

2.5.1. Concept

Train integrity is an on-board function responsible for verifying the completeness of the train, while the train is in operation.

This TD consists concretely in monitoring the status of the train's tail: if the last wagon is regularly advancing in a way that is coherent with the movement of the rest of the train, then train integrity system can easily deduce that everything is working properly.

In cases where this does not happen, the on-board system should detect the anomaly, indicating the possibility that the train is no longer intact, namely that one or more carriages have been separated from the remaining convoy.

Obviously the latter case would constitute a serious danger for the next train, being a possible unexpected obstacle on the line, and therefore should be promptly reported to the signalling system.

The key issue of train integrity is that this function prompts the need for the implementation of more efficient signalling systems based on concepts such as moving block or train position delivered by on-board equipment. Systems based on these concepts will deliver very significant advantages in terms of capacity, reduced headway, capital and maintenance cost, removal of track infrastructure for block detection, resiliency, compatibility among lines, etc.

In particular, the adoption of the moving block concept, as prescribed by ERTMS L3 and CBTC systems, implies that the train integrity monitoring and detection could not be carried out by fixed wayside infrastructures. Conventional train detection systems such as track circuits, axle counters and others could be used just as a fallback system or to confirm the train position in degraded situations.

In addition to the new functional and performance requirements, On-board Train Integrity (OTI) could be the enabler in achieving economic sustainability of new railway lines, especially for freight and low-density mixed-traffic lines. In these cases, OTI allows the elimination of fixed infrastructures along the line, relying on the autonomous position and integrity information, with consequent important economic advantages.

2.5.2. Technical objectives

The primary objectives of this TD are to define and prototype an innovative OTI solution, based on suitable architectures and components, to fulfil several SPDs' requirements, and to guarantee safety and assessing mechanisms for easier authorisation/standardisation.

The main goals of the solution must be:

1. autonomous localisation of the train tail without interaction with trackside equipment;
2. capability to establish a wireless communication between the tail and the front cabin, in order to transfer the confirmation of integrity, without any trackside network support, in the case of absence of a hardwired train communication line;
3. safe detection (SIL-4) of train interruption, filtering false-alarm conditions;
4. an innovative solution to supply the required power for OTI equipment in freight convoys, where the solution will involve both the generation of energy and its possible storage.

Table 31 summarises the objectives and related deliverables of this TD.

*Table 31 / **Objectives and deliverables***

OBJECTIVES	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Solutions for on-board train tail detection	Autonomous on-board localisation of the train tail, without interaction with trackside equipment, maximising the possible interactions with TD2.4	Specification, development and demonstration of on-board train tail detection, based on autonomous localisation (interactions with TD2.4 expected)
Solutions for direct transfer of the train's tail position information to the train front cabin, without any trackside support	Two different solutions for freight and passenger convoys, respectively: • wireless communication between the tail and the front cabin, without any trackside network support, in case of absence of a hardwired train communication line • interface with TCMS network, maximising the possible interactions with TD1.2	Specification, development and demonstration of two different solutions for freight and passenger's convoy: • wireless communication between the tail and the front cabin • interface with TCMS network
Solutions for safe detection (SIL 4) of train interruption	Solutions for train interruption detection, filtering false alarms conditions, etc., suitable to fulfil SIL 4 requirements	Specification, development and demonstration of safe detection (SIL 4) of train interruption
Solutions for autonomous power supply of OTI equipment	Solutions for the autonomous power supply of OTI equipment for freight lines, including generation of energy and its possible storage	Specification, development and demonstration of autonomous power supply of OTI equipment

2.5.3. Technical vision

The Train Integrity Monitoring System (TIMS) Working Group of the former European economic interest grouping ERTMS Users Group finalised its work on the TIMS FRS. The foreseeable requirements of ETCS L3 have been considered within the UIC ERTMS regional project and a pilot application on a Swedish regional line.

Nevertheless, the lack of suitable solutions on trains that do not have electrical networks limits the introduction of ETCS L3 to passenger lines or corridors operated with state-of-the-art trains equipped with a train bus system.

Patent applications in this field were more numerous in the early 2000s but were not followed by as many applications in recent years. The field on which most of the patent applications have focused is related to freight lines, owing to the lack of electrical infrastructure along the trains and the need for tracking goods. This is most challenging but will offer the most promising market and is the aspect on which most efforts are being focused.

Analysing the overall picture, it seems quite obvious that a reliable solution could be constituted by integrating more technologies and making sure that the functions that constitute the OTI cooperate with each other.

Table 32 summarises how this TD will advance the state of the art and overcome today's limitations and difficulties.

Table 32 / ***Comparison between the state of the art and the future of OTI***

STATE OF THE ART	FUTURE ON-BOARD TRAIN INTEGRITY
Today the train integrity function is mainly operated at the trackside, using very expensive infrastructure along the lines	The OTI system will be operated exclusively on board, without any involvement of the trackside part
Train integrity mainly depends on the presence of an overall electrical network along the train. When this network is missing, there is only the air brake pipe as a possible exploitable link between the wagons, besides the mechanical coupling	The OTI system will be able to adapt to the various typologies of on-board physical infrastructures and to operate even in the absence of these, such as in the case of freight lines
Most of the present solutions on the market are mainly based on the detection of brake air pipe pressure reduction on the tail. This phenomenon is more evident in the tail, while it is not obvious in the front cabin, because of delays. At present the performance is not satisfactory and is not suitable to guarantee safety	Solutions adopted for train interruption detection and train completeness monitoring will be able to filter false-alarm conditions, and will be suitable to fulfil SIL 4 requirements
The higher cost of maintenance is especially unaffordable on freight and regional lines, owing to the presence of equipment along the lines	Trackside costs will be removed and on-board costs will be minimised

This state of the art constitutes the baseline against which the project will compare its progress.

Interactions with other TDs (in the same IP and/or in other IPs)

The demonstration of the achievement of the TD2.5 results will be obtained in two stages.

1. The first one will consist of laboratory tests performed on prototypes and mock-ups, aiming to verify and demonstrate the right technical choices and to allow performance analysis.

2. In a second stage, the TD2.5 results will be demonstrated in a real environment, in order to validate what will be already demonstrated in the laboratory and, in particular, its suitability to operate in a harsh environment and with high energy efficiency. The real environment will be selected to demonstrate in particular the suitability of the candidate solution for freight and low-traffic lines.

Concerning the tests in a real environment, in order to verify if it will be possible to perform the TD2.5 tests in synergy with them:

- TD2.1, Adaptable Communication Systems for All Railways – to investigate a possible common communication network solution to be adopted or harmonised for data transmission along the train, for performing OTI;
- TD2.2, Railway Network Capacity Increase – to check possible interface with on-board ATO to manage automatic coupling and uncoupling;
- TD2.3, Moving Block – essential collaboration to provide the enabling technology for ETCS level 3;
- TD2.4, Fail-safe Train Positioning – to investigate possible synergies with satellite-based localisation solutions for OTI;
- TD2.7, Formal Methods and Standardisation for Smart Signalling Systems – to verify application of formal methodology in the development phase;

- TD2.8, Virtually Coupled Train Sets – to investigate solutions to achieve OTI through proximity functions/devices.

The expected relationships with other TDs, in terms of inputs and outputs, are summarised in the following table.

Table 33 / ***Interaction with other TDs and IPs***

OTHER TD	MAIN OUTPUTS FROM TD2.5	MAIN INPUTS TO TD2.5
TD1.2 Train Control and Monitoring System	Provide OTI requirements and system behaviour aiming to make TCMS suitable also for OTI purposes in passenger convoy applications	Collecting information on TCMS functionalities and performances in order to investigate possible integration with OTI in passenger convoy applications
TD2.1 Adaptable Communication for All Railways	Provide OTI T2T communication requirements, for both wireless and wireline cases, associated with different application scenarios	Information about possible TD2.1 communication solutions that could be integrated into or harmonised with OTI architecture
TD2.2 Railway Network Capacity Increase (ATO up to GoA 4 – UTO)	Provide information about OTI functional architecture and interface to be used for ATO, in particular to manage automatic coupling and uncoupling.	N/A
TD2.3 Moving Block	Provide information about OTI functional architecture and interface with the aim of integrating it into the Moving Block solution	Train integrity requirements for moving block signalling system
TD2.4 Fail-safe Train Positioning (including satellite technology)	Cooperate to understand how localisation based on new sensors and/or GNSS information can contribute to the train integrity function	Provide requirements and system behaviour to exploit the possible advantages of the new train positioning system
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	Provide a system view in order to take advantage of TD2.7 outcomes	Cooperate to follow common methodology in writing documents (FRS, SRS)
TD2.8 Virtually Coupled Train Sets	Provide information to understand how OTI information can be used inside a virtually coupled train consist (convoy of trains)	Requirements to be considered in order to define what is needed to provide the convoy integrity for a convoy of trains

2.5.4. Impact and enabling innovation capabilities

The main innovation is to identify a rigorous but efficient and practical approach based on the following principles.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Approach based on the existing solutions	To follow an approach based on the existing solutions – suitably improved if needed- and some new technologies to be developed or integrated with others within the project.
Number of different system architectures	To define a number of different system architectures (system scenarios) relevant to this function, to be able to identify a number of OTI product classes, depending on the system scenarios they can be applied to
Specific requirements for each OTI product class	To define specific requirements for each OTI product class, providing a path to facilitate the design and deployment of the systems
Providing the information requirements to the current OTI solution vendors	To provide the information requirements to the current OTI solution vendors and offer them ways to improve their solutions in collaboration with the JU
Identifying new technology	To identify some new technology approaches and perform feasibility studies and research aiming to apply it
Assessment of products adapted	To assess the products adapted by the collaborating vendors and facilitate their integration into the demonstrators
Demonstration, by simulation and in real systems, of the expected outcomes of the technology	To demonstrate both by means of simulation and in real systems the expected outcomes of the technology
Standardisation of train integrity function	To take a significant step towards the standardisation of the train integrity function and certification of products

This TD will contribute to enable the innovation capabilities as described below.

Building blocks related to TD2.5 are:

- BB2.5.1, Safe on-board train detection and tail position.
- BB2.5.2, On-board energy generation and harvesting for OTI.

INNOVATION CAPABILITY	TD2.5 TIMS ENABLERS – TRL 6/7
1 – Automated train operation	• BB2.5.1 allows implementing new operational approach of moving blocks and virtual coupling. • BB2.5.2 allows applying new operational approach also to freight trains without power lines
6 – Service timed to the second	• BB2.5.1 allows implementing new operational approach of moving blocks and virtual coupling. • BB2.5.2 allows applying new operational approach also to freight trains without power lines
7 – Low-cost railway	• BB2.5.1 allows cost reduction in trackside infrastructure in terms of both CAPEX and OPEX. • BB2.5.2 allows reducing energy costs for powering OTI-related devices
9 – Intelligent trains	• BB2.5.1 allows implementing new operational approach of moving blocks and virtual coupling. • BB2.5.2 allows applying new operational approach also to freight trains without power lines

2.5.5. Demonstration activities and deployment

The tasks related to TD2.5 are listed below.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
On-board Train Integrity	Provide solutions for detecting train integrity by means of on-board subsystems	OTI demonstrator for regional and freight application domains	Regional, freight	6/7	OTI, wireless on-board communication and energy harvesting

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	On-board Train Integrity (OTI)		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.5.1 Train Integrity Concept	2																												
	2.5.2 Definition of Requirements	2														◆														
TD2.5	2.5.3 Technology Research & Development	2																		◆										
	2.5.4 Adaptation of Existing Solutions	3																				○								
	2.5.5 Demonstration and Assessment	4/7																												◆
	2.5.6 Standardization Proposal	4/7																												◆

◆ milestone

○ quick win

contracted activities

planned activities

Table 34 / ***TD2.5 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
M42	Performing research activities and development on radio communications and energy-harvesting technologies and transferring the relevant results to the demonstrator’	Demonstrator for freight application domain

Table 35 / ***TD2.5 milestones***

WHEN	WHAT
M12	Concept
M24	Definition of requirements
M42	Demonstrator implementation
M66	Site testing and preliminary safety assessment
M66	Standardisation proposal

The estimated total budget for TD2.5 is around EUR 9.95 million.

2.6. TD2.6 Zero On-site Testing

2.6.1. Concept

System and integration test is a fundamental method of system verification across many different industrial sectors. Various experiences show that the effort and time consumption for the test is about 30 % to 50 % of the project time. Because of the complexity of signalling systems and the differences between sites, a large number of tests must be carried out on site. On-site tests take about 5 to 10 times as much effort as similar tests done in the lab. Reduction in on-site tests for signalling systems is hence a reasonable approach to reducing testing costs.

However, technical means for testing in the lab need to model the reality sufficiently and the assessment and authorisation process needs an essential minimum of on-site tests serving as evidence for valid system behaviour and also to confirm lab test results.

This implies improving the lab-testing capabilities by broadening the test scope as well as decreasing the number of on-site test cases until the normative and legislative limits are reached.

To reach such an ideal state the following strategy will be applied to make lab tests strictly focused on real needs and make it easier to control the costs:

- definition of a dedicated system test architecture for the lab tests;
- specification of a standardised method to derive and describe test cases;
- fixing a common test process framework.

The planned system test architecture should allow for flexible creation of signalling environments and should serve for stepwise integration approaches as well as for different ranges of complexity. Application of real system components and simulated environment elements in various mixes should be supported. These configurations should be easily created and controlled. The architecture should provide a unified interface concept and standardised interface specifications to allow several suppliers and also third parties to contribute to the same testing project. A unified test derivation method, being essential to make test case portfolios optimised and comparable, should be based on existing model-based approaches and should provide a unified description method including standard notation.

2.6.2. Technical objectives

Signalling system projects are expected to grow in complexity in the future, resulting in a growing number of suppliers being involved in the system testing. This will require a clear process definition as mentioned above, but also rules about responsibilities and obligations of the different parties.

A common test process framework is needed to achieve a single understanding of test scopes. It should define elementary terms needed for a common understanding as well as define a process flow showing inputs, required steps and interaction with other processes for assessment and authorisation.

The topics explained above focus on the first constraint, the improvement of the technical means for system testing. The strategy to handle this constraint is focused on the following topics:

- definition of common criteria to select the test cases that need to be executed on-site as the minimum number required to provide sufficient evidence for validation;

- definition of conditions under which a minimum number of on-site tests can serve as confirmation that the lab tests are meaningful.

The treatment of these two topics requires close cooperation with European organisations dealing with the harmonisation of assessment and authorisation. Other industrial sectors, such as automotive and aerospace, also integrate and test complex, vital systems. Experiences and best practices developed in these sectors should be used to optimise the system and integration test approach. An in-depth analysis of best practices and their applicability in the railway domain is therefore an essential part of this TD.

The key objective of Zero On-site Testing is to perform system and integration tests in the laboratory instead of testing on site, in order to:

- save time (95 %);

- save effort (95 %);

- reduce necessary resources (99 %).

2.6.3. Technical vision

The innovation capability of TD2.6 is in defining a dedicated system test architecture providing the capability of interoperability as well as connectivity between the different systems and components necessary to be tested.

Further innovation is delivered in specifying standardised methods to derive and describe test cases. In this area of research, different aspects will be taken into account. In this area of innovation, the support of TD2.7, Formal Methods and Standardisation for Smart Signalling

Systems, will be taken into account and the methodologies analysed and provided will be made available to the approach of TD2.6.

A common test process framework will be key for improving the testing and the shifting of tests from the field to the lab. The test architecture will be an essential part of this innovation.

Flexibility, adaptability and scalability will be drivers of the innovation capabilities to be achieved in order to be able to master the future complexity of signalling systems as well as the introduction of new functionalities. The upcoming changes due to further digitalisation will be taken into account.

Table 36 / ***Future test based on Zero On-site Testing***

STATE OF THE ART	ZERO ON-SITE TESTING
Definition of the scope of IOP testing, the overall process and embedding into other processes of assessment	• Assessment of today's practice of field testing • Benchmarking with automotive/avionics industries • Based on this distributed environment, the test process defined within the TD will be verified and validated • In addition, a clear distinction will be made between generic application and specific application. It will be shown that the effort for the specific application test and validation on site can be reduced
Specification of a generic test architecture, a unified interface concept and dedicated interface specifications for ETCS constituents	• Assessment of today's practice of field testing • Benchmarking with automotive/avionics industries • Definition/implementation of a dedicated system test architecture for lab testing supporting Zero On-site Testing • The distributed test environment will provide the possibility of integrating multiple test candidates based on standardised interfaces
Specification of a test case description format, a semantic description for track data and a related track data notation	• Definition of a common test process framework • Specification of a standardised method to derive and describe test cases • Based on the results of TD2.7 (Formal Methods and Standardisation for Smart Signalling Systems) a formalised approach for data engineering as well as the derivation of test cases will be shown

Interaction with other TDs (in the same IP and/or in other IPs)

Besides the abovementioned interactions with other TDs/IPs, the following interactions are taken into account.

Table 37 / ***Interaction with other TDs and IPs***

OTHER TD	MAIN OUTPUTS FROM TD2.6	MAIN INPUTS TO TD2.6
TD2.1 Adaptable Communication System for All Railways	N/A	Standardised communication environment
TD2.2 Railway Network Capacity Increase (ATO up to GoA 4)	Zero On-site Testing principle applicable to ATO	N/A
TD2.3 Moving Block	N/A	Interface specifications to enable development of test environment

OTHER TD	MAIN OUTPUTS FROM TD2.6	MAIN INPUTS TO TD2.6
TD2.4 Fail-safe Train Positioning	To understand the use of TD2.6 outcomes for reducing the need to carry out test activities on site, and to inject faults for verifying critical system properties	Alternative communication environment to be tested
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	N/A	Will provide inputs to apply formal methods to the development of test cases and to prove specifications
TD2.8 Virtually Coupled Train Sets	Test environment, test cases and methodologies	Field requirements to be simulated in the laboratory
TD2.10 Smart Radio-connected All-in-All Wayside Objects	May derive testability requirements as input for the object controller	Resulting architecture and interfaces will provide requirements for Zero On-site Testing, as basis for test definitions
TD2.11 Cybersecurity	N/A	Provides input to ensure security at the correct level for virtualisation of test plat-forms and cloud management

2.6.4. Impact and enabling innovation capabilities

Significant reduction of testing efforts and reduction of testing on site are the main objectives of TD2.6, supported by:

- identification and analysis of best practices of the automobile and aeronautics industries,
- definition of a dedicated system test architecture and standardised interfaces for lab tests, including remote tests,
- practical validation of test environments in all relevant configurations with product demonstrators,
- specification of a standardised method to derive and describe test cases,
- definition of common test process framework including real-time distributed testing connecting existing test labs and, for example, on-site tests (hybrid testing).

By the end of the proposed work the market will benefit from unification of testing. Integration of complex rail-signalling solutions will be significantly easier and the test coverage will be increased before solutions enter the field, because all suppliers can use the architecture, the test process framework, etc. to perform/improve their in-house testing.

The evolution of rail-signalling solutions clearly shows a trend towards standardising the communication interfaces, starting with the physical transport medium to protocols and eventually defining standards for interfaces between different components of a solution such as interlocking-interlocking, interlocking to radio block centre (RBC), interlocking to field elements, etc. This will be supported by the envisaged test environment.

Finally, increased in-lab testing with support of simulators allows many more faults in the system to be detected than ever could be tested in the field. By this, the probability of outages in the field due to errors will be reduced, leading to significantly increased availability of infrastructure.

TD2.6 has the following impacts on S2R targets.

Capacity:

- Minor impact on this target. Only indirect, since it could help to bring into service more quickly new technologies that have a direct positive effect on capacity.

- Less outage time in the field, since time for field testing will be reduced to the absolute minimum necessary.

Competitiveness:

- Major impact on this target. Less effect on traffic due to faults in signalling systems and field testing, since more will be tested in the lab, and test coverage, especially fault insertion, will increase with lab testing/simulation.

- In addition, it will help the European industry to deliver complex solutions with low LCC and low impact on operational traffic. New and more advanced technologies/methodologies (such as model-based test design) will help the industry to employ the state of the art and benefit from the growing number of tools.

Operational reliability:

- Major impact, since outage time on lines that are in operation will be reduced: tests in the field will be significantly limited.

- More in-lab testing with support of simulators allows many more faults in the system to be simulated than ever can be tested in the field. By this, the probability of outages in the field due to errors can be reduced.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Overall cost reduction in projects due to more and better lab testing instead of field testing • Overall quality improvement due to improved test coverage by doing more simulated tests (fault insertion, load) • Introduction of state-of-the-art technology in testing and benefiting from growing number of supporting tools • Reduced number of test resources needed to be built in different places
Compliance with EU objectives	• Interoperability tests done more easily in the lab (adaptors/simulators, etc.) • Standardisation supported • Competition increased
Degree of maturity of the envisaged solutions	• Methods/improvements proven in real pilot projects focusing on the new developments of other TDs

This TD will contribute to enabling the following two innovation capabilities.

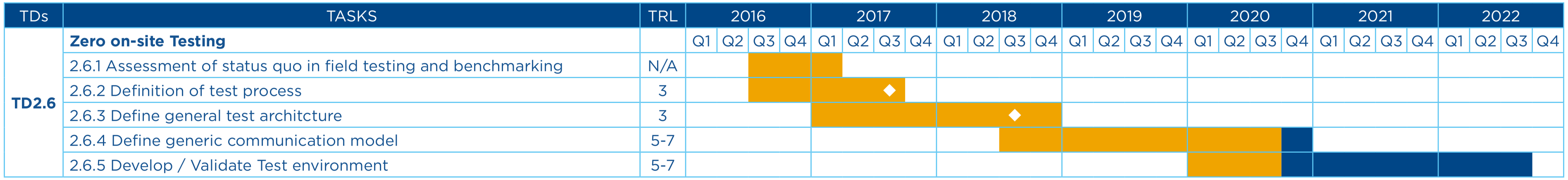
INNOVATION CAPABILITY	TD2.6 ZERO ON-SITE TESTING ENABLERS
7 – Low-cost railway	By means of standardised methodology for performing lab tests, which reduces the overall CAPEX. • BB2.6.1: Definition of a dedicated system test architecture for lab test • BB2.6.2: Specification of standardised method to derive and describe test cases • BB2.63: Identify common test process framework
12 – Rapid and reliable R&D delivery	By means of a well-defined and complete set of laboratory tests able to reduce time to market. • BB2.6.1: Definition of a dedicated system test architecture for lab test • BB2.6.2: Specification of standardised method to derive and describe test cases • BB2.63: Identify common test process framework

2.6.5. Demonstration activities and deployment

The following table summarises the contribution of TD2.6 Zero On-site Testing to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Zero On-site Testing	Definition of a dedicated system test architecture and standardised interfaces for lab tests, including remote tests	Interface specification (test environment), architecture definition of future test system	Main line	6	Analyse existing test architectures, IOP test capabilities, current requirements on system testing, limits of lab testing Define common architecture to overcome current existing limitations Provide new architecture concept taking decentralised and virtual test environments into account Results of open call will be aligned
			Regional/ freight	6	
	Specification of a standardised method to derive and describe test cases	Analysis of data models, analysis of different methods to derive test cases; specification of test automation	Main line	6	Define methodology in line and in cooperation with TD2.7 Formal Methods and Standardisation for Smart Signalling Systems
			Regional/ freight	6	
	Definition of common test process framework, including real-time distributed testing, connecting existing test labs and, for example, on-site tests (hybrid testing)	Definition of scenarios and common test process necessities; definition of obstacles preventing the shifting of tests; definition of common interfaces and interconnections	Main line	6	Test process description flexible for adaptation to new requirements; integrate the results of the open call; align with IM experiences from current projects; demonstrators showing connectivity and distribution capabilities
			Regional/ freight	6	

Planning and budget



- ◆ milestone
- ○ quick win
- contracted activities
- planned activities

*Table 38 / **TD2.6 quick wins***

WHEN	WHAT
Q2 2017	Benchmarking report on testing/system testing
Q4 2018	Common high-level test architecture based on the test process agreed before. Another major input is the current limitations on performing tests in the lab instead of the field
Q3 2021	Demonstrator implementations for the different areas of improvement following the defined architecture and process

The estimated total budget for TD2.6 is around EUR 20.9 million.

2.7. TD2.7 Formal Methods and Standardisation for Smart Signalling Systems

2.7.1. Concept

It is a challenge to ensure correct behaviour, interoperability, safety and reliability in railway signalling. Delivery schedules for systems are long and hardly predictable, and costs to procure, develop and maintain systems are high. Two main root causes are vague and imprecise system requirements, and that verification is mainly based on traditional review and test methods. Requirements on safety, security and reliability are complex, since they cover a vast state space, and because they use many concepts of multiple domains. To ensure that such requirements are satisfied is only possible by using **formal methods** in specification, development and verification. Formal methods provide techniques and tools to define and precisely analyse such concepts and relationships, and to verify requirements exhaustively. In addition to improved verification of critical system properties to reduce time to market and cost, formal methods also improve requirement quality and reliability.

TD2.7 will propose and apply formal methods and **standard interfaces** in application demonstrators, and a business case for using formal methods and standard interfaces will be prepared. TD2.7 will specify at least one new standard interface (functional interface specification (FIS)/FFFIS). Common interfaces are key to increase competition and to enable more efficient use of formal methods to reduce cost and time in development, approval and commissioning of signalling systems.

The **objectives** of TD2.7 are to use formal methods and standardisation in development of railway signalling systems to achieve:

- increased know-how about using formal methods;
- increased market competition and standardisation;
- improved interoperability and reliability;
- reduced LCC in signalling system life cycle;
- shorter time to market of new products.

2.7.2. Technical objectives

The main technical objectives of this TD with respect to **formal methods** are to propose, use and demonstrate state-of-the-art formal methods (languages and tools for specification of requirements, automated design and code creation, and the use and role of formal verification for safety assessment) as well as semi-formal languages where appropriate, considering:

- reuse of best-practice approaches and results when available;
- compatibility with existing practice, observing existing framework of development in the rail domain;
- viability with respect to expected objectives and results;
- accessibility of proposed solutions to all stakeholders;
- applicability to other lines of activities within S2R;
- demonstration of formal verification of safety requirements to achieve significant reductions in effort and cost compared with traditional safety assessment.

The following are the main technical objectives of this TD:

1. Demonstrate state-of-the-art formal methods for specification of requirements, automated design and software code creation.
2. Demonstrate improvements to high-level specification thanks to the use of semi-formal languages.
3. Demonstrate formal verification of safety requirements to achieve significant reductions in effort and cost compared with traditional safety assessment.
4. Demonstrate creation of a standard interface (FIS/FFFIS) in collaboration with another TD.

The technical objectives of this TD with respect to **standardisation** include promoting standard interfaces (e.g. RBC to RBC interface, interlocking to RBC interface, interlocking to point object controller interface, interlocking to level-crossing interface), since this is key to achieving more standard systems (with all the benefits this brings in itself), and since this provides more potential for reuse and automation in application of formal methods, with improved quality of results. Key challenges include agreeing on standard interfaces and formal methods to use; a pragmatic approach is planned with respect to both. The most suitable standard interface candidates will be selected and used in the demonstrator(s), and a one-formal-method-fits-all solution will not be proposed; different aspects of the demonstrator(s) may require use of different formal methods. While standardisation of signalling systems, rules and procedures is difficult, because of different rules and traditions among different railways, progress in this direction can be expected. The use of formal methods and standard interfaces should consider both IM and supplier perspectives, to enable significant improvements with respect to the objectives of TD2.7. The long-term vision is to provide standardised means (languages, methods, tools) for:

- requirement capture and formulation;
- specification of interfaces;
- system design and implementation;
- verification and validation;
- safety assessment based on formal verification.

2.7.3. Technical vision

The technical vision for TD2.7 is based on using formal methods and standardisation in development and implementation of rail signalling systems, to achieve:

- overall cost reduction in signalling projects due to the use of formal methods that reduce cost for safety approval of systems thanks to efficient formal verification of safety;
- reduced cost for system development due to the use of formal methods that result in systems that are correct at first installation;
- increased competitiveness and removal of vendor lock-in due to the use of standardised interfaces, which also enable more efficient use of formal methods with reduced development cost.

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged with other TDs and/or IPs are to deliver results from TD2.7 to such other TDs and/or IPs, and to provide guidance for use of formal methods in, for example, SRS, in earlier phases (e.g. using semi-formal methods) and throughout system development phases. The following identifies the main interactions with other IP2 TDs:

- TD2.3, TD2.5 and TD2.6 but also other TDs will benefit from TD2.7's results regarding formal methods classification (taxonomy), use cases and proposed methods and tools for, for example, requirement specification and formal methods-based verification and validation and development;
- TD2.6, Zero On-site Testing – contribute to the use of formal methods to develop test cases and reduce on-site testing;
- TD2.10, Smart Wayside Objects – provide inputs to applied formal methods to standard interfaces.

2.7.4. Impact and enabling innovation capabilities

This section provides a summary of the impact this TD will have on strategic aspects and innovation capabilities, providing an overview of the expected effects of the TD results on a larger scale.

This TD will contribute to three main strategic aspects, described in the following table.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Overall cost reduction in signalling projects due to the use of formal methods that reduce cost for safety approval • Reduced cost for system development due to the use of formal methods that result in systems that are correct at first installation • Increased competitiveness and removal of vendor lock-in due to the use of standard interfaces, which also enable more efficient application of formal methods • Reduced complexity due to standardised interfaces, enabling to build complex systems with standard components, saving cost and time. • Reduced time-to-market due to reduced number of development cycles and reduced effort required to develop such systems • Improved quality due to more rigorous system requirements defined with formal methods, providing better quality requirements for all stakeholders
Compliance with EU objectives	• Standard interfaces for European signalling systems to increase interoperability • First delivery of signalling system on time and with correct functionality • Improved quality and efficiency of safety approval • Increased competition and reduced vendor lock-in
Degree of maturity of the envisaged solutions	• Formal methods are well established, but different formal methods have different TRLs for different contexts and stakeholders • The formal methods to be used are in the range TRL 4 (technology validation in lab) to TRL 6 (demonstration in relevant environment). The same range of TRLs applies to standard interfaces • The formal methods and standard interfaces will be applied in system demonstrators

This TD will contribute to enabling two innovation capabilities, as set out in the following table.

INNOVATION CAPABILITY	TD2.7 ENABLERS TRL 3–7
7 – Low-cost railway	Demonstrate reduced LCC for signalling systems, through the following building block achievements: • BB2.7.1: Formal and semi-formal methods for requirement capture, design, verification and validation, proposing open standards, TRL 3–7 • BB2.7.2: Standardisation of crucial interfaces between parts of selected state-of-the-art interfaces (FIS and FFFIS), TRL 6 • BB1.2.2 : Drive-by data, TRL 6/7
12 – Rapid and reliable R&D delivery	Demonstrate reduced effort and time in specification, development, verification and validation of signalling systems, through the following building block achievements: • BB2.7.1: Formal and semi-formal methods for requirement capture, design, verification and validation, proposing open standards, TRL 3–7 • BB2.7.2: Standardisation of crucial interfaces between parts of selected state-of-the-art interfaces (FIS and FFFIS), TRL 6

2.7.5. Demonstration activities and deployment

TD2.7 will perform a state-of-the-art survey of formal methods and create a taxonomy, including use cases for the use of formal methods for railway signalling systems. Methods and application area will be selected and used to create select system platform demonstrators. Finally, this work will be validated and reviewed, including creating a business case. Standard interfaces will be addressed in relation to the application of formal methods to selected interfaces. The aim is to put into practice a process to support the standardisation of interfaces (up to FIS and/or FFFIS), demonstrating the benefits of formal methods and standard interfaces in development, design and delivery processes.

The following table summarises the planned contribution of TD2.7 to its three demonstrators (within X2Rail-2, within an Open Call and within X2Rail-4, respectively); each demonstrator will:

1. demonstrate formal methods technologies and standard interfaces in a realistic lab-based environment to give credibility and show the benefits clearly;
2. use common standard architectures with interoperable 'black box' concepts;
3. consider applicable technical standards, to increase the confidence of future clients and facilitate deployment in new projects.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Formal methods and standardisation	Demonstrate formal methods	Application demonstrators 1, 2, 3	Generic	3/7	Demonstrate state-of-the-art formal methods for specification of requirements, automated design and software code creation
	High-level specification	Application demonstrators 1, 2, 3	Generic	3/7	Demonstrate improvements to high-level specification thanks to the use of semi-formal languages
	Formal verification	Application demonstrators 1, 2, 3	Generic	3/7	Demonstrate formal verification of safety requirements to achieve significant reduction of effort and cost compared with traditional safety assessment
	Standard interface	Application demonstrators 1, 2, 3	Generic	6	Application of formal methods to contribute specifying standards (FIS/FFFIS) for selected interface

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Formal methods		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD2.6	2.7.1 Formal metods	3--7																												
	2.7.2 Standardized interfaces	6																												

contracted activities

planned activities

The estimated budget for TD2.7 is around EUR 8.03 million.

2.8. TD2.8 Virtually Coupled Train Sets

2.8.1. Concept

Many European railway lines are very busy today and have a problem handling the required capacity. New lines are built and tracks added to existing lines, but this is slow and expensive and will not create the needed capacity in the near future. The objective of VCTS is to increase line capacity by at least 100 % (depends on existing infrastructure, traffic patterns and train characteristics) without building new tracks, and to do this faster and with less investment and lower maintenance and operational cost, by improving the technical systems (mainly signalling).

The current lines must be better exploited by increasing the performance and functionality of current systems in order to reduce headway, optimise the use of station platforms, optimise timetables and solve conflicting traffic situations through smarter and more flexible functionality and behaviour.

TD2.8 will explore the innovative concept of virtual trains being capable of operating physical trains much closer to one another (inside their absolute braking distance) and dynamically modifying their own composition on the move. This is a total deviation from the traditional railway operational and signalling concept, universally accepted and used since the very beginning of the introduction of the railways.

The proposal of the study is to start from the current interoperable signalling system, Unisig BL3 ETCS/ERTMS. It is deemed essential because:

- ERTMS is the common signalling system already applied and has been in service for many years;
- the common knowledge of ERTMS facilitates the understanding of what it is necessary to upgrade in order to get the required behaviour;
- it simplifies the interface with the signalling system, avoiding the need to study the impact of TD2.8 on the legacy applications, so making work more effective and feasible.

VCTS, whose complete title is Virtually Coupled Train Sets and Smart Switching and Crossing, has several sub-functions; each of them needs specific investigation. They are:

- increase the length of a (virtual) train to allow more passengers and/or freight wagons to pass in a given time;
- for passenger traffic, overcome platform length limitation, optimising platform usage according to the length of a single virtually coupled train (e.g. first part of the convoy going to platform x; second part to platform y);
- for freight traffic, allow longer and heavier virtual trains, designing lines with shorter passing sidings than would otherwise be required;
- reduce headway, the distance between two trains, when the second (i.e. the following) train has to change direction/route or when traffic needs dynamically require improved capacity;
- the impact of VCTS on operational rules, i.e. what combinations of trains are allowed/forbidden (e.g. dangerous goods and passenger trains);

- provide suitable train-control support tools for efficient operation of VCTS, e.g. what combinations of trains and services to avoid (e.g. commuter train ahead of long-distance HST).

VCTS basically performs the objective of dynamically managing headway, increasing line capacity. The new required functionality could be seen as the extreme limit of the moving block on relative braking, removing the absolute braking and the traditional fixed block statement of ‘one block, one train’ limitations. It is worth underlining that the VCTS system is not limited to the on-board environment; in order to work properly, it needs new features, upgraded functionalities and new architecture that also have an impact on the main trackside signalling and supervision systems.

2.8.2. Technical objectives

The technical ambition of the VCTS system is to overcome the fixed block principle, taking advantage of the moving block concept and relative braking distance, permitting more than one train in each block (of sufficient length) and allowing trains to run as close to the preceding train as to just be able to stop in time to not run into the other train if it stops. This can increase line capacity by more than 100 %, possibly 300 %. The solution is to link the preceding train with the following train by data radio to create virtual coupling, running the trains together.

VCTS’s main technical objectives are:

- Manage dynamic train convoy joining/splitting including during normal traffic and running time.

- Manage new train separation systems overcoming the limitation of the brick wall concept (absolute braking distance).

- Accomplish traffic regulation through an updated supervision system in order to manage dynamic train consists and timetables for multiple trains joined in a single convoy.

- Guarantee, through updated on board automatic train protection/ATO systems, safety and automatic driving in accordance with the new physical constraints and scenario. Automatic train protection systems/ATOs of different trains would cooperate through a common network in order to achieve full convoy control. This is a new concept, which enlarges the current train control features.

- Overcome the limitation of communication dealing with a new frontier of T2T data exchange (new standard interface necessary).

It is trivial to reiterate that all the above technical points must be achieved without reducing the current level of safety in all working scenarios (normal and degraded), but improving it. This all clearly shows how deep the impact of the new VCTS system on the existing train control system will be.

2.8.3. Technical vision

The current train separation paradigm envisages trains following at a distance that is actually shorter than the braking distance of each consist: each running train, even in the most optimised moving block systems, considers the rear end of the preceding train as the end of authority, so that it maintains a distance from the rear end of the preceding train that actually is comparable (with appropriate additional safety margins) to the required braking distance to reach standstill.

With VCTS this paradigm is overcome because it allows trains to interact and break the standard train separation concept and therefore the limitation related to distance.

The following table identifies the main breakthroughs introduced by VCTS.

STATE OF THE ART	VCTS
Each train localises its rear end to RBC, RBC assigns movement authority to each train, with end of authority located, in the best case, at the rear end of the previous train in accordance with the absolute braking distance	With VCTS, trains will be allowed to break this principle, by applying a new protection concept that is actually inside and not at the end of the absolute braking curve
No T2T communication	Trains will be allowed to exchange relevant information for the VCTS mechanisms
Each train managed as an individual consist from a train control system perspective	Multiple trains will be combined in a single virtual consist
Train scheduling and line capacity mostly driven and limited by the current train separation mechanism	Network capacity can be maximised, bringing the number of trains circulating to the best achievable
Train separation carried out of separate blocks	New train separation concept allows achieving less than a standard block
Train separation on fixed blocks defined by block sizes and by their absolute braking distance	Trains run as close as communication and control delays and braking distance variations/uncertainties permit
Train separation on moving block based on absolute braking distance	Trains run as close as communication and control delays and braking distance variations/uncertainties permit

Table 39 / ***Future VCTS architecture***

FUNCTION	TODAY	WITH VIRTUAL COUPLING
Train separation	Separate blocks	Much less than a block
Train separation	Defined by block sizes	As close as communication and control delays and braking distance variations/uncertainties permit
Train separation	Moving block based on absolute braking distance	As close as communication and control delays and braking distance variations/uncertainties permit
Following train driven by	Driver	Virtual coupling on-board computer(s)
Track occupation detection	Track circuit (axle counter)	VCTS system
Scheduling of trains – high level	Planning system, train control	Planning system, train control
Locating train	Track circuit (by block) (axle counter), positive train location	VCTS by measuring distance from balises passed and train length, positive train location
Scheduling/running trains – low level/real time	Train control/driver	VCTS
Route-setting requests	Train control/interlocking operator	VCTS

Interaction with other TDs (in the same IP and/or in other IPs)

The VCTS maximises its performance in a moving block system, so that synergies with TD2.3 are expected to be mutually relevant. Both TDs face the same challenge and performance constraints, as they rely on a communication network to gather the relevant safety-related information about train stopping position (either when communicating with train rear end for moving blocks, or when exchanging virtual-coupling-related data).

Strong cooperation is also expected with TD2.1 (Adaptable Communication for All Railways), as one of the core constraints limiting VCTS is the existing network infrastructure for timely and safely exchange of the relevant information.

The table below shows the expected relationships with other TDs, not only in IP2.

OTHER TD	MAIN OUTPUTS FROM TD2.8	MAIN INPUTS TO TD2.8
TD1.2 Train Control and Monitoring System	Provide requirements and system behaviour in order to define the needs for a convoy of trains	Understand how TCMS could be applied to integrate solutions for T2T communication and within a convoy of trains
TD2.1 Adaptable Communication System for All Railways	Provide requirements and system behaviour in order to define the T2T communication needs	Cooperate to understand how new technologies can facilitate and suggest solutions for T2T communication Provide solutions in terms of communication between trains that can comply with the needs
TD2.2 Railway Network Capacity Increase (ATO up to GoA 4 – UTO)	Provide requirements and system behaviour in order to identify impacts on ATO (on board and trackside)	N/A
TD2.3 Moving Block	Provide requirements and system behaviour in order to define the needs for a convoy of trains	Cooperate to understand similarities and common approach and solutions in case relative braking distance concept is applied
TD2.4 Fail-safe Train Positioning (including satellite technology)	Provide requirements and system behaviour in order to define the needs for a convoy of trains	Understand the use of possible improvements to odometry data to establish train location or distance between trains in convoy
TD2.5 On-board Train Integrity	Provide requirements and system behaviour in order to define the needs to provide convoy integrity for a convoy of trains	Cooperate to understand how train integrity information can be used inside a virtually coupled train consist (convoy of trains)
TD2.6 Zero On-site Testing	Provide requirements and system behaviour in order to identify the needs for a simulation	Understand the use of TD2.6 outcomes for reducing the need to carry out test activities on site. Improve simulation technology
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	Provide a system view in order to take advantage of TD2.7 outcomes	Cooperate to follow common methodology in writing documents (FRS, SRS)
TD2.11 Cybersecurity	Provide requirements and system behaviour in order to identify security needs	Cooperate to verify the need to encrypt data for T2T communications
TD3.2 Next Generation Switches and Crossings	Provide requirements and system behaviour in order to identify functional and operational synergies	Cooperate to evaluate possible synergies due to introduction of VCTS

2.8.4. Impact and enabling innovation capabilities

The vision is to have a very effective line management through the innovation of signalling and modifying the basic concepts of train separation (moving block on relative braking). In the future, flexible signalling will allow a dynamic approach to train control in which train on-board systems will become even more smart.

That must also be seen in a very wide connection network in which each signalling element will have and will exchange the rights and the necessary information to perform functions with the other signalling elements of the network.

That view opens up not only the possibility of trains communicating with each other but also new horizons in which the traditional signalling logic, for instance the classic interlocking, could be shared and activated by on-board subsystems when needed in terms of controlled area in time.

VCTS is seen as the first attempt to overcome the limits on train control drawing insights from the automotive industry, in which the idea of an automatically driven car, inside a fully integrated road environment, is the subject of studies and research.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Network capacity maximisation	VCTS offers the possibility of reaching the best line exploitation without the need to improve railway infrastructure
T2T communication	VTCS identifies the main safety-related constraints for T2T exchange of information, especially for addressing safety-related functionalities. This can foster research into telecommunication for on-board purposes, not only dedicated to VCTS
Simplified traffic management	VCTS allows different consists to be treated as a single logical unit within the overall TMS, without necessarily the need for physical coupling of the associated consists

Most of the competencies and sub-capabilities are addressed by TD2.8 because it affects the entire signalling, supervision and telecommunication system as well as trains and control systems.

The main TD will contribute to enabling the innovation capabilities listed in the table below.

INNOVATION CAPABILITY	TD2.8 VIRTUAL COUPLING TRAIN SETS ENABLERS – TRL3
1 – Automated train operation	Specifically, the building blocks contribute to improving self-automated, autonomous, single-unit trains that guide themselves through the system. The VCTS introduces the concept of trains that are automatically and logically joined to a leading unit and thus simplifies the management of the overall network when higher capacity performances are targeted. • BB2.8.1: Identify feasibility and safety issues of the virtual coupling concept • BB2.8.2: Define system, architecture and functional ratios • BB2.8.3: Identify impact on whole railway system
3 – Logistics and demand	Automatic virtual coupling and decoupling can significantly increase flexibility of freight transport, improving planning, tracking and shipment depending on the real-time customer demand. VCTS actually offers a solution to increase capacity of the line by allowing the breach of current limitations of the standard train separation principles and thus maximising the line capacity as much as possible. • BB2.8.1: Identify feasibility and safety issues of the virtual coupling concept • BB2.8.2: Define system, architecture and functional ratios • BB2.8.3: Identify impact on whole railway system
6 – Service operation timed to the second	Enhanced automated trains contribute to improving flexibility and facilitating recovery from disruption. TD2.8 building blocks contribute to achieving a more robust, resilient service by means of new and more efficient line exploitation in terms of capacity and systems (signalling and supervision) reacting to dynamic traffic change and demand. Specifically, VCTS allows tuning of the line capacity depending on current demand, with minimal effort on the part of the operator, as it allows longer consists to be dynamically and virtually composed. • BB2.8.1: Identify feasibility and safety issues of the virtual coupling concept • BB2.8.2: Define system, architecture and functional ratios • BB2.8.3: Identify impact on whole railway system
7 – Low-cost railway	Virtual coupling building blocks contribute to achieving a simplified and customised control–command system, reducing human intervention and therefore affecting operational expenditure. Specifically, the flexibility introduced by the VCTS allows the line capacity to be tuned depending on current traffic demand and thus optimising usage of assets. • BB2.8.1: Identify feasibility and safety issues of the virtual coupling concept • BB2.8.2: Define system, architecture and functional ratios • BB2.8.3: Identify impact on whole railway system
9 – Intelligent trains	TD2.8 building blocks contribute to significantly improving the train-centric system, whereby many of the signalling and automation functions might be moved to an on-board system. Autonomous driving and T2T communication are also fostered by virtual coupling building blocks. VCTS can be also seen as an initial step towards further developments of the train-based railway signalling functionality, especially because it introduces the concept of safe T2T interaction, which can become the basis of additional developments of the overall signalling functionalities. • BB2.8.1: Identify feasibility and safety issues of the virtual coupling concept • BB2.8.2: Define system, architecture and functional ratios • BB2.8.3: Identify impact on whole railway system

2.8.5. Demonstration activities and deployment

TD2.8 does not address deployment of the system, but mostly addresses an overall feasibility analysis that cuts across technology, safety and business aspects of the VCTS deployment. No prototypes of the VCTS are expected to be produced.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Virtually – Coupled Train Sets (VCTS)		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.8.1 Virtual Coupling Concept	2														◆														
	2.8.2 Safety and Performance Analysis	2																◆												
TD2.8	2.8.3 Feasibility Analysis	2																		◆										
	2.8.4 Functional Architecture SAS and FRS	2-3																												
	2.8.5 Functional Architecture FIS	2-3																					◆							
	2.8.6 Impact Analysis	2-3																							◆					

◆ milestone

○ quick win

contracted activities

*Table 40 / **TD2.8 milestones***

WHEN	WHAT
Q2 2019	Conceptual analysis and boundaries definition for the VCTS
Q4 2019	System hazard and safety risk analysis, hazard log, risk assessment for the VCTS
Q2 2020	Feasibility analysis and technological implementation proposal
Q1 2021	VCTS system requirements specification
Q3 2021	System impact analysis and business case

The estimated total budget for TD2.8 is around EUR 4.8 million.

2.9. TD2.9 Traffic Management Evolution

2.9.1. Concept

The integration layer is a new communication platform that links, in the first step, traffic management, traffic control asset management and energy (grid) control systems, signalling field infrastructure and vehicles for signalling purposes (ETCS).

It also provides a gateway (WEB-IF) for communication with external clients and services.

Freight application integration is in the scope of CCA WA4.2 and is executed under the Impact-2 programme.

In a possible next step, the status data from extra services, e.g. all vehicle constituents linked with the TCMS (TD1.2) are envisaged to be integrated into the data model, and a structure for a centralised track-to-train communication set-up may be specified and designed.

A framework for applications connected to the integration layer allows easy installation and administration of the business software modules under this programme.

A standardised operator workstation will enable the allocation of tasks inside a control centre to different workstations, benefiting from the availability of the different data on an integrated network.

The real-time availability of data for multiple clients supported is the basis of new business service applications for TMS and traffic control.

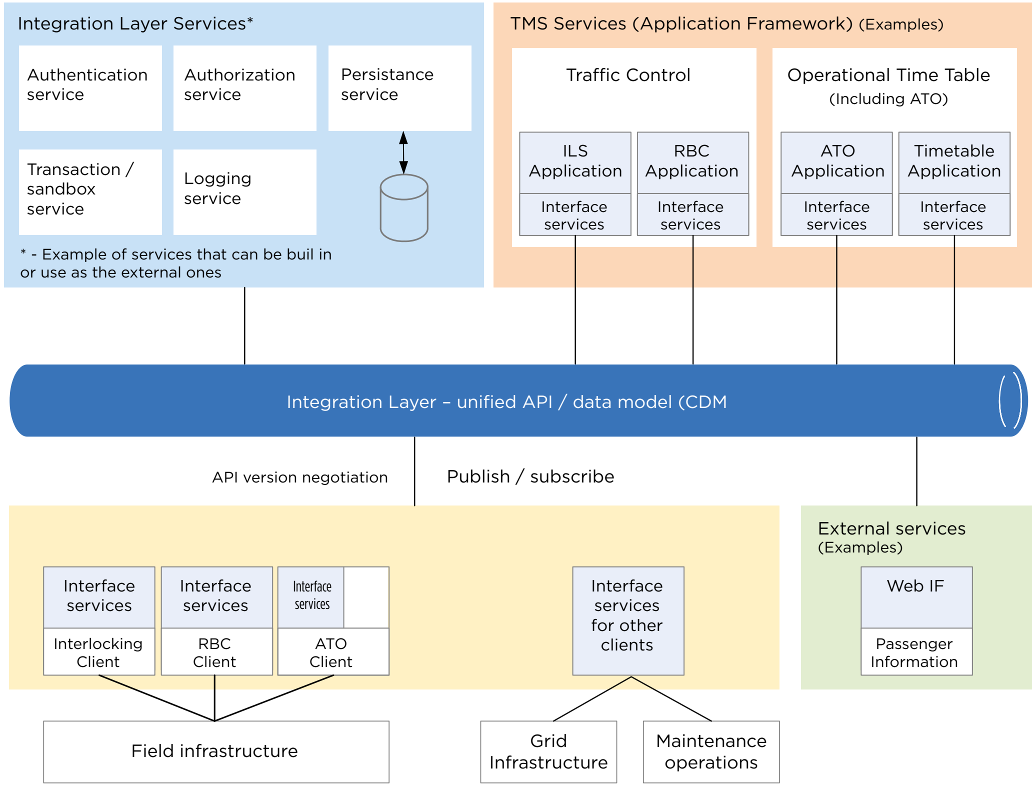


Figure 17 / ***System architecture***

2.9.2. Technical objectives

- **Seamless and dynamic data exchange between the various rail services:** integrated and automated data exchange processes and permanent availability of this information in one common layer are two of the key requirements to improve the efficiency of decision processes to achieve the targets for capacity growth, reliability improvement and cost reduction.

- **New business applications for traffic management and control, and the integration and enabling of new S2R functionalities into rail operation processes:** new business software using the new communication environment will enable advanced processes for traffic control and traffic management to optimise the flow of traffic and decision-making to deliver the production timetable with fewer delays.

- **Integration of new technologies/functionalities:** the new system will integrate new technologies developed under the S2R programme such as ATO, Moving Block (IP2), data provision/exchange for new advanced maintenance strategies (IP3), passenger information services (IP4) and freight transport (IP5).

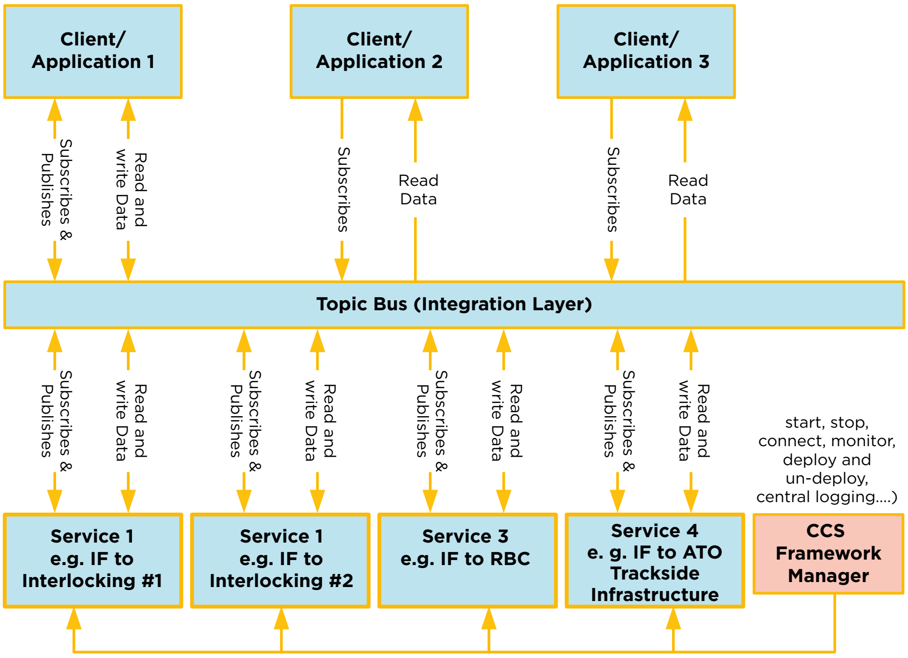


Figure 18 / ***Integration of different rail operation services***

- **Standardising of constituents and workflows inside a control centre:** a standardised operators' workstation and the framework with plug-and-play features will allow increased efficiency and reduced cost of control centres, and the framework will enable easy (plug and play) installation and operation of applications. The application programming interface will be developed from the integration layer to different types of services, including ATO, RBC and interlockings.

- **Canonical data model:** a scalable and flexible canonical data model (CDM) is developed to secure the integration of legacy and future applications into one communication structure, which will be developed into an S2R data model.

2.9.3. Technical vision

- The proposed architecture, interfaces and data model allow the integration of legacy installations through application programming interfaces into one network.

- The communication principle changes from a point-to-point principle to a 'publish and subscribe' methodology. This allows the application of new possible scenarios to substitute for and simplify traditional operational processes.

- It can be envisaged that the integration layer will be linked in future with the vehicle TCMS (IP1) via a dedicated communication resource pool to become the main data highway comprising rolling stock and all trackside services.

- The integrated data exchange can be extended to many other fields of rail operations e.g. IOP testing using the integration layer to operate simulated constituents (e. g. a train with ETCS on-board unit (OBU) operating under the control of real implemented RBCs and interlockings, preparation of service activities in depots as per transmitted condition status of vehicle components.

STATE OF THE ART	INTEGRATED CONTROL CENTRE USING INTEGRATION LAYER
Various 'islands' for the different applications with non-automated data exchange for trackside-based services in a control centre	One integrated system with automated data exchange, standardised frameworks to host applications and flexible operators' workstations
	Integrated vehicle–trackside communication network
	Integration layer supports Zero On-site Testing and other programmes of S2R
Competing data models: ETCS, eu-LynX, railML, others	One S2R CDM
Point-to-point communication	Subscribe and publish methodology

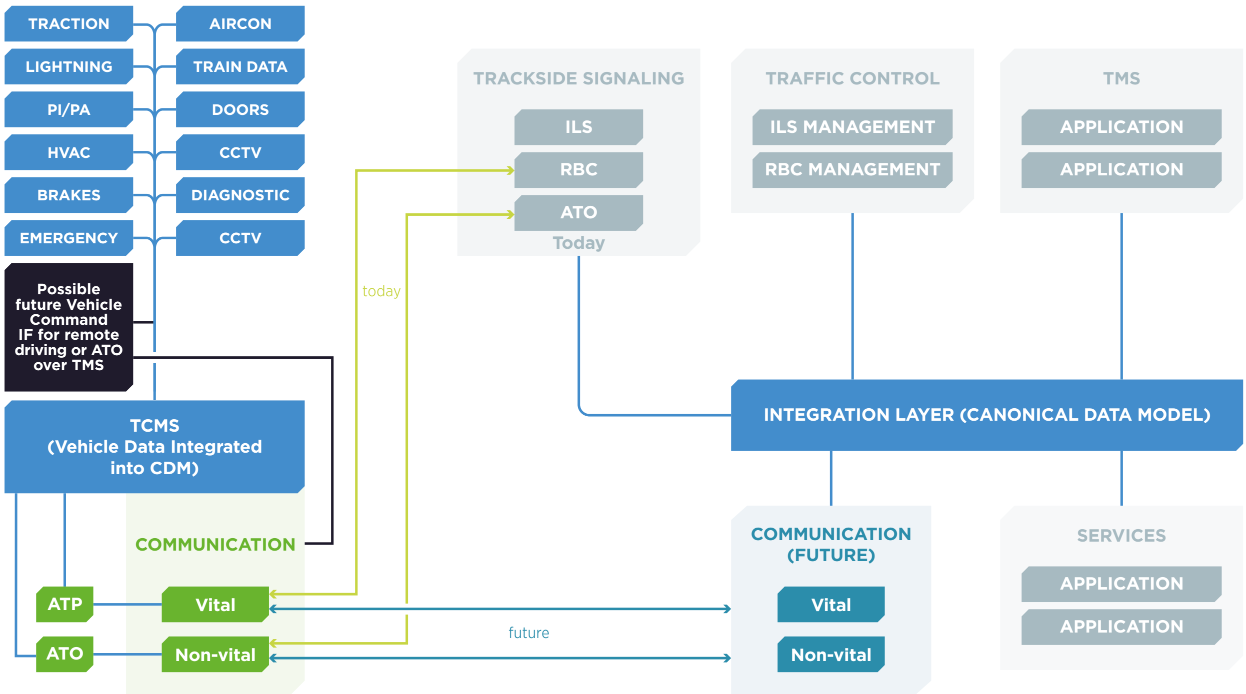


*Figure 19 / **Future view: integration TCMS with integration layer***

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs both from the point of view of technologies employed and from that of interaction in performance and objectives are:

- TD1.2, TCMS – providing data elements to be integrated into CDM of Integration layer;
- TD2.1, Adaptable Communication System for All Railways – providing concept to utilise the different technologies for a new T2T interface;
- TD2.2, ATO – agreement about where to allocate the different functionalities (TMS, ATO-TS, OBU) and which data the different constituents need to secure targeted operation;
- TD2.3, Moving Block – agreement on operational processes needed to provide traffic regulation under Moving Block operation;
- TD2.11, Cybersecurity – follow-up of the results of this TD to ensure security of the communication network proposed;
- IP3 – inputs required for data elements to be integrated into CDM;

- WA4.2, Integrated Mobility Management – delivery of SRS of integration to this WP;
- OC S2R-OC-IP2-03-2019 – support to development of demonstrator platform for traffic management.

2.9.4. Impact and enabling innovation capabilities

The following table summarises the main objectives of TD2.9 and provides an overview of some of the concrete deliverables that can be expected to result from the activities undertaken in the IP.

IMPACT	KEY CONTRIBUTION FROM TD2.9
Line capacity increase	New ATO and Moving Block traffic regulation applications in the TMS together with the related vehicle-based functionalities secure better utilisation of line capacity
Operational reliability increase	Seamless updated status information of all the rail infrastructure assets and vehicles will allow automated and optimised decision processes for traffic regulation applications to deliver the production timetable with fewer delays. The distribution of traffic status forecast to asset management services will allow much better scheduling of preventive service and maintenance activities and increase the overall availability and reliability of infrastructure assets
Railway system LCC reduction	Standardisation of the frameworks, data structures and interfaces will deliver a reduction of the investment for new integrated installations linking several functional rail services such as traffic management, maintenance management and energy supply A standardised operators' workstation will further reduce cost for investments into work-station operations, training efforts and HW and SW maintenance cost for workstations. New features such as a traffic optimisation application at sector or corridor level will re-duce overall system energy use by up to 10 %, with better average distribution of energy consumption in a sector or corridor, and support reducing carbon emissions and air pol-lution

TD2.9 addresses the following innovation capabilities.

INNOVATION CAPABILITY	TD2.9 TRAFFIC MANAGEMENT EVOLUTION ENABLERS – TRL6
1 – Automated train operation	Services, processes and building blocks of TD2.9 organise the flow of traffic enabling ATO. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
2 – Mobility as a service	Building blocks of TD2.9 provide all subscribed clients or services with real-time updated status information about traffic, and all related information to improve mobility. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes

INNOVATION CAPABILITY	TD2.9 TRAFFIC MANAGEMENT EVOLUTION ENABLERS – TRL6
3 – Logistics on demand	Building blocks of TD2.9 enable internal and external services (e.g. freight operations) and clients to deliver their demands in terms of traffic to the TMS and receive optimised proposals to increase the efficiency of their logistics. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
4 – More value from data	Building blocks (integration layer) of TD2.9 apply a standardised data structure (CDM) for all information carried on the network, hence allowing it to integrate information presented in different data formats to the communication network. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
5 – Optimum energy use	Services, processes and building blocks of TD2.9 optimise the flow of traffic in terms of reducing delays, braking and accelerating manoeuvres of trains to contribute to a more efficient use of energy • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
6 – Service timed to the second	Services, processes and building blocks of TD2.9 optimise the flow of traffic by including status information about assets, energy (grid) system, vehicle, staff and external information, e.g. weather, in the decision processes to secure the delivery of the production timetable. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
7 – Low-cost railway	Services, processes and building blocks of TD2.9 organise the flow of traffic and integrate many of the new developments in S2R, e.g. ATO, Moving Block, and contribute directly or enable other new developed functionalities to deliver their cost improvements. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes
8 – Guaranteed asset health and availability	Services, processes and building blocks of TD2.9 integrate asset status information into the decision processes of traffic management and delivers the updated traffic status information to asset management services to increase efficiency of the service and maintenance operations. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes

INNOVATION CAPABILITY	TD2.9 TRAFFIC MANAGEMENT EVOLUTION ENABLERS – TRL6
9 – Intelligent trains	Services, processes and building blocks of TD2.9 provide the traffic status and real-time information of other business services to all subscribed clients or trains via the track-to-train communication network. • BB2.9.1: Standardisation of frameworks, data structures, real-time data management, messaging and communication infrastructure • BB2.9.2: Plug and play of functional service application modules • BB2.9.3: Standardised workstation addressing heterogeneous working processes

2.9.5. Demonstration activities and deployment

The following table summarises the contribution of TD2.9 to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Evolution of Traffic Management	Data exchange between the various rail services	SRS for integration layer, specification of CDM according to scope of TD2.9	Mainline	6	Specification and development of prototypes of constituents of the integration layer Specification and development of the CDM
			Regional	6	
	Business applications for traffic management and traffic control	SRS for applications according to scope of TD2.9	Mainline	6	Specification and development of new applications for traffic management and traffic control
			Regional	6	
	Integration of new technologies/ functionalities that are developed under the S2R IP2 programme	SRS for traffic regulation for moving block and ATO (GoA 2)	Mainline	6	Specification and development of new applications for traffic management and traffic control
			Regional	6	
	Operators' workstation, application framework	System requirement specification	Mainline	3/4	Specification and development of new applications for traffic management and traffic control
			Regional	3/4	

One demonstrator for the new TMS addressing both regional and mainline markets is planned. This installation will become the reference and promoter for all future implementations that follow the new technology.

The partners of TD2.9 that have proposed prototypes for constituents of the system or business application are developing a guideline to secure interoperability of the prototypes and specify, together with the partners of the open call, the specific details of the demonstrator platform.

The specifications will be part of X2Rail-2 and will be updated if necessary in X2Rail-4.

Prototypes are proposed for TRL 3 in the first step and will reach TRL 6 at the end of the project.

The overall guidance for the CDM will be allocated to a group of experts representing all IPs in S2R, to ensure that all TDs are able to set their data according to a standardised rule book to use the new communication infrastructure for their best benefit. This coordination group will also set the strategy for how to manage the CDM beyond the end of S2R.

It can be expected that between 3 and 5 years after S2R the new developments will be implemented in a high percentage of all new installations for TMS and traffic control.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Traffic Management System		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.9.1 Integration Layer	3/4												◆						◆										
	2.9.2 Shell of the Traffic Management System	3/4												◆								◆								
	2.9.3 Framework for Traffic Management Business Service	3/4														◆								◆						
TD2.9	2.9.4 Applications	6/7																◆								◆				
	2.9.5 Standardized Operator Workstation	6/7																◆												
	2.9.6 Functionalities and Interfaces for Dynamic Demand and Information Management	3/4												◆						◆										
	2.9.7 Integrated Demonstrator	6/7																										◆		

- ◆ milestone
- ○ quick win
- lighthouse project
- contracted activities
- planned activities

Table 41 / ***TD2.9 milestones***

WHEN	WHAT
Q1 2019	D6.2 SRS for application framework D6.4 Description of key principles for design and test of prototypes D6.6 SRS for WEB-IF
Q3 2019	D6.5 SRS for operators' workstation
Q1 2020	D6.1 SRS for integration layer D6.3 Description of use cases for new traffic management principles
Q1 2020	Concept of demonstrator
Q1 2021	OC delivery of fully implemented test platform for integration layer (critical dependency)
Q3 2021	Prototypes available to be integrated into demonstrator platform
Q1 2022	Deliverables: updates of SRS for integration layer, application framework, traffic operators' workstation, WEB-IF
Q3 2022	Prototypes validated

The estimated total budget for TD2.9 is around EUR 24.4 million.

2.10. TD2.10 Smart Radio-Connected All-in-All Wayside Objects

2.10.1. Concept

The concept of Smart Radio-Connected All-in-All Wayside Objects is based on a solution of object controllers realising a decentralised approach to rail automation. This approach will be scalable from high-performance lines to regional and freight application. Although modern signalling systems will have considerably reduced trackside equipment, this solution is still relevant, as at least interfaces to points and level crossings will remain, as will other necessary interfaces, depending on the specific project requirements.

Today's field element controllers are designed and developed by each supplier in a different way. They are connected with copper, at least to be connected to the required power supply. The connection to interlocking, RBC and TMSs follows rules and requirements given by railway authorities.

Currently trackside objects are interfaced to control systems in one of two ways:

1. where trackside objects are fairly near signalling equipment, tail cables to individual objects are used;
2. where trackside objects are geographically distributed, object controllers are placed near the trackside objects, controlling a number of them, with a data link back to the signalling equipment.

There are disadvantages to these solutions:

- it is expensive to provide cabling for power and data to remote trackside objects, especially in freight lines or regional lines with little traffic;
- the cable provided is vulnerable to cable theft, which is costly, and causes disruption;
- changes within track layouts (position of trackside equipment) are complex and costly;
- the usage of cable restricts distances between trackside objects and signalling equipment, which might mean a need for additional signalling equipment (object controllers).

An avoidance of all cabling in the field will reduce life-cycle costs of future railway projects significantly, including material costs, installation costs, maintenance costs, energy costs and costs occurring because of cable thefts.

2.10.2. Technical objectives

A solution in which locally derived power and radio communications (or any wireless network communication), together with maximum decentralisation (up to the level of one object controller for every individual trackside object), are used overcomes these disadvantages and meets the Master Plan in terms of improved reliability, enhanced capacity, lower investments, reduced operating costs, improved standardisation and therefore simplified certification/authorisation. Besides the provision of local power supply, the challenge for this demonstration project is to provide radio communications to individual remote trackside objects and guaranteeing safety and security justifications.

The innovation of TD2.10 is to provide fully decentralised control of remote trackside objects such as points, level crossings, etc., using standardised interfaces without requiring the use of trackside cabling, associated cable routes, ducting, etc. In addition, the larger bandwidths will be used for transmission of status reports/maintenance information and further required data.

A cable-free connection between objects/machines is increasingly becoming the state of the art. Existing devices mostly deal with less safety-relevant information/applications. For TD2.10 we have to assure safety and security of data on the one hand and on the other hand we have to implement energy-harvesting systems – which have to be as reliable as is demanded by railway requirements.

A detailed analysis of existing technical solutions/possibilities has to be done at the beginning of the project.

Objectives to be achieved within the project:

- smart radio-connected all-in-all wayside objects,
- locally derived power supply,
- reduction in power consumption,
- reduction in required cabling,
- data exchange with existing and/or new TMSs,
- availability of maintenance data.

2.10.3. Technical vision

The basic idea of a wireless connection between technical devices is known within several industrial areas. Some specific but non-standardised signalling solutions even exist already. A detailed analysis of existing technical solutions/possibilities has to be done at the beginning of the project.

The novel part is the application of such systems within the safety context of railway signalling systems. Therefore the main risks are related to the derivation of safety and security concepts.

It might be possible to use experiences from ETCS projects where a successful standard for the airgap interface between trackside equipment and trains exists or other solutions are available on the market, including the internet of things (IoT).

The introduction of network-connected object controllers will permit the possibility of a direct connection between train-carried equipment and the trackside object controllers, for example to report the status of the trackside objects to the train. This would, for example, permit the train to react to failure of trackside equipment. A further step would enable the train-carried systems to control the trackside object controllers.

The TD intends to exploit existing technologies for communications and the outcomes of other TDs. Therefore it is not expected, that this TD will create specific standards or affect existing ones.

Existing standards (especially safety and security aspects) will be analysed at the beginning of the project.

STATE OF THE ART	SMART RADIO-CONNECTED ALL-IN-ALL WAYSIDE OBJECTS
Where trackside objects are fairly near signalling equipment, tail cables to individual objects are used	A solution where locally derived power and radio communications (or any wireless network communication), together with maximum decentralisation (up to the level of one object controller for every individual trackside object), are used overcomes these disadvantages and meets the Master Plan in terms of improved reliability, enhanced capacity, lower investments, reduced operating costs, improved standardisation and therefore simplified certification/authorisation
Where trackside objects are geographically distributed, object controllers are placed near the trackside objects, controlling a number of them, with a data link back to the signalling equipment	A solution will be scalable and flexible enough to fulfil different configurations and scenarios. The proposed approach will be scalable from high-performance lines to regional and freight application

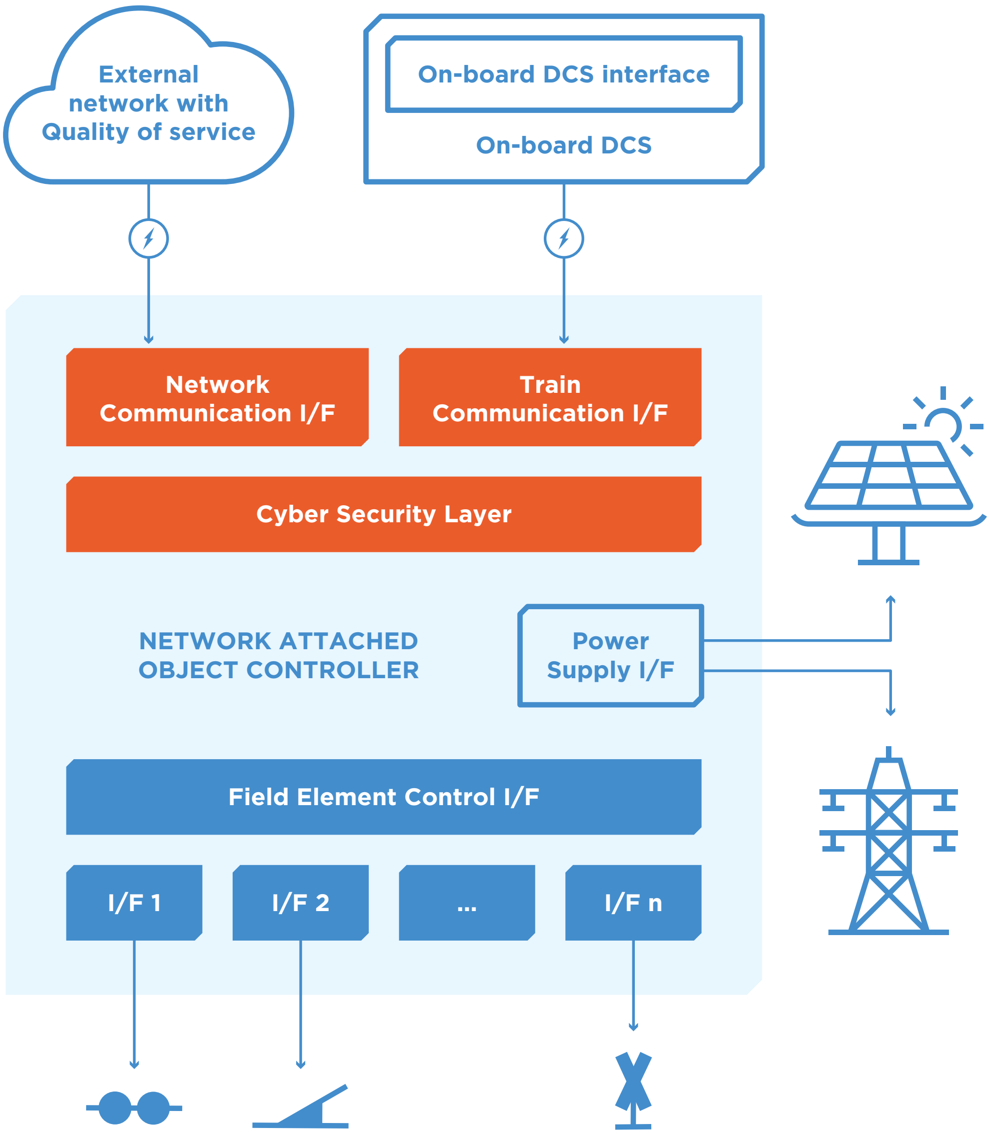


*Figure 20 / **Future architecture***

Interaction with other TDs (in the same IP and/or in other IPs)

Beside the abovementioned interactions with other TDs/IPs, the following ones are taken into account.

Table 42 / ***Interaction with other TDs and IPs***

OTHER TD	MAIN OUTPUTS FROM TD2.10	MAIN INPUTS TO TD2.10
TD2.1 Adaptable Communication System for All Railways	Provide the communication QoS requirements and architecture for the smart radio-connected wayside objects	Smart radio connection over the common communication network
TD2.6 Zero On-site Testing	Architecture and interfaces will provide requirements for Zero On-site Testing, as basis for test definitions	May derive testability requirements as input for the object controller
TD2.7 Formal Methods and Standardisation for Smart Signalling Systems	N/A	Will provide inputs to apply formal methods to the development
TD2.11 Cybersecurity	Provide the communication QoS requirements and architecture for the smart radio-connected wayside objects	Provide a cybersecurity system solution able to secure the communication needs of the smart radio-connected wayside objects
IP3 with regard to cost-effective infrastructure and maintainability, interactions with TD3.1 and 3.2 (for S&C) and TD3.6, 3.7 and 3.8 (for diagnostic data)	The use of smart object controllers will help to reduce the initial cost and maintenance costs of infrastructure	Provide structure for integrating diagnostic data from signalling devices
WA5.1 Energy	Power supply and energy-saving solution	To get help and support all energy-saving-related works
FP7 NGTC WP6 Radio-Based Communication	N/A	As input for the state of the art of communication techniques

2.10.4. Impact and enabling innovation capabilities

Business benefits will be seen first in Europe and eventually worldwide. They key contributions from TD2.10 include:

- significantly lowering the effort for project-specific engineering, installation and commissioning;
- minimising deployment of dedicated data communication cables and instead exploiting existing radio communication systems, public internet protocol network access points or satellite communication systems;
- eliminating the cost for replacement of cables and related services caused by cable theft and civil works impacts;
- using locally derived supply power, yielding reduced energy losses via long-tail cables and greening transport;
- significant LCC reduction (estimated value 50 % in total for freight and regional lines);
- raising the levels of safety and operational efficiency of signalling systems, while reducing investment costs;

- very high maturity of the communication systems as such: TRL 5–7 (strongly dependent on the outcomes of other TDs, which will be implemented inside the object controller, e.g. the communication solutions and cybersecurity, and on the advances made in the locally derived power supply technologies).

The outcomes of the TD should result in measurable reductions in the following LCCs:

- basic investment – costs of cabling and material,
- installation costs – complexity, expenditure of time, human resources required,
- maintenance cost (taking into account new hardware configuration as well as new functional possibilities with data exchange with TMS), mean time between repairs, mean time between failures,
- cable theft,
- engineering efforts.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Improved services and customer quality: improved reliability thanks to reduction in cabling and thus in theft risk. Also higher availability thanks to redundancy and high dependability of wireless connections • Reduced system LCC: reduced LCC thanks to reduced need of cables (only those for powering devices are necessary). Less cost of purchasing, installation and maintenance of cables. Overall objective is significant LCC reduction (estimated value 50 % in total for freight and regional lines), minimising deployment of dedicated data communication cables and instead exploiting existing radio communication systems, public internet protocol network access points or satellite communication systems • Enhanced interoperability and safety: it raises the levels of safety and operational efficiency of signalling systems, while reducing investment costs. • Simplified business processes: interfaces between object controllers and interlockings or either train can be easily standardised in terms of physical and functional links. Open network will produce interchangeability of object controllers and interlockings
Compliance with EU objectives	• Promotion of modal shift: a big impact made by the implementation of these new technologies towards ATO, avoiding service disruptions and adding new innovation capabilities, as described in the next table • Support to capacity increase: as mentioned above, this is allowed by flexible wayside object handling and fewer service disruptions due to lack of operational availability • Greening of transport through overall energy consumption reduction and the use of local energy alternatives can be achieved by developing a combination of energy consumption optimisation and the integration of local and green energy harvesting solutions
Degree of maturity of the envisaged solutions	The different wireless communications technologies are at different stages of maturity and they are in constant evolution. Actions taken in this TD are required to apply such technologies to the railway domain, guaranteeing the safety and security requirements. In the case of energy harvesting, the evolution of new proposed technologies is envisaged, starting at TRL 1 or 2 (principles observed and the possibility of using them formulated). At the end of S2R it is expected that the successful concepts will be brought to TRL 6 or 7

This TD will contribute to enabling the following five innovation capabilities.

INNOVATION CAPABILITY	TD2.10 SMART RADIO-CONNECTED ALL-IN-ALL WAYSIDE OBJECTS ENABLERS TRL 5–7
1 – Automated train operation	By means of fostering new communication channels within a broad and new automated system. • BB2.10.1: Use of radio means for commanding/controlling object controllers • BB2.10.2: Define a suitable object controller open to radio communication • BB2.10.3: Allow the signalling system to direct communication of train to wayside object controller • BB2.10.4: Define a suitable energy generation and harvesting system.
6 – Service timed to the second	By means of improving reliability of the system. • BB2.10.1: Use of radio means for commanding/controlling object controllers • BB2.10.2: Define a suitable object controller open to radio communication • BB2.10.3: Allow the signalling system to direct communication of train to wayside object controller • BB2.10.4: Define a suitable energy generation and harvesting system
7 –Low-cost railway	By means of reducing the CAPEX thanks to cable deployment reduction. • BB2.10.1: Use of radio means for commanding/controlling object controllers • BB2.10.4: Define a suitable energy generation and harvesting system
8 – Guaranteed asset health and availability	By means of improving the capability of remote diagnostics and maintenance. • BB2.10.1: Use of radio means for commanding/controlling object controllers • BB2.10.2: Define a suitable object controller open to radio communication • BB2.10.4: Define a suitable energy generation and harvesting system
9 – Intelligent trains	By means of fostering the introduction of new shared functionalities within the signalling and automation system. • BB2.10.1: Use of radio means for commanding/controlling object controllers • BB2.10.2: Define a suitable object controller open to radio communication • BB2.10.3: Allow the signalling system to direct communication of train to wayside object controller

2.10.5. Demonstration activities and deployment

The following table summarises the contribution of TD2.10 Smart Radio-Connected All-in-All Wayside Objects to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Smart Radio-Connected All-in-All Wayside Objects	Wireless object controller	Radio technology, specifications, architecture and protocols	Main line	6/7	Incorporate wireless technologies to the object controller communication network solutions while keeping consistency with TD2.1 and considering safety-relevant aspects
			Regional/ freight	6/7	
	Locally derived energy harvesting	Power specifications, architecture and interface definition	Main line	5	Incorporate the use of locally derived energy-harvesting solutions including power consumption optimisation, including the outcomes of energy experts OC and considering safety-relevant aspects
			Regional/ freight	5	
	Functional distributed architecture	Specification, architecture and procedures	Main line	6/7	New architectural concept based on decentralised architecture up to the level of one object controller for every individual trackside object.
			Regional/ freight	6/7	A solution scalable and flexible enough to fulfil different configurations and scenarios, from high-performance lines to regional and freight application
	Enhanced maintainability	Specification, interface definition and procedures	Generic	6/7	Advanced communication means and maintenance interface standardisation will be used for remote maintenance and the transmission of status reports/maintenance information (and further required data) towards predictive maintenance

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Smart radio-connected all-in-all wayside objects		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.10.1 Analyses of existing lines and economic models	2																												
	2.10.2 Analyses of railway requirements / standards	2																												
TD2.10	2.10.3 Definition of system architecture	3															◆													
	2.10.4 Development and verification of PDs (Prototypes)	5-7																												
	2.10.5 Validation (incl. Integration and Validation at SPD Level – paperwork at P1 / real integration P2)	5-7																										◆		
	2.10.6 Optimisation Works	5-7																												

◆ milestone

o quick win

contracted activities

planned activities

Table 43 / ***TD2.10 milestones***

WHEN	WHAT
Q3 2019	Functional architecture and interface definition
Q2 2022	Prototype validation tests executed in laboratory and real environment. Validation test results

The estimated total budget for TD2.10 is around EUR 12.5 million.

2.11. TD2.11 Cybersecurity

2.11.1. Concept

Nowadays the wired and wireless networks used by railways operators are usually heterogeneous, are not protected well enough and do not fulfil the minimum cybersecurity requirements in terms of attack surface reduction, sustainability, protection and attack detection.

The S2R cybersecurity technical demonstrator aims to define a consistent cybersecurity approach shared by railway stakeholders taking into account the railway requirements and specifications to deliver a safe and secure system.

The approach will be of such a level that it can be understood and applied by all key stakeholders: product suppliers when delivering products to the railway infrastructure; project integration teams when building, renewing or interfacing with systems and infrastructure; and asset owners when accounting for the overall safety and security of the system.

This common approach brings clear advantages to the rail sector, since on the one hand a common understanding of security requirements allows reduction in time and cost for introduction of secure systems, subsystems and components supplied to the railway infrastructure, and on the other hand asset owners understand the risk and appropriate measures required to protect the assets from cyberexploitation.

2.11.2. Technical objectives

The main goals of the railway cybersecurity system in the framework of TD2.11 are the following.

Security and safety improvement

Applied to the railway system, the main objective of the security system is to ensure high availability, authentication and integrity of the railways system by preventing and detecting attacks or errors. The railways system is a safety-related system, and safety relates closely to security. Safety cannot be ensured in the absence of security.

As most of the railway devices are computer-based, this security mostly focuses on computer and network security, called cybersecurity.

Cybersecurity addresses:

- the protection of data against unauthorised disclosure, modification or destruction,
- the protection of the computers against unauthorised use, modification or denial of service,

- protection of the railway's information technology (IT) network against attacks and malicious acts,
- the development of railway/urban subsystems that are secure by design.

More widely, the security applied to railways also addresses the buildings, the infrastructure and the trains. Improving the security on European railways also implies more controlled and restricted physical access.

Cost reduction and standardisation

The second goal is reducing the infrastructure and maintenance costs for railway operators through the definition of common references for cybersecurity implementation on railways and through improving compatibility and interoperability by standardising the security approach at European level. This will apply to all new information and communications technology (ICT) used in railway (e.g. traffic management, interlocking, urban signalling communication).

Technical output to be delivered by this TD

1 Definition of a cybersecurity system dedicated to railways

This cybersecurity system is intended to be comprehensive, easily sustainable and integrated. It has to provide, among other things:

- a common approach to security assessment, including the definition of the common threat landscape, common assessment processes and risk matrices,
- definitions of the process, organisational and technical requirements in terms of threat detection, prevention and response.

2 Definition of a security-by-design process dedicated to railways

Defining the requirements for the security-by-design approach, this guideline will fulfil the following objectives:

- define a framework of requirements and processes for development, deployment, verification and validation, and maintenance of railway components;
- ensure that railway components follow the defence-in-depth principle;
- ensure a systematic approach to developing and validating security requirements and to assessing the quality assurance level of security requirements' implementation;
- ensure clear requirements and responsibilities among stakeholders.

3 Develop a network of railway cybersecurity experts

Alongside the two main objectives presented above, this third objective concerns the development of a network of security experts in the railway community.

This network of experts will analyse the feasibility of the deployment of a railway-dedicated computer security incident response team (CSIRT) or information-sharing and analysis centre (ISAC).

If the outcome of this analysis is positive, this network will be the basis of the CSIRT/ISAC, and will propose a prototype of the ontology and of the work flow network model to support this CSIRT/ISAC.

2.11.3. Technical vision

The railway infrastructure mostly relies on computer-based devices that are interconnected through wired or wireless networks, making railway transport vulnerable to cyberattacks.

However, railways, like most critical infrastructures, were considered to be isolated from any external influence and therefore immune to security threats and attacks, so no specific protection against cyberthreats has been implemented.

Moreover, compared with other critical infrastructures, railways face some specificities that could make them more prone to cyberrisks:

- distributed aspect – electronic components scattered along track or train, leading to access protection issues,
- heterogeneous aspect of railway network and high level of certification, leading to integration, defence in depth and patch management issues,
- very long life cycle (much greater than 25 years), leading to legacy management issues,
- long design life cycle for railway-specific components, leading to time-to-market issues if no common reference.

This evidence of potential high cybersecurity risks and the observation that a cost- and time-effective solution can be provided only if all the stakeholders have the same cybersecurity framework led to the specification of TD2.11.

The building of this common cybersecurity framework will be done through the pursuit of our three objectives:

1. definition of a cybersecurity system dedicated to railways,
2. definition of a security-by-design process dedicated to railways,
3. development of a network of railway cybersecurity experts.

Table 44 / ***Comparison between the state of the art and the future of the railway cybersecurity framework***

FIELD	STATE OF THE ART OF THE RAILWAY NETWORK	CYBERSECURITY SYSTEM
Standardisation	No standardisation at European level except for ETCS protocols	Standardised CSS that could be applied to railway and urban subsystems. Standardised security-by-design method that could be applied to the design of railway and urban subsystems. Common approach for security assessment Definition of generic protection profile for railway components/subsystems
CSS integration	No integration	Rules for integrated network at European level
Security	Weak protection of most of the network (when the network is protected) and not standardised, except for the interfaces standardised through ERTMS	Provided through a strong, upgradable and standardised secured network Provided through security assessment generalisation Provided through the definition of a common approach to security by design and of generic protection profiles

FIELD	STATE OF THE ART OF THE RAILWAY NETWORK	CYBERSECURITY SYSTEM
Deployment cost	High owing to the diversity of networks and protection means	Low owing to the use of standardised CSS, protection profiles, security-by-design processes and means of protection
Maintenance cost	High owing to the diversity of network and to the significant level of manual operation to be performed on site	Low owing to the standardisation of the CSS, of the use of a common approach to the security assessment and of the definition of a generic profile for service providers
Sustainability in degraded situation	Very low owing to the diversity of the network and the lack of a co-ordinated incident or disaster recovery management plan	Very high owing to the development of the CSIRT/ISAC, the implementation of the CSIRT/ISAC environment, and the specification of the disaster recovery management plan and of the related workflows

Interaction with other TDs (in the same IP and/or in other IPs)

*Table 45 / **Interaction with other TDs and IPs***

IP1 TD	Contribution to TD2.11	Contribution from TD2.11
TD1.2: Train Control and Monitoring System Demonstrator	Provide the cybersecurity requirements applicable to the next generation of TCMS.	The interconnection between the onboard signalling system and the TCSM being crucial for train operation, the TD2.11 will provide to the TCMS TD the cybersecurity requirements for the signalling system and the specification of Cybersecurity System. Based on input from both TDs, rules for interconnection of both communication sub-systems should be defined.
IP2 TD	**Contribution to TD2.11**	**Contribution from TD2.11**
TD2.1: Adaptable communications	Provide to the TD2.11 the "adaptable communications" user requirements and then the specification of the communication system.	Provide to the TD2.1 the security assessment and the Cybersecurity System specification. Make sure that the specified Cybersecurity System is compliant with the specified "adaptable communications".
TD2.2: ATO up to GoA4	N/A	The proposed Cybersecurity System should be used to protect the communication between the ATO trackside and embedded devices.
TD2.4: Fail-Safe Train Positioning (including satellite technology)	Provide requirements and system behaviour to identify security needs in the context of the GNSS Signal In Space.	Cooperate to quantitatively evaluate the risks of intentional radio frequency interferences on GNSS Signal In Space and , if needed, the possible mitigations from the components point of view (e.g. antenna, GNSS receivers) up to the system level.
TD2.6: Zero on-site testing	N/A	Services provided by the TD2.11 will facilitate and secure the remote testing between labs through the use of a common Cybersecurity System.
TD2.8: Virtual Coupling	Provide to the TD2.11 the communication QOS requirements for virtual train coupling.	Assess if the defined Cybersecurity System is able to cover short or medium range communications needed for virtual train coupling.
TD2.9: TMS evolution	Provide to the TD2.11 the communication QOS requirements and architecture for next generation TMS.	Make sure that the specified Cybersecurity System is able to secure the TMS communication needs.
TD2.10: Smart radio-connected all-in-all wayside objects	Provide to the TD2.11 the communication requirements and architecture for the Smart radio-connected wayside objects	Make sure that the specified Cybersecurity System is able to secure the communication needs of the smart radio-connected wayside objects.
IP3 TD	Contribution to TD2.11	Contribution from TD2.11
TD3.6: Dyn. Railway Inform. Management Sys.	N/A	Provide to the DRIMS, the "asset" based security assessment and specification of Cyber Security System for data mining management.
IP4 TD	Contribution to TD2.11	Contribution from TD2.11
TD4.1: Interoperability Framework	N/A	Provide to the TD4.1 the cybersecurity framework specified for the traffic management and control systems.Provide to the TD4.1 the security assessment.

2.11.4. Impact and enabling innovation capabilities

The rail sector has been considered up to now to be immune to any external cyberthreat thanks to its isolation. This is definitively no more the case, and protection of critical infrastructure, including transport, is a strategic challenge for our society.

In this context, TD2.11 will play a leading role by proposing a concerted and shared approach by all the railway stakeholders for implementing railway-specific cybersecurity solutions.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	The European railway security system should encounter the same success as the European train control system, since it offers the same standardisation and interoperability advantages. Railway companies involved in the elaboration of this common security system will add a significant feature to the solutions they currently propose, and the involved European companies specialised in information security will find new applications and new markets for their products
Compliance with EU objectives	The European objectives are met, since TD2.11 contributes significantly to the availability and safety of European railway traffic by protecting against the substantial rise in cyber-attacks against critical infrastructures, and since the development of common and standardised solutions and processes are two of the main objectives of TD2.11
Degree of maturity of the envisaged solutions	Cybersecurity technologies are considered mature even if in constant evolution. Actions taken to apply them to railway networks are quite recent and defining the way to do it is still at the beginning. The target of TD2.11 is definitively to play the role of game changer for cybersecurity within the railway through the definition of common security contexts, processes and security requirements shared between all railway stakeholders. Most of the proposed railway cybersecurity technologies are currently at TRL 1/2. The target of the technical demonstrator is to raise this level to TRL 4 to 6

This TD will contribute to enabling the following innovation capabilities.

INNOVATION CAPABILITY	TD2.11 CYBERSECURITY ENABLERS TRL 5–7
1 – Automated train operation	Automation of train preparation processes can be reached only through a secure process that will ensure the authenticity and the integrity of the data installed in an automatic way into the railway equipment. Security processes for data preparation will be analysed during the security risk assessment process. • BB2.11.1: Define a security system dedicated to railways • BB2.11.2: Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection
4 – More value from data	The fourth innovation capability includes the following objectives: a. definition of secure, robust, scalable and resilient open architectures and protocols allowing full interoperability b. use of the IoT and artificial intelligence (AI) providing efficient capture, storage, management and interpretation of data c. specification of state-of-the-art cybersecurity ensuring reliable and secure ICT services, protection of the rail system and business continuity in case of an incident. TD2.11 will contribute to these objectives through the specification and application to generic railway architecture of security risk assessment processes allowing identification of the significant threats to the rail sector and the countermeasures needed. This process will use as a framework the most up-to-date industrial cybersecurity framework and consider the railway specificities. A specific study will tackle the analysis of the security impact of the IoT's integration into railways. • BB2.11.1: Define a security system dedicated to railways

INNOVATION CAPABILITY	TD2.11 CYBERSECURITY ENABLERS TRL 5–7
7 – Low-cost railway	The time-consuming certification process and the very long life cycle of the railway components lead to major patch management issues for security-related updates. Moreover, the small size of the rail sector will prevent it from imposing its own cybersecurity certification scheme without being exposed to monopolistic risk. In order to tackle both issues, the cybersecurity TD will include in its studies the specification of security and safety requirements for efficient patch management processes and potential cross-compliance schemes for cybersecurity certification. • BB2.11.1: Definition of a security system dedicated to railways • BB2.11.2: Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection
8 – Guaranteed asset health and availability	The use of remote sensors and of the industrial IoT will increase significantly the railway's exposure to cybersecurity threats, with potential impacts on the system's availability, integrity and confidentiality. The integration of the IoT and of remote sensors in the system will be part of a dedicated security risk assessment that will provide security recommendations for such components. • BB2.11.1: Define a security system dedicated to railways • BB2.11.2: Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection • BB2.11.3: Railway cybersecurity experts (CSIRT) network
9 – Intelligent trains	One of the objectives of the ninth innovation capability is to provide seamless connection and data transfer between trains, and between train and infrastructure. This exchange of information will be achievable only if it is done in a secure way. TD2.11 will provide the processes to evaluate the level of risk of such connections and to identify the controls needed in order to reduce this risk to an acceptable level. • BB2.11.1: Define a security system dedicated to railways • BB2.11.2: Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection
10 – Stations and smart city mobility	One of the objectives of the tenth innovation capability is to provide seamless connection and data transfer between railways and smart city mobility platforms. This exchange of information will be achievable only if it is done in a secure way. TD2.11 will provide the processes to evaluate the level of risk of such connections and to identify the controls needed in order to reduce this risk to an acceptable level. • BB2.11.1: Define a security system dedicated to railways • BB2.11.2: Define and develop demonstrators based on a methodology ensuring infrastructure, train and communication protection • BB2.11.3: Railway cybersecurity experts (CSIRT) network

2.11.5. Demonstration activities and deployment

The following table summarises the contribution of TD2.11 cybersecurity to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Cybersecurity	Secure network and systems	Security assessment, architecture and protocols	High-speed, mixed traffic lines, urban/ suburban	5/7	After having agreed, specified and applied a security assessment method to generic railway architecture, standardised interfaces, monitoring functions, security protocols, security requirements and security architectures for secure systems have to be specified. Efficiency and robustness of the standardised guidelines have to be demonstrated through a technical demonstrator (demonstrator 1). Specific attention will be paid to some railway specificities and demonstrated through a technical demonstrator (demonstrator 2)
	Secure railway application	Cybersecure design standard and security profiles	High-speed, mixed traffic lines, urban/ suburban	5/6	After having identified protection profiles dedicated to railway components and a security-by-design standard applicable to railway development, demonstrate their applicability through railway applications (demonstrator 1)
	Develop a network of railway cybersecurity experts (CSIRT/ ISAC)	Define holistic knowledge database Specify CSIRT model for railways	High-speed, mixed traffic lines, urban/ suburban	4	After having defined a common understanding of cybersecurity matters for railways, including the definition of a common language, specify CSIRT/ISAC model for railway and develop a prototype of the CSIRT/ISAC railway environment (demonstrator 3)

By the end of the proposed work, all the principal elements required for rapid market uptake after the S2R will have been taken into account in this proposal. These elements consist in a set of common references and guidelines and their feasibility demonstration through the demonstrators. These common references and guidelines are:

- common and standardised architecture, interface and security requirement specifications for interoperable railway system,
- common up-to-date cybersecurity approach for railway networks and applications, including common security assessment, security-by-design and patch management guidelines,
- monitoring and protection tools dedicated to the railway cybersecurity system,
- feasibility studies of railway CSIRT/ISAC,
- model of collaborative environment dedicated to the railway CSIRT/ISAC.

Then we will demonstrate the feasibility of the guideline and model implementation through three different demonstrators.

1. The first demonstrator should focus on the implementation of the cybersecurity guidelines in railways. It will demonstrate the use of protection profiles among specific type of assets as one important aspect of the overall security-by-design approach. During this task a protection profile will be specified for a selected demonstrator of TD2.1 Adaptable Communications for All Railways. The demonstrator provided from the other work package will be verified and validated regarding systemic effectiveness and completeness of the protection profile used. By conducting security tests and evaluation of the results, the benefit of protection protect profiles will be demonstrated.

2. The second demonstrator will demonstrate the adequacy of our guidelines with some railway specificities, e.g. to review and analyse the capabilities and limitations of the standard IEC 62443-2-3 ‘Patch management in the IACS environment’ for its applicability within the railway business.

3. The third demonstrator will propose a model for a railway-specific CSIRT/ISAC.

Planning and budget

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022
	Cyber security		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
TD2.11	2.11.1 Cyber Security System: Security assessment limited to ETCS and an urban system	3							
	2.11.2 Cyber Security System: Threat Detection, Prevention and Response	3							
	2.11.3 Cyber Security System: Guidelines/standards limited to standardised interface	3							
	2.11.4 Cyber Security System: Technical demonstrator	5/7							
	2.11.5 Security by design: basic standard selection and security profile definition	3							
	2.11.6 Security by design: "security-by-design" standard applied to railway	3							
	2.11.7 Security by design: technical demonstrator	5/6							
	2.11.8 CERT: Combining expertize – Designing a holistic knowledge base	2							
	2.11.9 CERT: Design and validate CERT model dedicated to railway	4							
	2.11.10 CERT: Design and validate CERT collaborative environment	4							

◆ milestone

○ quick win

contracted activities

planned activities

Table 46 / ***TD2.11 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2018	Detailed security assessment of generic railway architecture	Main outcome of task 2.11.1
Q1 2019	Definition of generic protection profile for railway subsystems/components	Main outcome of task 2.11.5

Table 47 / ***TD2.11 milestones***

WHEN	WHAT
Q1 2020	Guidelines for the railway cybersecurity system
Q1 2020	Guidelines for railway security by design
Q2 2021	Railway life-cycle and specificities analyses
Q3 2022	Demonstrators

The estimated total budget for TD2.11 is around EUR 12.5 million.

3. IP3 – Cost-efficient and reliable infrastructure

Context and motivation

The next 20–30 years will see unprecedented demand for growth in transport. European railways have to deliver increased productivity to fulfil growth demands across all modes in freight and passenger services of 80 % and 50 % respectively by 2050. S2R IP3 focuses on innovative design and optimisation of core infrastructure elements as well as improvement in the management of the railway system by adopting a holistic, system-wide approach. The focus will be on priority research areas as identified later in this section.

The European railway network has been incrementally developed over many years and is, too often, a patchwork of components, subsystems and localised improvements. Railway networks are in general non-optimised and susceptible to performance issues due to this legacy. As a result of this:

- The fundamental designs of critical infrastructure assets, e.g. switches and crossings (S&C) and track systems, are not capable of meeting the demands of future rail transport, and in general do not follow a whole-system approach.
- Rather than adopting risk and condition-based lean approaches to optimise reliability, availability, maintainability, safety (RAMS) and life-cycle costs, asset maintenance activities predominantly follow costly time-based regimes that often fail to define and target the root causes of degradation.
- The wealth of data and information on the status of assets and traffic has varying levels of quality and is distributed over a wide range of information systems and differing standards that restrict data access and exploitation.
- Power systems incur high and unnecessary energy losses: no closed-loop systems exist to balance energy demands.

Objectives of the IP and expected results

IP3 will enable a resilient, consistent, cost-efficient, high capacity and attractive European network by delivering operation-critical research, development, and innovation for rail infrastructure. This will be achieved by the adoption of a whole-system approach linking infrastructure and station design with maintenance actions, asset management and energy management.

IP3 will target the following overall Shift2Rail objectives:

- enhancing the existing **capacity**, fulfilling user demands on the European rail system;
- increasing the **reliability**, delivering better and consistent quality of service of the European rail system;
- reducing the **LCC**, increasing the competitiveness of the European rail system and the European rail supply industry.

Specific technical impacts are listed for each TD in the following sections.

IP3 will deliver outcomes that will produce a step change in the way that the European rail network is developed and operated, such that the infrastructure will improve the economic viability and attractiveness of the network. Some overall objectives to characterise this improvement are:

- overall LCC and RAMS,
- track performance and traffic disturbance,
- environmental performance.

Corresponding societal benefits include:

- capacity,
- operational reliability,
- competitiveness – share of transport.

These objectives are all geared to achieving the overall objectives outlined in the Strategic Master Plan:

- improved reliability,
- enhanced capacity,
- improved customer experience,
- lower investment costs,
- reduced operating costs,
- respect and adaption of TSIs,
- removal of open points,
- improved standardisation.

More specific objectives are listed under the respective TDs.

In meeting these goals there are a number of challenges, which are discussed under each TD. In short, some major overall challenges are as follows:

- to ensure a rapid implementation process – this is targeted by the inclusion of all affected parties in IP3;
- to ensure the identification of high-importance issues and the generation of relevant solutions;
- to ensure a working cooperation between partners – this is also partly addressed by having many of the partners involved in In2Rail.

Structure and set-up of IP3

IP3 is organised around 11 TDs, which are briefly presented below and described in detail in later subsections. Figure 21 provides an overview of the interrelations between all of the TDs of IP3 and also shows how the TDs are clustered together into three ITDs. ITDs combine TD prototypes at system level (lab and on-site) and provide an opportunity to test optimisation and validation.

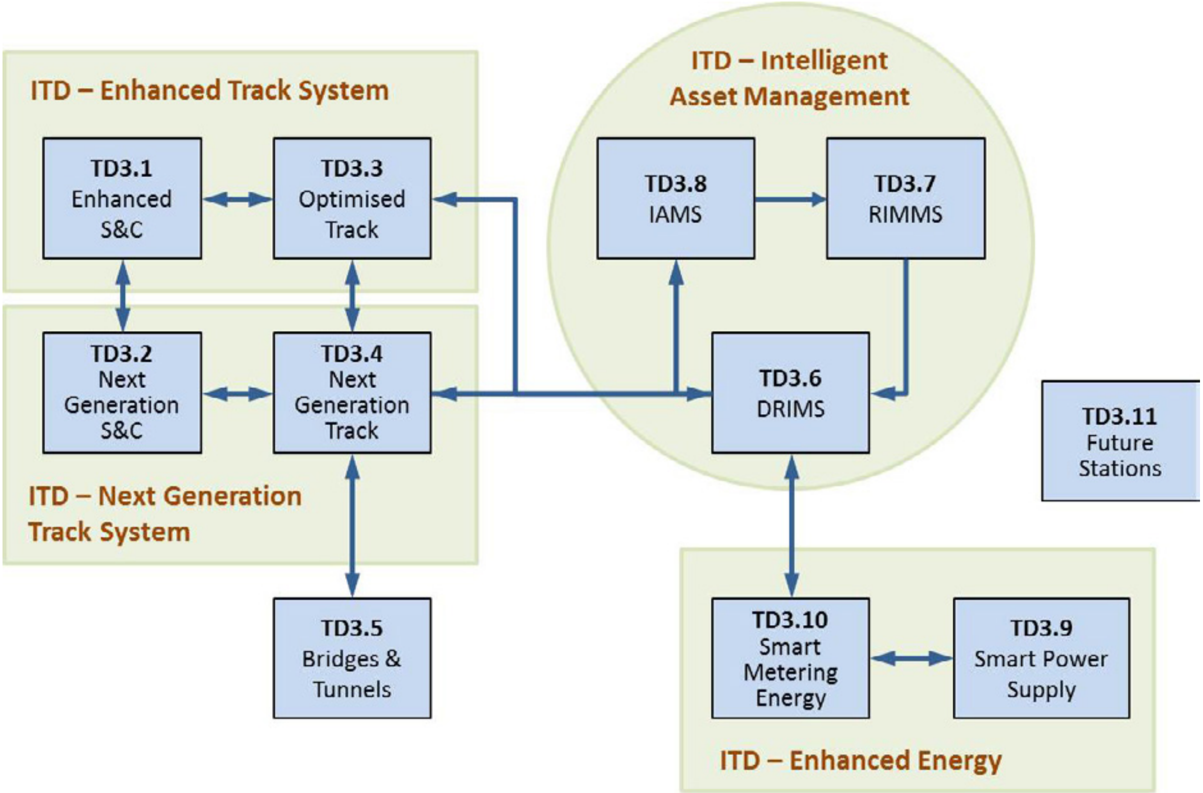


Figure 21 / ***TDs and ITDs in IP3***

TD3.1 Enhanced Switch and Crossing System

The main objective of this TD is to improve the operational performance of existing S&C designs through the delivery of new S&C subsystems with enhanced RAMS, LCC, sensing and monitoring capabilities, self-adjustment, noise and vibration performance, interoperability and modularity. The TD is organised into tasks with gradually more detailed analysis and design decisions.

TD3.2 Next Generation Switch and Crossing System

The TD aims to provide radical new system solutions that deliver new methods for directing trains to change tracks, with the aim of increasing capacity while reducing maintenance needs, traffic disturbances and life-cycle costs. The TD is organised into a mixture of tasks with gradually more detailed analysis and design decisions, and tasks related to specific technical challenges.

TD3.3 Optimised Track System

The TD challenges track construction assumptions, currently implicit in track design, and explores how innovative solutions in the form of products, processes and procedures can provide higher levels of reliability, sustainability, capacity and LCC savings. The aim is to derive medium-term solutions, which require that the solutions need to be harmonised with current solutions and regulations. The TD is organised around a gradual refinement in design/evaluation of solutions.

TD3.4 Next Generation Track System

The TD aims at drastically improving the track system, targeting a time horizon some 40 years beyond the present state of the art. This implies that step changes in performance are highly prioritised. The TD process follows a tightly integrated chain, setting out from initial identification of long-term needs of the railway and potential solutions to meet these. The TD is organised around a gradual refinement in the design/evaluation of solutions.

TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade

The main objective of the TD is to improve inspection methods and repair techniques to reduce costs, improve quality and extend their service life if possible. The reduction of noise and vibration is also a prioritised objective. The TD is organised around the different technical challenges to reach this end.

TD3.6 Dynamic Railway Information Management System

The TD defines an innovative system for the management, processing and analysis of railway data obtained from TD3.7. The focus is to provide high-quality input to the intelligent asset management actions within TD3.8. The TD is organised around the different steps required for developing such an analysis framework.

TD3.7 Railway Integrated Measuring and Monitoring System

The TD is to provide innovative tools and techniques for capturing information on the current status of assets in a non-intrusive and fully integrated manner. To this end, the TD focuses on asset status data collection in close interaction with TD3.1–TD3.5. The TD is organised around the different technical systems of the railway.

TD3.8 Intelligent Asset Management Strategies

The vision is a holistic, whole-system approach to asset management employing collected and processed data provided by TD3.6 and TD3.7. This includes putting long-term strategies in the context of day-to-day execution of maintenance and other maintenance activities.

TD3.9 Smart Power Supply

The global objective of a railway smart grid is to develop a railway power grid in an overall interconnected and communicating system. The TD is organised with successively refined designs to obtain this target.

TD3.10 Smart Metering for Railway Distributed Energy Resource Management System

The objective of the smart metering demonstrator is to achieve a fine mapping of energy flows within the entire railway system, as a basis of any energy management strategy. To this end, the TD is organised with successively refined analyses and developments.

TD3.11 Future Stations

The primary objective is improved customer experience at stations. The TD is organised around four identified key functional demands; two demands relate to improving capacity and security in large stations, one demand relates to the design of small stations with the objective of reducing whole-life costs and standardising design where possible, and the final demand relates to accessibility.

Links to other IPs

There are also interfaces between IP3 and other IPs. Track and S&C interact with the operating vehicles (IP1 and IP5). In addition, there is an interface with the power supply and metering from IP1 and IP5. Stations have a strong interaction with passenger services (IP1) and with IT solutions (IP4). Maintenance TDs will be influenced by the operating vehicles (IP1 and IP5) and will also affect traffic management (IP2). Finally, requirements on tunnels and bridges relate to operating traffic (IP1 and IP5). These interactions are graphically presented in Figure 22.

This motivates a high priority of IP3, and also imposes demands on IP3 to interact closely with other IPs. In addition, IP3 relates to basically all crosscutting activities.

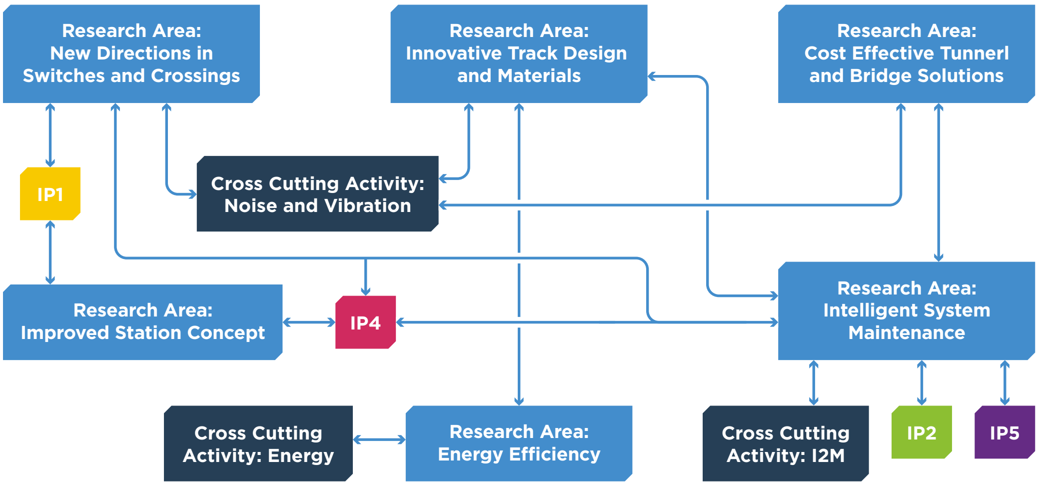


Figure 22 / ***Relationship of IP3 with other IPs and CCA***

In addition, the existing interactions with other IPs and within relevant TDs of IP3 take into account the work on the S2R system architecture performed in IPx.

Approach in IP3 - Whole-life value and cost appraisal

Innovations in the infrastructure IP are aimed at optimising the balance between performance, cost and risk over the life cycle of the asset. It is necessary, therefore, to have an appraisal method that can determine these parameters on a consistent and comparable basis for all the innovations under consideration. The most promising solutions from the prototypes that will be taken forward to full-scale tests will be selected using this appraisal method. Figure 23 provides the modelling framework proposed for undertaking a whole-life cost and value appraisal.

The objective of the framework is to enable a range of options to be analysed at any point in the asset life cycle and to determine the impact of each option on performance, cost and risk. The framework has five main components, each of which is summarised below.

Controllable decisions

These are the options that need to be considered at each stage of the asset life cycle. For example, radically different options will be considered in the concept and design phase. It will also be necessary to consider the maintenance strategy, the timing of renewal and if operational limitations may be required. The appraisal method should allow options to be analysed individually or in combination.

Constraints

The whole-life appraisal will recognise potential constraints. These include limitations on possessions for highly utilised routes, potential for limited access to the assets for working to inspect and repair faults, and may also include limitations in the supply chain or the availability of funding that could impact the delivery in a non-optimal way. Such constraints may limit the roll-out of new technologies and therefore the timescales over which the benefits are realised.

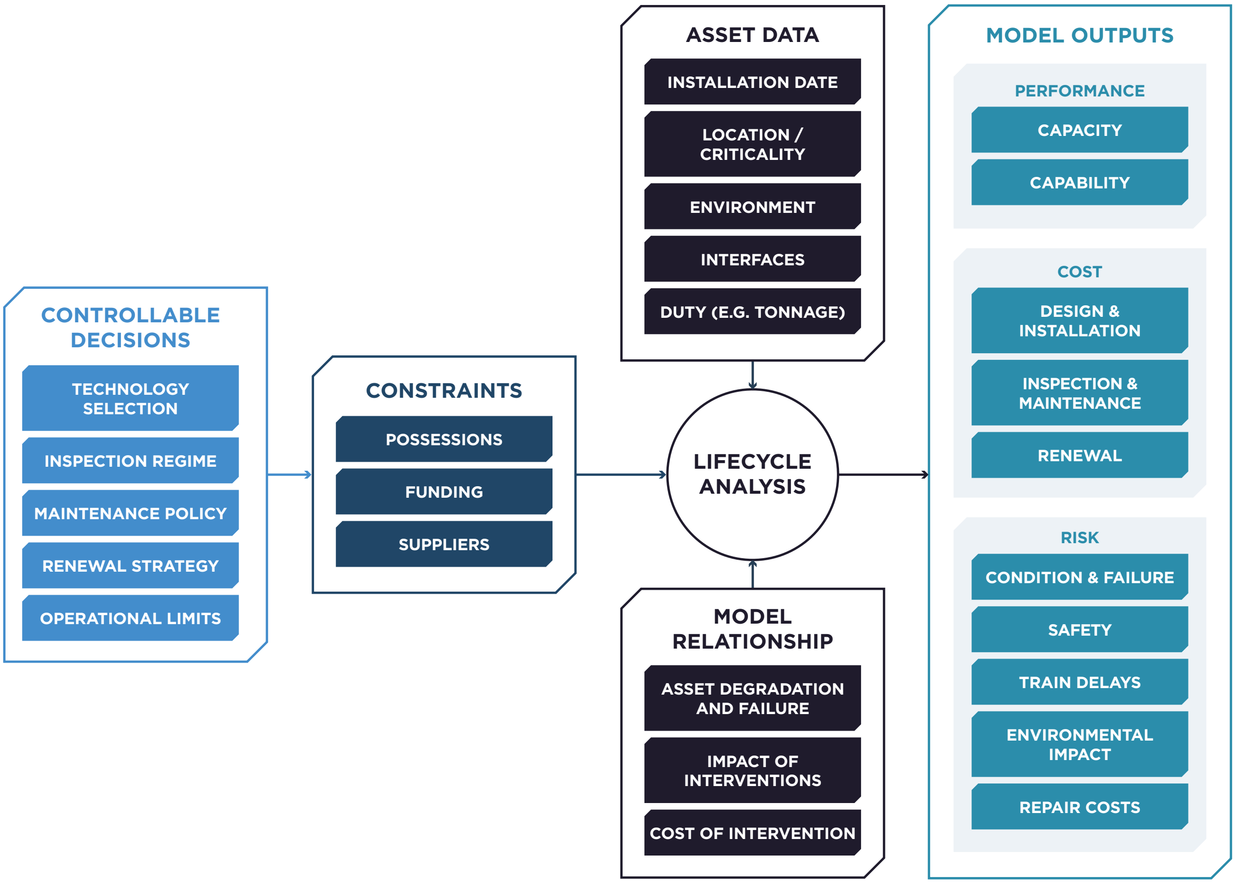


Figure 23 / ***Appraisal framework for whole life value and cost analysis***

Model relationships

These are the key relationships that support the calculation of performance, cost and risk at each stage of the life cycle from the whole-system point of view. These include, for example, the vehicle dynamics together with simulation models representing asset degradation and failure (including interactions between assets), the impact of intervention activities and the modelling of variable costs, e.g. possessions.

Asset data

The model relationships require a range of data inputs. This includes direct information on the asset, such as the installation timing, operating environment, system interfaces and locations. All of these parameters will be modelled for a range of railways that can be found within the EU. The datasets also include other user-defined parameters such as discount rates and the time horizon for the calculation.

Outputs

The outputs will support continuous evaluation of the performance, cost and risk of an option or combination of options.

3.1. TD3.1 Enhanced Switch and Crossing System

3.1.1. Concept

S&C are a critical subsystem of the railway infrastructure, in terms of safety and performance. Service-affecting failures associated with S&C account for some 25–30 % of all infrastructure failures on European railways. Furthermore, a significant proportion of the LCC of S&C also relates to monitoring and maintenance activities required to ensure that the system is functional for the safe running of trains. With the target of Shift2Rail to increase the operational capacity of railway networks, it is important that these activities and critical S&C failure modes are significantly reduced.

The greatest potential for innovation and development for TD3.1 is to address the deficiencies by designing out all known failure modes from all associated subsystems while considering the wheel–rail interface and rail support conditions. This can be achieved by adopting a systems engineering approach for developing new technical solutions for components, and by integrating remote condition monitoring with a feedback loop for self-diagnosis and adjustment.

The resulting system must be robust, reliable, immune to extreme weather and with low LCC. Emphasis will be placed on sustainability and environmental issues with the objective of ensuring that a holistic strategy to minimise environmental footprint and whole-life energy consumption.

The innovative approach is to adopt the growing trend of blending mechanical, electro-mechanical and digital control systems and electronic design elements into one integrated S&C system. This opens new opportunities for infrastructure maintainers to provide in-time preventative maintenance that increases system longevity and availability and therefore service revenue, and reduces manual intervention. Designing for maintainability and manufacturability will also be included as key considerations throughout the duration of TD3.1. New designs will also consider interoperability and interchangeability needs of the European railway systems.

3.1.2. Technical objectives

The main objective of TD3.1 is to improve the operational performance of existing S&C designs. This will be achieved through the delivery of new S&C subsystems with enhanced RAMS, LCC, sensing and monitoring capabilities, self-adjustment, noise and vibration performance, interoperability and modularity. In particular, the following technical objectives are envisaged by the implementation in TD3.1.

1. Increased availability through reduced complexity.
2. Increased availability and reduced LCC through improved asset management.
3. Increased availability and lower LCC through improved maintenance.
4. Improved competitiveness and public acceptance through improved green credentials, less noise and vibrations, and improved sustainability.
5. Cost reduction.

3.1.3. Technical vision

The vision for the Enhanced Switch and Crossing System TD is to seek, by performing trials, the validation of new S&C components within current S&C designs. This has the benefit of bringing forward incremental improvements to the existing S&C system performance.

STATE OF THE ART	ENHANCED S&C
Design The current S&C systems have been designed and optimised on a subsystem level but not with a whole-system perspective and thus potential improvements with respect to RAMS still exist	**Design** An integrated whole-system approach will be used to achieve multidisciplinary optimisation. This results in fewer and more reliable components, more elasticity and flexibility, interchangeability, and easier integration and commissioning procedures
Assessment Individual assessment processes for new S&C systems for individual railway operators are time-consuming	**Assessment** Guidelines and procedures will be produced for hybrid assessment (virtual + experimental) and cross-acceptance for new materials, components and systems
Installation Installation and replacement of S&C require many steps and manual actions to locate the unit in its new home	**Installation** The proposed switch design will attempt to make the unit and all parts more geared towards automated installation, maintenance and in situ service
Operational Some existing S&C do not have the necessary level of redundancy to ensure that the switch remains operational under right-side failure conditions	**Operational** The enhanced switch design will include multiple levels of system redundancy together with information systems to ensure that right-side failures do not affect railway operations
Inspection and maintenance Current design is labour intensive and requires maintenance staff to tend to the assets at regular intervals to survey the state of the asset as well as to adjust and refill consumables	**Inspection and maintenance** The new design will utilise enhanced S&C component designs and remote sensors to permit a reduction in the need to visit the unit for condition surveys. Adjustments will as far as possible be automatic

Interaction with other TDs (in the same IP and/or in other IPs)

This TD will interact with:

- TD1.4, Running Gear – curve negotiation behaviour is influenced by S&C and running gear design (lightweight running gear, actuator and control technology);
- TD2.10, Smart Radio-Connected All-in-all Wayside Objects – security definitions influence the transmission of data from sensor-equipped S&C;
- TD3.2, Next Generation Switch & Crossing Systems – TD3.2 takes TD3.1 to the next generation by radically removing limitations while building upon TD3.1's experience; outcomes may direct TD3.1's further enhancement even beyond S2R;
- TD3.3, Optimised Track Systems – innovative track solutions can be applied in both S&C and track, e.g. under-sleeper pads, sleeper design;
- TD3.4, Next Generation Track Systems – outcomes may direct TD3.1's further enhancement even beyond S2R;

- TD3.6, TD3.7, TD3.8, intelligence maintenance demonstrators – embedded sensors provide data for TD3.6 to TD3.8, based on shared requirements on monitoring parameters, techniques and data models;
- TD5.3, Smart Freight Wagon Concepts – curve negotiation behaviour is influenced by S&C and wagon design;
- WA 3.2, Standardisation – standards relating to the areas of S&C, track, ballast, installation, inspection and maintenance;
- WA 3.1, Safety.

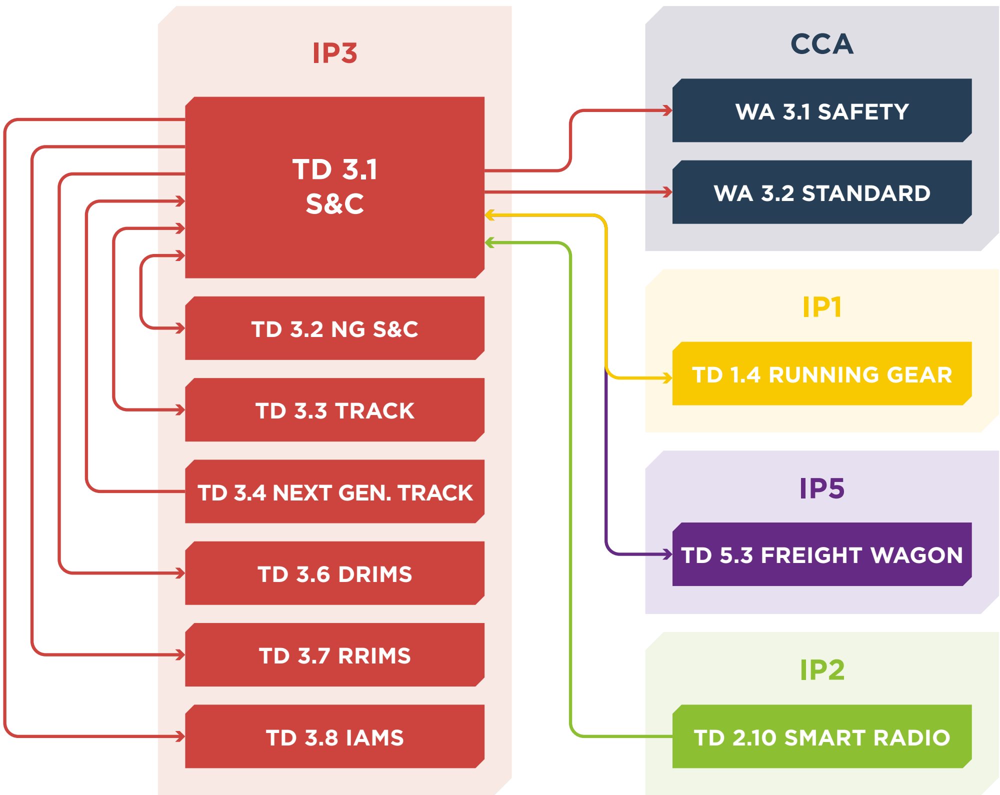


Figure 24 / ***Interaction with other TDs within IP3***

3.1.4. Impact and enabling innovation capabilities

The specific benefits of TD3.1 will have a major impact on the S2R system-level KPIs.

<table>
<tr><th>STRATEGIC ASPECT</th><th colspan="2">KEY CONTRIBUTION FROM THE TD</th></tr>
<tr><td rowspan="9">Support the competitiveness of the EU industry</td><td>Whole-system modelling to reduce existing S&C failure modes through design</td><td rowspan="4">Global technological leadership supported by a combination of innovation and technical standards, setting up an effective advantage for the European industry</td></tr>
<tr><td>Integrated S&C reliability-centred maintenance (RCM) with automated self-correction and adjustment</td></tr>
<tr><td>Enhanced wheel-to-S&C interface conditions</td></tr>
<tr><td>Improved redundancy of safety-critical systems for enhanced system reliability</td></tr>
<tr><td>Increase in operational reliability through more robust systems thanks to fewer components, enhanced assessment and debugging concepts, and more flexible information processing</td><td rowspan="4">Increased attractiveness and competitiveness</td></tr>
<tr><td>Asset LCC reduction through virtual assessment, lower physical complexity of systems and increased RAMS performance</td></tr>
<tr><td>Capacity increase through reduced service affecting failures</td></tr>
<tr><td>Automation of S&C inspection (through RCM) reduces manual surveillance (improving safety and maintenance efficiency) and reduces the reliance on subjective views of asset condition</td></tr>
<tr><td>Improved customer ride quality through improved wheel–rail interface conditions</td><td>Enhanced customer experience</td></tr>
<tr><td rowspan="4">Compliance with EU objectives</td><td>Improved avoiding of service disruptions and adding new capabilities</td><td rowspan="4">Promotion of modal shift</td></tr>
<tr><td>Improved S&C green credentials through lowering LCC and increasing asset life, performance and availability through whole-system design. Data trending will further reduce LCC through enabling predictive and preventative maintenance</td></tr>
<tr><td>Supported fair and efficient supplier competition and enhanced interoperability through interchangeable solutions. This will support achieving a SERA</td></tr>
<tr><td>Support to capacity increase by introducing additional levels of redundancy and hence reliability to existing S&C systems. This will reduce service-affecting failures</td></tr>
<tr><td>Degree of maturity of the envisaged solutions</td><td colspan="2">Currently, most of the proposed technologies are at low TRLs of 1 or 2. At the end of Shift2Rail, it is expected that the successful concepts will be brought to TRL 6 or 7</td></tr>
</table>

This TD will contribute to enabling the innovation capabilities as shown in the table below.

INNOVATION CAPABILITY	TD3.1 ENHANCED S&C ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	Complete virtual prototyping aggregates all related linked data. The models can be used to generate production information for scheduling, planning and operation, further improving efficiency and reducing errors. Relevant building block: • BB3.1.1: Enhanced S&C whole-system modelling, simulation and design, TRL 5 Advanced S&C control can provide functional status to a maintainer for fault finding and a minimal-trigger-type control for the S&C unit itself. S&C deterioration data, obtained through embedded and integrated sensors, will be fed into TD3.6 to inform an innovative asset management system. Relevant building block: • BB3.1.3: Enhanced control, monitoring and sensors systems, TRL 6/7
7 – Low-cost railway	Integrated modelling, simulation and design methods will be used from the start to integrate the mechanical, electrical and software components into the design to deliver the required improved capabilities. Relevant building block: • BB3.1.1 Enhanced S&C whole-system modelling, simulation and design, TRL 5 Further develop existing S&C systems by improving encapsulated designs such that they can be pre-assembled and ‘plug and play’ into new layouts or retrofits. This includes the ability to use components from different manufacturers within the same design. Relevant building block: • BB3.1.2: Enhanced S&C design including materials and components, TRL 6/7
8 – Guaranteed asset health and availability	Integrated modelling, simulation and design methods will be used from the start to integrate the mechanical, electrical and software components into the design to deliver the required improved capabilities. The use of computer-aided engineering (CAE) methods together with integrated testing of materials, components and subsystems enables iterative optimisation of the design. This then leads to a complete virtual prototyping of the planned design that contains all related linked data. Relevant building block: • BB3.1.1: Enhanced S&C whole-system modelling, simulation and design, TRL 5 This demonstrator provides an opportunity to improve not only components but subsystems such that there are reduced problems and improved physical protection to critical components. Enhanced welding processes and technologies will also be considered with regard to both construction and repair. Relevant building block: • BB3.1.2: Enhanced S&C design including materials and components, TRL 6/7 Advanced S&C control can provide functional status to a maintainer for fault finding and a minimal-trigger-type control for the S&C unit itself. The enhanced S&C technology demonstrator will develop reliable and robust switch actuation, locking and detection system designs that will be intelligently controlled with self-adjustment capabilities. Relevant building block: • BB3.1.3: Enhanced control, monitoring and sensors systems, TRL 6/7

<table>
<tr><th>INNOVATION CAPABILITY</th><th>TD3.1 ENHANCED S&C ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS</th></tr>
<tr><td>11 – Environmental and social sustainability</td><td>The use of CAE methods together with integrated testing of materials, components and subsystems enables iterative optimisation of the design and thus optimal usage of resources. Relevant building block:

• BB3.1.1: Enhanced S&C whole-system modelling, simulation and design, TRL 5

The component design optimisation considers constraints from environmental sustainability by thrifty usage of materials, sustainable choice of materials and easy reparability, e.g. enhanced welding processes. Relevant building block:

• BB3.1.2: Enhanced S&C design including materials and components, TRL 6/7

S&C deterioration data, obtained through embedded and integrated sensors, will deliver the possibility of online status monitoring, an innovative asset that enables management procedures and strategies. Relevant building block:

• BB3.1.3: Enhanced control, monitoring and sensors systems, TRL 6/7</td></tr>
<tr><td>12 – Rapid and reliable R&D delivery</td><td>Virtual prototyping includes virtual testing of the planned design and thus reduces the necessary physical in situ testing while speeding up design to match need. Relevant building block:

• BB3.1.1: Enhanced S&C whole-system modelling, simulation and design, TRL 5</td></tr>
</table>

3.1.5. Demonstration activities and deployment

The following table summarises the contribution of TD3.1 Enhanced S&C to the different S2R SPDs.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Enhanced Switch & Crossing System	RAMS-optimised S&C	Enhanced design and material properties, concrete bearers with under sleeper pad, optimised elasticity along the turnout, innovative drive, locking and detection system with integrated sensors	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6/7	Optimise S&C following a whole-system approach including geometry and overrunning, crossing AMS casting, novel rail grade, resilient pads, rail-fastening system, base plates, switch roller system, concrete bearers with under-sleeper pads, stiffness variation, innovative drive and locking system Extensive monitoring programme
	Joint welding of bainitic components	S&C including welding of bainitic sub-components, fatigue of cast manganese crossing		5/6	Develop welding technology to join bainitic with pearlite steel components Experimental evaluation of fatigue of cast manganese crossing
	Virtual mock-up	Virtual mock-up of enhanced S&C to simulate the dynamic behaviour and the related deterioration of components resulting from the interaction with the passing vehicles		4/5	Develop model framework following the whole-system approach to simulate the dynamic behaviour of S&C and the deterioration of their components resulting from vehicle interaction. Support the development towards virtual authorisation
	Innovative sensor system	Design and implement a set of innovative (embedded) sensors for analysing stresses and wear conditions		4/5	Design, develop, test and implement a set of innovative sensors (both ground and embedded) to meet the expectations of operators and maintainers in terms of maintenance performance availability, at low cost. Connected objects are part of the innovations of wireless-connected sensor system, sharing information with operators capable of perceiving, analysing and acting according to the contexts and the environment

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Enhanced Switch and Crossing System	up to	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD3.1	3.1.1 Identify Best Practices for S&C	2																												
	3.1.2 S&C High-Level Upgrade Specs	2-3																												
	3.1.3 Modelling. Trialling and Testing for small scale objects	2-5																												
	3.1.4 In-track full scale test and assessment	4-7																												
	3.1.5 Performance Data Gathering and Assessment	-																												

- ◆ milestone
- ○ quick win
- lighthouse projects
- contracted activities
- future activities

*Table 48 / **TD3.1 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2019	First full-scale high-speed/mainline S&C demonstrator in operation	Early installation of S&C demonstrator incorporating latest enhancements to serve as basis for further development, e.g. sensor data processing
Q4 2018	First full-scale laboratory demonstrator of whole S&C RCM system	Testing of novel sensor and algorithms considering RCM in laboratory environment to pave the way for installation in operational environment
Q2 2020	First field demonstration of additively manufactured (i.e. contact surface clad) cast crossing	Test performance of additive manufactured components to assess further potential for implementation in operational environment

*Table 49 / **TD3.1 milestones***

WHEN	WHAT
Q2 2016	Start of In2Track project
Q4 2017	Collection, analysis of existing S&C components including RAMS finished
Q2 2018	Enhancements specified
Q4 2018	Whole-system model specification, preliminary designs and specifications for components and sensors available
Q2 2022	Test methodologies, tests and validation in place
Q4 2022	Analysis of tests, performance and LCC in place End of In2Track project

The estimated budget for the TD is around EUR 15.5 million.

3.2. TD3.2 Next Generation Switches and Crossings

3.2.1. Concept

The competitive nature of today's world markets places even more emphasis on the rail industry becoming more efficient and having a stronger presence in trans-European and global contexts. The European rail industry must accelerate its efforts to stay relevant in this emergent global commercial environment, in order to contribute to the success of the economies within the European Union.

A number of key components within the traditional railway system are particularly vulnerable to failure, the consequences of which on the overall performance and safety of the railway infrastructure are profound. One such element is S&C assemblies, the fundamental design principles of which have remained unchanged since their inception and currently account for 25–30 % of all infrastructure failures on most European railway networks. The duty cycle on S&C rails is arduous and complex, and advances in rail steel technology needs to be developed to resist abrasive wear and rolling contact fatigue.

This technology demonstrator aims to provide radical new system solutions that deliver completely new methods for directing trains to change tracks. TD3.2 will adopt a structured R&D process to achieve technology demonstration through component-, subsystem- and system-level innovations. The approach will draw upon other spheres of industry that have successfully addressed the problem of gaining improvements beyond conventional incremental development.

The radical new designs will embrace new methods of switching trains between tracks in a manner that drastically improves capacity, performance and reduces costs while maintaining safety as an overriding consideration. Advances in materials, enhanced elastomeric components, optimised sensor technologies, adaptive control with active closed-loop feedback, and providing self-adjustment will all be incorporated to significantly lower overall life costs. A number of possible new S&C concepts will be created, each of which is not constrained by the principles imposed by today's common S&C design features. One final concept will be selected for detailed design, prototyping and whole-system technology demonstration.

3.2.2. Technical objectives

Existing S&C-related system failures account for a significant proportion of all infrastructure failures on European railways. The new switch and crossing system will seek to significantly reduce and/or eliminate these failures by achieving step change improvements. The following major topics will be covered throughout the duration of TD3.2.

Next generation design, materials and components

S&C rely on standard profiles that are machined to the specific shapes required by the S&C configuration. Traditionally, the design application engineering is different between European railways. Modern S&C strives for predictable wear-resistant steel properties that can be maintained in an efficient way. To progress beyond the current state of the art, TD3.2 will examine technology transfer opportunities from other industries as well as developing bespoke materials science solutions alongside state-of-the-art manufacturing techniques. The wheel–rail interface will be optimised to enable the development of radically new mechanisms for switching a train from one line to another.

Next generation kinematic systems

Existing S&C systems still use historical design features originally intended for hand operation. Modern actuators and motors deliver increased switch actuation forces, which can reduce the asset's operational life. The next generation S&C design will incorporate a completely new switching function using novel kinematic elements with radically different components and will be designed from a whole-system perspective. Single points of failure will be eliminated through integrated redundancy to optimise RAMS performance and whole-asset LCC.

Next generation control, monitoring and sensor systems

Existing S&C systems do not utilise sophisticated sensor systems with feedback control loops. New control methods will offer real-time functional status reporting and preventative intervention control. Through new technology development and transfer from other industries, the next generation S&C design will incorporate intelligent self-diagnostics systems with the capability to self-adjust, self-repair and self-heal within predefined system operating tolerances. The next generation S&C system will significantly reduce manual maintenance interventions through self-management.

Towards maintenance- and degradation-free S&C

It is vital that the S&C unit has a stable spatial position over time and the correct support conditions to counter the dynamic forces it will experience over its operational life. It is common for the S&C to be treated as an extension of the normal plain line track system, utilising the same design and construction techniques. The next generation S&C design will allow a different approach to the S&C support elements and will be designed together as a whole system.

3.2.3. Technical vision

The technical vision for TD3.2 Next Generation Switches and Crossings is to seek, by trialling, the radical redesign of S&C. Long-term, whole-system developments will also build on the improvements achieved in TD3.1 Enhanced S&C System.

Table 50 / ***Next generation S&C***

STATE OF THE ART	NEW GENERATION SWITCHES AND CROSSINGS
Installation Installation of S&C requires many steps and manual actions to place the unit in position	**Installation** A switch unit designed for automated installation and maintenance
Maintainability The current design is labour intensive and requires maintenance staff to tend to the assets at regular intervals to survey their state as well as to make adjustments and refill consumables	**Maintainability** Embedded remote sensors to reduce manual condition surveys. Adjustments will be automatic as far as possible and the design will not require consumables
Availability Within existing switch panel designs, the switch rails are some of the highest loaded components within the S&C system and are therefore significantly affected by wear, fatigue fracture and rolling contact fatigue	**Availability** S&C with increased availability through reduced complexity and being designed for degradation resistance and the ability to resist and/or remove dynamic forces
Operational Existing points-operating equipment may incorporate sensors that work independently from the whole system. For example, the relationships between drive forces, system lubrication and switch position cannot be automatically assessed and hence the whole-system condition is not known until a comprehensive manual inspection is complete	**Operational** An integrated and intelligent self-diagnostics system to enable self-adjustment, self-correcting, self-repairing and self-healing capabilities. New, advanced materials will also be used to significantly reduce asset degradation. Nano-technologies for self-healing materials are already in development and, subject to technology maturity, will be used within both the switch and crossing panels
System degradation Currently the system for making vehicles change direction is part of the infrastructure, causing wear and tear and failure modes to be associated with these locations	**System degradation** Alternative vehicle guidance techniques considered with the aim of removing (or significantly reducing) system degradation and critical failure modes. This will improve LCC and enhance safety and reliability through fewer and less invasive maintenance interventions. This aim will be to work towards zero maintenance interventions
Life-cycle cost The current S&C design considers existing materials, computers, electronics and mechanics but does not take a whole-system perspective. As a result, the existing state-of-the-art solutions have, in many ways, not been optimised with regard to RAMS and procedures	**Life-cycle cost** New architectures, technologies and tools to reduce cost during engineering, integration and commissioning phases. Fewer and more reliable components, more flexibility, elasticity and modularity, and easier integration and commissioning due to CAE methods

Interaction with other TDs (in the same IP and/or in other IPs)

This TD will interact with:

- TD1.2, Train Control and Monitoring System
- TD1.4, Running Gear
- TD2.1, Adaptable Communication System for All Railways
- TD2.9, Traffic Management Evolution
- TD2.10, Smart Radio-Connected All-in-All Wayside Objects
- TD3.1, Enhanced Switch and Crossing System
- TD3.3, Optimised Track System
- TD3.4, Next Generation Track
- TD3.6, TD3.7 and TD3.8, intelligence asset management
- TD5.3, Smart Freight Wagon Concepts
- WA2, KPI method development and integrated assessment
- WA3, Safety, standardisation, smart maintenance, smart materials and virtual authorisation

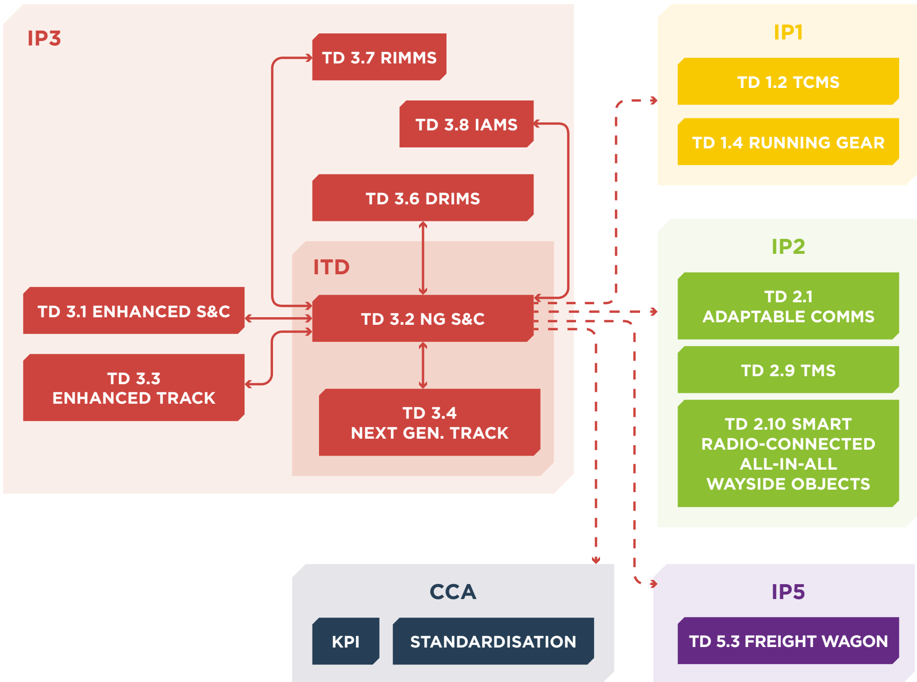


Figure 25 / ***Interaction with other TDs and IPs***

3.2.4. Impact and enabling innovation capabilities

The following technical impacts are envisaged by the implementation of TD3.2 and have been developed in the context of the three specific Shift2Rail global targets.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
100 % capacity increase	• RAMS performance of S&C will improve through optimised S&C whole-system design • The next generation S&C will create a set of wheel interaction conditions that significantly reduce wheel dynamic forces, thus reducing damage to vehicle bogie components • The operational performance of equipment to enable trains to move between tracks will be significantly improved by reducing failures and the need for maintenance
30 % reduction in LCC and increased safety	• The new S&C will be less energy intensive to manufacture and allow recycling in accordance with the principles of sustainable and green asset management • New systems will offer optimised whole-life cost for rolling stock and infrastructure elements • The new systems will be designed for automated manufacture, enabling low-cost production measures to be implemented. It will also reduce the number of components embodied in a compact system design
50 % increase in reliability and punctuality	• Rolling stock components will have a reduced duty cycle exposure due to reduced dynamic track forces, and hence alternative materials could be used and optimisation of strength and weight could be achieved • The new design will incorporate new aspects of maintenance-free operation and also optimise any residual maintenance activities and resilience against environmental operating conditions • An intelligent sensor system will be embedded within the next generation S&C system design to allow the system to self-manage with respect to system set-up, adjustment and maintenance • The improvements in S&C will reduce the forces transmitted to the rolling stock and hence failure modes associated with bogies and other train-borne subsystems

This TD will contribute to enabling European rail industry innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.2 NEXT GENERATION S&C ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
1 – Automated train operation	Next generation S&C designs to eliminate and/or minimise existing failure modes through design. Alternative methods of vehicle switching will be developed in parallel to the requirements of next generation vehicles and their operation. Relevant building blocks: • BB3.2.4: Alternative vehicle guidance techniques
4 – More value from data	Whole-system modelling to enable enhanced understanding of system performance and impact of components/subsystem changes. Relevant building blocks: • BB3.1.1: Enhanced S&C whole-system modelling, simulation and design Whole-system, integrated remote condition monitoring for prognostic health monitoring to enable predictive maintenance and optimised renewals planning. Relevant building block: • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM

INNOVATION CAPABILITY	TD3.2 NEXT GENERATION S&C ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
5 – Optimum energy use	Next generation S&C design optimising energy use through reliability of switch kinematics. Enhanced materials will provide sustainable, whole-system solutions to minimise environmental impact. Integrated RCM will enable prognostic health monitoring and assessment of asset performance. Relevant building blocks: • BB3.2.1: Enhanced materials for optimised asset life-cycle costs • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM • BB3.2_4 Alternative vehicle guidance techniques
6 – Service operation timed to the second	Next generation component, system and monitoring solutions to maximise asset availability and minimise disruption to train services. RCM solutions that inform traffic management of short-term asset availability. Relevant building blocks: • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM • BB3.2.3: Nano-technologies for self-healing/lubricating materials • BB3.2.4: Alternative vehicle guidance techniques
7 – Low-cost railway	Alignment of IMs' system and design resources and targets with suppliers to increase both the effort and funding available to generate radical solutions. S&C system designed with aligned component life cycles to promote a reduction in IMs' maintenance and renewal costs. Relevant building blocks: • BB3.2.1: Enhanced materials for optimised asset life-cycle costs • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM
8 – Guaranteed asset health and availability	New designs and materials explored capable of self-healing and self-maintaining while reducing asset failures and noise and vibration through optimised design and track support conditions through tailored stiffness transition zones. RCM solutions that enable predictive asset health monitoring and inform traffic management of medium- to long-term assets' remaining operational life (i.e. to inform optimised maintenance and renewal strategies). Relevant building blocks: • BB3.2.1: Enhanced materials for optimised asset life-cycle costs • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM • BB3.2.3: Nano-technologies for self-healing/lubricating materials • BB3.2.4: Alternative vehicle guidance techniques
9 – Intelligent trains	Next generation S&C systems compatible with intelligent train systems, enabling train-to-infrastructure communication and informing advanced traffic management. Relevant building blocks: • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM
10 – Stations and smart city mobility	Next generation S&C systems with optimised RAMS performance to enable railways to be connected to smart cities and provide seamless end-to-end journeys and interchange between modes of transport. Relevant building blocks: • BB3.2.1: Enhanced materials for optimised asset life-cycle costs • BB3.2.2: Intelligent self-diagnostics systems with embedded RCM • BB3.2.3: Nano-technologies for self-healing/lubricating materials • BB3.2.4: Alternative vehicle guidance techniques

INNOVATION CAPABILITY	TD3.2 NEXT GENERATION S&C ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
11 – Environmental and social sustainability	New materials assessed for improved S&C RAMS performance and whole-asset LCC with reduced carbon footprint. System resilience to climate change embedded within next generation system designs while ensuring low levels of noise and vibration. Relevant building blocks: • BB3.2.1: Enhanced materials for optimised asset life-cycle costs • BB3.2.4: Alternative vehicle guidance techniques

3.2.5. Demonstration activities and deployment

To support the overall aspiration of TD3.2, a two-stage test and validation process will be adopted.

Small-scale prototypes and virtual testing (TRL 4–5)

Designing and building a series of small-scale prototypes to evaluate a number of radically different concepts for future S&C systems. The evaluation phase will enable the project to focus on the most promising options. These will then be developed into full-scale prototypes for trialling within a suitable railway test environment.

Full-scale prototypes and virtual testing (TRL 5–6)

The full-scale test phase will confirm the safety and performance of the proposed design. Once they are confirmed, a full-scale accelerated life test will be conducted to understand wear, friction, damage, maintenance and whole-life needs of the new design. When confidence has been established that a viable design has been achieved, a preliminary safety case will be established for the proposed design in preparation for future full-scale tests in service operation conditions within mainline railways.

Owing to the advanced nature of the next generation S&C solution, it is expected that there will be heavy reliance on both virtual and laboratory testing within both stages of technology demonstration.

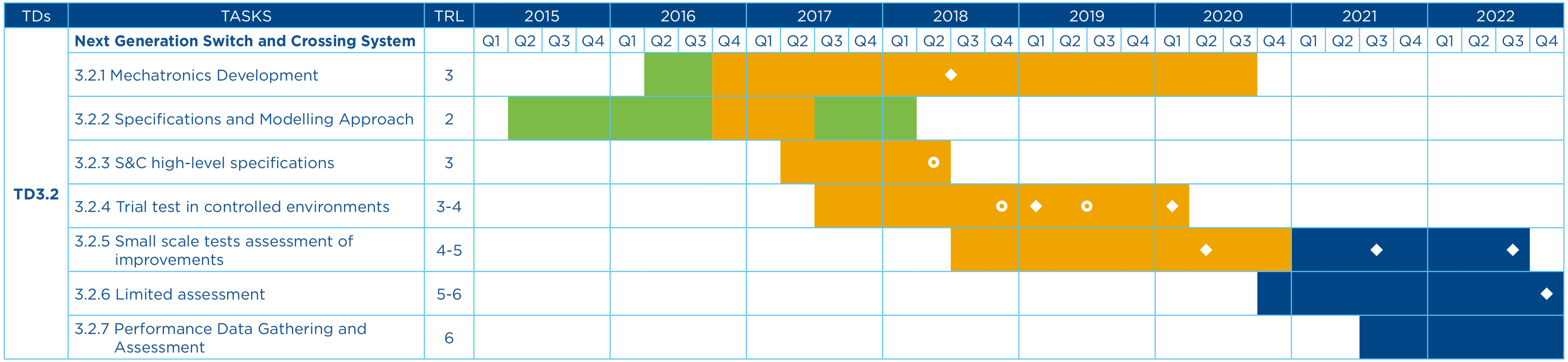
The full-scale test will form part of an ITD alongside TD 3.4 Next Generation Track Systems and will link to TD3.6, TD3.7 and TD3.8, intelligent system maintenance. It is expected that the ITD will be hosted on a Network Rail test track facility that has been upgraded to represent realistic operational conditions.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Switches and Crossings	Next generation switches and crossings	Next generation S&C prototype with optimised RAMS performance and LCC. Whole-system demonstrator may also form an ITD alongside TD3.4 for Next Generation Track	Generic	5/6	Next generation design, materials and manufacturing to provide a step change in asset performance. A radically new S&C asset designed from functional requirements as opposed to incremental improvements of existing systems. Bringing together of S&C subsystems into a whole-system demonstration
	Fault-tolerant S&C control system		Generic	4/5	Fault-tolerant switch control systems being developed and seeking to achieve virtual validation to TRL 3–4 by 2019. The most feasible concepts will be further developed in order to embed advanced switch control within the Next Generation Switches and Crossings TD. Initial laboratory demonstrations will be made prior to integration within the Next Generation Switches and Crossings TD
	Optimised crossing design and manufacture	Radically new crossing design with optimised S&C support	Generic	5/6	Optimised design, materials and manufacturing of a next generation crossing solution to provide a step change in asset performance. Radically new crossing design with asset life to meet operational demands. Overall design will be combined with optimised S&C support solutions to provide a sustainable whole system with optimised RAMS and LCC
	Low N&V tramway crossing	Design study for a next generation moveable girder rail crossing with actuator (drive, locking and detection)	Urban/ suburban passenger rail	6/7	Impact sound, airborne N&V measurements and analysis will be undertaken. The aim is to install a girder rail swing nose crossing in service for the reduction of N&V and to be able to do a first evaluation of the overall performance. This product should be the solution for devices located in critical, neuralgic location in cities
	Innovative S&C sensor system	Innovative S&C monitoring solution that is integrated within the design and manufacturing stage of the asset. Early demonstration of a set of innovative (embedded) sensors	Generic	4/5	Design, development and complete functional testing of an automatic S&C-monitoring system in order to optimise inspection and enable intelligent decision-making for predictive maintenance and renewal. This will include the design and implementation of innovative sensors (both ground and embedded) and defining a strategy for analysing next generation switch degradation

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Switches and Crossings	Next generation S&C materials and components	Design, manufacture and demonstration of a range of S&C materials and components that will be integrated within the next generation S&C whole-system demonstrator	Generic	4/7	A range of next generation S&C materials and components to be developed (i.e. adjustable fastening systems). Depending on the level of compatibility with existing systems and the safety case presented, some of these next generation technologies have the potential to be demonstrated within the operational railway or live test track environment (i.e. self-healing concretes)
	Asphalt track for optimised S&C support	Research on understanding the benefits and technical requirements for installation of an asphalt track solution under S&C	Generic	6/7	A site trial for demonstration defined in collaboration with WP4 for next generation track application. This will include instrumentation and monitoring to support future assessment of asphalt performance

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Switches and Crossings	Next generation S&C transition zones	Detailed conceptual design of the next generation S&C transition into plain line track	Generic	4/5	Transition zones, where abrupt changes in track stiffness occur, are usually subject to amplified dynamic effects and therefore accelerated rates of deterioration. This research will be based upon the fundamental principle of minimising the rate of change of system stiffness for the avoidance of S&C settlement issues. The objective of this work will be to harmonise the S&C life cycle with that of plain line track while aiming to reduce the impact of N&V
	Optimised S&C support conditions	Modular continuous support track, a ballastless beam track offering efficient, lower cost rail technology for all track configurations (including turnouts)	Generic	5/7	The development of this concept will be done by completing detailed design of the switch in parallel to designing the track modules and starting to build and qualify the new fastening systems
	S&C digital twin	Demonstration of an S&C digital twin providing an exact digital replica of an operational asset	Generic	5/6	Development of an S&C digital twin, which will form part of the overall strategy for validation and demonstration of next generation S&C system concepts. The digital twin is a representation of a system that mimics its real-world behaviour and, in some cases, the surrounding environment. This may typically be a real-time updated collection of data, models, algorithms or analyses
	Automated inspection and repair	Prototype automated inspection and repair system using state-of-the-art technologies from within and external to the rail industry	Generic	4/5	This activity will seek to automate existing manual inspection and maintenance activities to improve the efficiency and quality of the activity undertaken

Planning and budget



◆ milestone
o quick win
lighthouse projects
contracted activities
future activities

Table 51 / ***TD3.2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Detailed conceptual design of back-of-flange steering	Virtual validation of preliminary radical S&C concept
Q4 2018	Robotic inspection prototypes	Next generation S&C inspection
Q2 2019	Laboratory demonstration of self-healing materials	Next generation S&C materials

Table 52 / ***TD3.2 milestones***

WHEN	WHAT
Q2 2018	Early designs for next generation S&C systems and subsystems (up to TRL 3)
Q1 2019	Component and subsystem experimental proof of concept in controlled environment (up to TRL 4)
Q1 2020	Technologies (components and subsystems) validated in controlled environment (up to TRL 4)
Q2 2020	Integrated next generation S&C system concept established for demonstration (up to TRL 4)
Q3 2021	Subsystem prototypes validated in relevant environment (up to TRL 5)
Q3 2022	Integrated next generation S&C concept demonstrated in relevant environment (up to TRL 6)
Q4 2022	Limited assessment of next generation S&C integrated concept (up to TRL 6)

The estimated total budget for the Next Generation Switches and Crossings TD is around EUR 16.7 million (Including EUR 0.87 million from In2Rail).

3.3. TD3.3 Optimised Track System

3.3.1. Concept

TD3.3 Optimised Track System will essentially challenge track construction assumptions that are implicit in current European track form design. The objective is to explore how new construction designs can make use of modern designs and materials that provide higher levels of sustainability, loading capability and LCC savings than existing construction types. Sustainable tracks and track components are a core issue for this TD. Digitalisation using built-in and integrated sensor systems in the track system and components will contribute to reaching the objectives.

Therefore, innovative solutions in the form of products, processes (e.g. planning and carrying out maintenance) and procedures (e.g. establishment of technical requirements) will be required. This approach will also be applied to the renewal of existing track assets and will establish how such new designs could be applied in this implementation context. The construction methodologies will also be defined and proven by a combination of simulations and structured (field/laboratory) tests.

The TD description is based on common problem areas and needs for higher performance and for development. As a result, the end user requirements are established. There is also a need for flexibility not to ignore future suggestions for innovative solutions that arise from within the consortium, or as a result of open calls etc. All solutions have to be developed and verified to interact with existing vehicles. To this end, the workplan is organised as a scheme to evaluate innovative solutions. Some of these innovative solutions are described in the following, whereas others will emerge after the project commences.

3.3.2. Technical objectives

The main technical objective of TD3.3 is to improve the operational performance of the existing track system, which includes the track designs. The solutions resulting from this TD will be evaluated based on LCC and RAMS performance. This will be achieved through the delivery of the following specific achievements from this TD.

TECHNICAL OBJECTIVES	IMPACT
Improved materials designs and processes	~ 10 % RP
Decreased rail deterioration through lubrication, grinding and rail grade optimisation	~ 5 % RP ~ 10 % LCC
Welding technologies developed to meet the future technical demands	~ 5 % RP
Enhanced rail support and improvement of transition zones	~5 % RP
Decreased consumption of limited natural resources and environmental footprint	EA
Ballasted track solutions that employ benefits of slab track	~ 5 % RP ~ 3 % CI
Development of wheel–rail interaction to reduce the degradation of the wheel–rail system	~ 5 % CI ~ 5 % LCC ~ 5 % RP
Enhance knowledge of track support and settlement conditions	—
Reduction of noise and vibration at the source	EA
Development of virtual and hybrid testing of track and track components	~ 5 % LCC ~ 5 % RP
Enhanced monitoring methods for track and track components	~ 5 % CI ~ 5 % LCC ~ 5 % RP
Improved performance of condition monitoring of track and track components	~ 5 % CI ~ 5 % LCC ~ 5 % RP
Better resistance to climate change	EA
Reduced time on track for on-site track works	~ 5 % CI
Accurate and timely knowledge to improve asset management	~ 5 % CI ~ 5 % LCC ~ 5 % RP

CI, capacity increase; EA, environmental aspects; LCC, reduction in LCC; RP, increase in reliability and punctuality.

3.3.3. Technical vision

The vision for the optimised track system demonstrator is to improve the track performance by better components of the track system. The benefits of each component combine at the track system level.

STATE OF THE ART	OPTIMISED TRACK SYSTEM
Although highly developed, current track structures are subjected to continuous increases in performance and demands on operational reliability	Optimised design and maintenance of track to allow improved performance, reduced LCC and enhanced RAMS of the entire track system
Rails suffer epidemic damage such as squats and other types of rolling contact fatigue, which cause high costs and operational disturbances	Significant extension of life by means of a deeper understanding of squats, rolling contact fatigue and wear. Predictive models to foresee potential complications including contrasting with measured operational data
Methods to evaluate track status and degradation rates exist, but are too limited to fulfil future demands	Improved monitoring concepts including accurate knowledge of what to monitor/measure, how to measure, and how to interpret gathered data and translate these into maintenance/re-investment plans. Enhanced knowledge measurement performance
The use of material derived from limited material resources is widespread, but becoming more and more unsustainable	Increased use of reused/recycled materials in the design and construction process. More environmentally friendly material choices sought
Maintenance procedures are becoming more and more unsustainable as time on track decreases whereas maintenance demands increase	Improved precision in which maintenance to carry out when. Enhanced maintenance methods and procedures
Noise and vibration emissions are decreasing, but will require even further reductions	Innovative solutions to mitigate emission, transmission and uptake of noise and vibrations. Increased knowledge of the phenomena, and noise and vibration issues combatted at the source
The track system deteriorates severely in specific track sections	Knowledge of influencing parameters for the local deficiency, collection and analysis of relevant data, and locally tuned solutions to mitigate the deficiencies
Asset management is handled through elaborate processes including significant hands-on manipulation and limited precision	Improved identification of relevant data, collection of these data, evaluation of health status and prediction of deterioration in an overall system
The wheel–rail interaction is not always efficient, which leads to more wear and higher costs for the infrastructure manager and the rolling stock operator	More knowledge needed, to deal with deficiencies in the interaction of wheels and rail. This should also be connected to stability as a comfort issue
Friction management is in use but the knowledge of the topic applied to railways is limited	Friction management to be further investigated in terms of the phenomena and how to deal with them in the field to improve operations from an LCC perspective. More environmentally friendly lubrications and their performance also to be investigated
The current tracks have been designed with a number of constrains by considering existing materials and technology and not from a whole-system perspective. As a result, the existing track solutions have not been optimised with regard to RAMS and LCC	New materials, technologies and other solutions to reduce cost during engineering, integration and commissioning phases. More reliable components, which are developed to fit the system. Maintainability and availability aspects to be considered in the whole development process. Safety to be a core aspect

Interaction with other TDs (in the same IP and/or in other IPs)

TD3.3 interacts in this IP (IP3) by exchanging information and data with TDs 3.1, 3.2, 3.4. 3.6, 3.7 and 3.8. Interaction has to be deepened with TD3.4 and also with TD3.1 and TD3.2 to verify responsibilities and limits. The technical aspects of the TDs also need to interact. Figure 26 shows the interactions between TD3.3 and other TDs in IP3, and interactions with other IPs.

TD3.3 should also interact with TDs in other IPs: TD1.4, Running Gear, in curve negotiation behaviour and running gear design; TD2.10, Smart Radio-Connected All-in-All Wayside Objects; and TD5.3, Smart Freight Wagon Concepts.

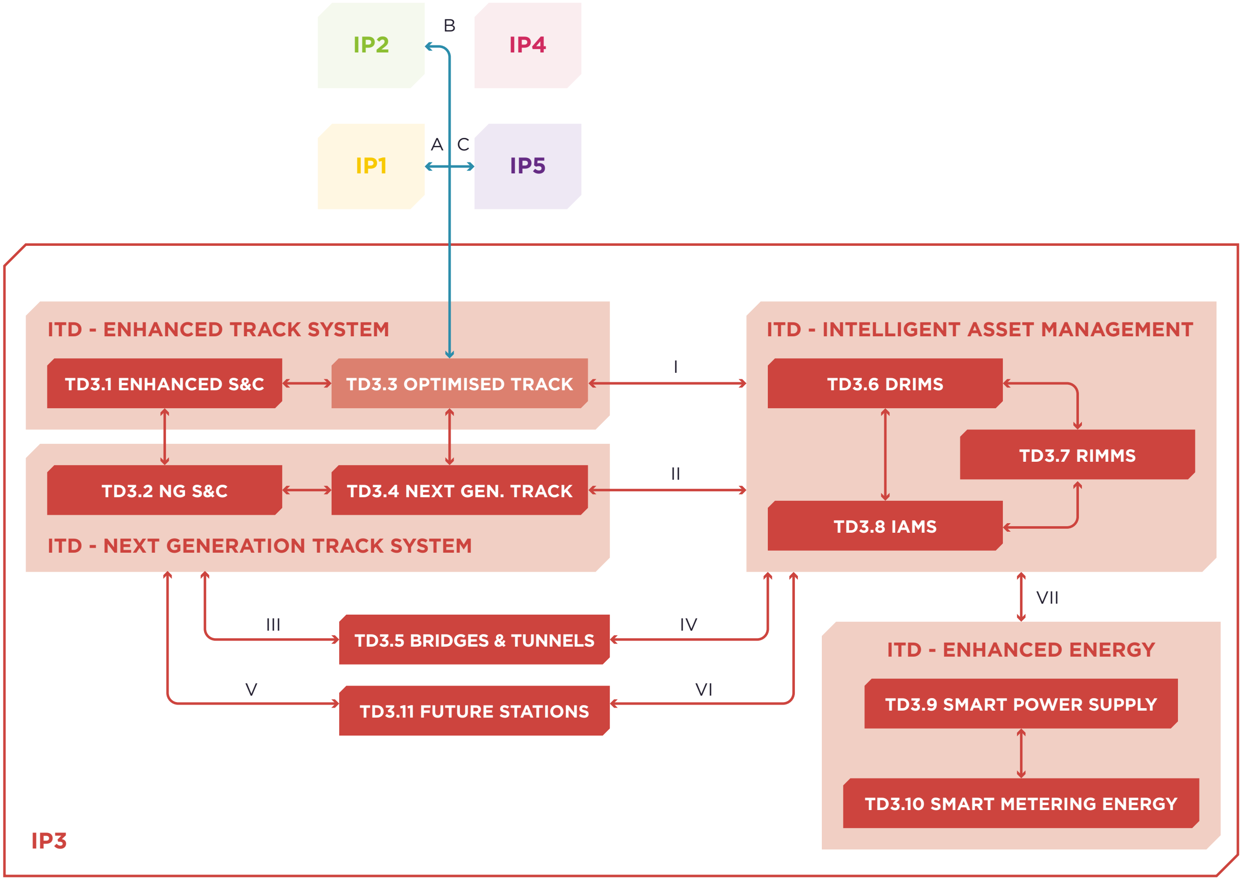


Figure 26 / ***Interaction with other TDs and IPs***

3.3.4. Impact and enabling innovation capabilities

The following technical impacts are envisaged from the implementation of TD3.3.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Increase in operational reliability through more robust systems with lower failure rates on components and subsystems. Higher punctuality for the railway in general
	Increased passenger comfort by better maintained track geometry. Higher satisfaction among passengers
	Improved wheel–rail interaction to enhance punctuality
	Lower LCC of assets, reducing cost of railway transport

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Compliance with EU objectives	Promotion of modal shift to more environmentally friendly transports: a major impact avoiding service disruptions and enhancing capacity brought about by the implementation of these improved and new technologies
	Support to capacity on track by using less capacity: by enhanced condition monitoring and improved reliability of components, the track can be utilised more
	Better utilisation of track and more environmentally friendly components to reduce emissions harmful to the environment
	Achieving a SERA due to a common understanding to make long-term decisions based on an ISO 55000 framework, monitoring the Europe-wide effect of new technologies, enabling further optimisation faster and for the whole of the European rail sector
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRL 2 (principles observed and the possibility of using them formulated). Some concepts will be designed. At the end of Shift2Rail it is expected that many successful concepts will be brought to TRL 6 or 7

This TD will contribute to enabling European rail industry innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.3 OPTIMISED TRACK SOLUTIONS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	/ Improve condition monitoring by investigating the deterioration processes of components and systems / Enhance understanding of system performance and impact of component/subsystem degradation / Find the right indicators for efficient condition monitoring / Ensure high Repair and Replace of the monitoring system Relevant building blocks: • BB3.3.2: Detailed understanding and qualification of track deterioration
7 – Low-cost railway	/ Increase the degree of modularisation, standardised interfaces and a harmonised assessment methodology for innovative solutions / Contribute to increased operational reliability, reduced costs for rail transport and enhanced capacity by improving track components and track system / Promote LCC philosophy for the track system Relevant building blocks: • BB3.3.1: Improved efficiency of product development, virtual testing and certification • BB3.3.2: Detailed understanding and qualification of track deterioration • BB3.3.3: Enhanced maintenance technologies and methods • BB3.3.4: Tailored materials and solutions for track components

INNOVATION CAPABILITY	TD3.3 OPTIMISED TRACK SOLUTIONS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
8 – Guaranteed asset health and availability	/ Improve solutions and develop new ones that require less maintenance, improve precision in identifying exact maintenance targets and improve installation methods / Improve the knowledge of material and component degradation / Develop materials and components to enhance the whole track system Relevant building blocks: • BB3.3.2: Detailed understanding and qualification of track deterioration • BB3.3.3: Enhanced maintenance technologies and methods • BB3.3.4: Tailored materials and solutions for track components
9 – Intelligent trains	/ Make condition monitoring of tracks and track components more reliable / Enable online connection/monitoring of track components to estimate remaining useful life / Promote digitalisation technologies on existing track Relevant building blocks: • BB3.3.2: Detailed understanding and qualification of track deterioration
10 – Stations and smart city mobility	/ Make condition monitoring of tracks and track components more reliable / Enable online connection/monitoring of track components to estimate remaining useful life Relevant building blocks: • BB3.3.1: Improved efficiency of product development, virtual testing and certification • BB3.3.2: Detailed understanding and qualification of track deterioration • BB3.3.3: Enhanced maintenance technologies and methods • BB3.3.4: Tailored materials and solutions for track components
11 – Environmental and social sustainability	/ Lessen environmental footprint of components by using more sustainable materials / Lessen noise and vibration pollution from railway traffic Relevant building blocks: • BB3.3.2: Detailed understanding and qualification of track deterioration • BB3.3.3: Enhanced maintenance technologies and methods • BB3.3.4: Tailored materials and solutions for track components

INNOVATION CAPABILITY	TD3.3 OPTIMISED TRACK SOLUTIONS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
12 – Rapid and reliable R&D delivery	/ Develop hybrid testing approach for faster and more precise component and system development / Simplify the certification process by using a hybrid test approach / Contribute to improving the interactions between companies and infrastructure managers in Europe / Attain global technological leadership through highly innovative solutions at a high technical level Relevant building blocks: • BB3.3.2: Detailed understanding and qualification of track deterioration • BB3.3.3: Enhanced maintenance technologies and methods • BB3.3.4: Tailored materials and solutions for track components

3.3.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Optimised Track System	Optimised track performance	Perform small-scale tests and detailed instructions of maintenance procedures	High-speed passenger rail, regional passenger rail	6	Ballastless track: define the maintenance of slab track system
		Give a demonstration in field with monitoring, data analysis	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6	Track system, new track concept
				6	Transition zone: improve the transition zone between ballasted track and slab track, bridge and open line, tunnel and open line, open line and S&C, etc.
		Build parts that verify the product and show the performance. Small-scale test in field		6	Novel geometry defect repair techniques to establish optimised asset management
	Friction management	Give a demonstration in field with monitoring, data analysis, etc.		6	Lubrication and top of rail friction modifier: develop the optimal system for lubrication of track
	Optimised track component performance	Give a demonstration in field with monitoring, data analysis, etc.		6	Rail performance/reliability management: improve rail in term of wear and crack tendency, including in combination with machining of rails
				6	Improved fastening system: develop more reliable fastening system
				6	Rail repairs: improve rail repairs and rail welding
				6	Ballast recycling: optimise ballast recycling, develop prototype of sorting machine based on advanced characterisation techniques
	Testing and certification process	Give a demonstration of the testing metrology, verify the results with laboratory and field tests		5–6	Hybrid testing metrology including laboratory and field testing to verify the model and adjust the physical model to be more reliable

Planning and budget

TDs	TASKS	TRL up to	2016 Q1	2016 Q2	2016 Q3	2016 Q4	2017 Q1	2017 Q2	2017 Q3	2017 Q4	2018 Q1	2018 Q2	2018 Q3	2018 Q4	2019 Q1	2019 Q2	2019 Q3	2019 Q4	2020 Q1	2020 Q2	2020 Q3	2020 Q4	2021 Q1	2021 Q2	2021 Q3	2021 Q4	2022 Q1	2022 Q2	2022 Q3	2022 Q4
TD3.3	**Optimised Track System**																													
	3.3.1 General specifications	3															◆													
	3.3.2 Demonstrator overview plan and design of optimised track	4																												
	3.3.3 Technology identification and development for optimised track	4												o																
	3.3.4 Design and definition of demonstrators for optimised track	5												o																
	3.3.5 Implementations of optimised track	6																								◆				
	3.3.6 Technical recommendations	6																								◆				
	3.3.7 Integration, demo and assessment	6																				o								
	3.3.8 Technical coordination	-																												

◆ milestone
o quick win
lighthouse projects
contracted activities
future activities

Table 53 / ***TD3.3 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2018	Verify performance of bituminous layer	Simulations and lab demonstration on smaller scale that build next step
Q4 2018	Repair methods for slab track	Lab demonstration on smaller scale, important to future development
Q4 2018	Material samples that represent rail formation	Lab demonstration on smaller scale, important to future development
Q3 2020	Novel lubrication system for on-board use	Demonstration in field environment, important to future development

Table 54 / ***TD3.3 milestones***

WHEN	WHAT
Q3 2019	Finished report Requirements for track design and maintenance defined in TD3.1. This will be considered in other tasks (TD3.3–TD3.6)
Q4 2021	Draft of technical recommendations ready for review
Q4 2021	First results from transition zone demonstrator

The estimated total budget for this TD is around EUR 18 million.

3.4. TD3.4 Next Generation Track System

3.4.1. Concept

TD3.4 Next Generation Track System will be using the same framework as TD3.3 Optimised Track System to identify and evaluate solutions. However, the solutions derived in this TD target a time horizon of around 40 years beyond the present state of the art. Therefore, harmonisation with today's railway system is less important, whereas step changes in performance are highly prioritised. Thus, all present perceptions regarding design, maintenance, operations, etc. are revisited with a much more open frame of mind. The overarching aim is to provide the key railway functionalities without being restricted to current practices for achieving this target. Solutions to be implemented in the demonstrators, in the form of products, processes and procedures, will thus have a very forward-looking character. All solutions will be developed and verified with a view to interaction with vehicles.

3.4.2. Technical objectives

The work in this TD aims to advance the track system substantially from the current state of the art and also from the short- to medium-term solutions developed within TD3.3. The solutions derived in this TD will be evaluated based on LCC and RAMS performance. However, these solutions are not confined to the current track structure of rails, fastenings, sleepers and track foundation. Instead, attention is given to providing the basic functional demands of the track system, including:

- a running surface that provides low running resistance, maintains gauge, provides steering and has very low deterioration;

- support for the running surface that keeps it fixed in vertical, lateral and rotational directions that also provides sufficient stiffness;
- a track foundation that provides sufficient and continuous stiffness in the lateral and vertical directions including smooth transition to bridges;
- monitoring practices that provide real-time access to relevant track data (including a specification of what 'relevant' means) at low cost;
- maintenance practices that introduce correct actions at the correct time with a minimum of intrusion in the track system (including a specification of what 'correct' means);
- eliminating noise and vibration pollution to the surrounding environment and to rail passengers.

Consideration will also be given to reducing maintenance requirements and improving logistics by providing standardised and modularised track components of limited complexity. The overall technical objective is to provide integrated (i.e. power, signalling, communications, monitoring, etc.) track designs for freight, regional or urban/suburban and high-speed railways. Among the technical requirements that need to be considered are speeds and loads, including their developments over the track's life cycle.

3.4.3. Technical vision

The development of demonstrators will begin from identified long-term demands on the track structure. These demands incorporate expectations on future operational loads, maintenance possibilities, LCC and RAMS levels, climate impact, etc. To derive long-term solutions, the main functions of the rail system will be reviewed. The main functions of an ideal track will be detailed (i.e. zero maintenance, zero climate impact, 100 % availability, zero accidents, low costs, etc.). The suggested solutions will provide goal fulfilment that significantly exceeds current and medium-term solutions (including solutions from parallel projects).

Running surface solutions

The target is to provide a running surface that provides optimal conditions for train operations. Examples of solutions that will be investigated include:

- identification and management of key functions and operational parameters of the running surface;
- optimised running surface damage prevention and mitigation;
- detailed measurement of the running surface condition;
- radically enhanced capabilities to adapt to climate change including short-term extreme weather and temperature variations;
- innovative manufacturing and assembly technologies including modification and tuning to account for significant altered technologies and material selections;
- optimised management of friction, running surface geometry and material selection with a zero maintenance aim;
- high-precision and very detailed geometry and stiffness measurements and the adoption of these in a zero maintenance/self-adjustment vision.

These solutions also demand radically increased knowledge of how different material and interface characteristics relate to rail damage, what operational consequences of altered conditions are, etc. There is also a very strong link to damage in switches and crossings (TD3.1 and TD3.2), which will be employed to obtain synergy effects.

Solutions to provide proper support for the running surface

The key function considered will be to keep the running surface fixed in the vertical, lateral and rotational directions while providing sufficient stiffness and damping. To derive drastically new solutions in this area, and especially solutions that are optimal for various conditions, will require a quantum leap in the understanding of how the technical characteristics of different solutions influence deterioration and life-cycle costs. Solutions to be considered may include:

- optimal use of existing and innovative materials to optimise rail support;
- reuse and recycling of materials in fastenings and pads – specifically, an analysis of the influence of these new materials in the reduction of noise and vibrations;
- new materials (reused and recycled) in the design of rail supports;
- new design for the reduction of loads and increased durability – this includes integration of elastomeric elements for vibration mitigation, decreasing variations in track stiffness especially in transition zones, and increase in lifetime of rail support and track foundation;
- improved design to account for different operational demands;
- fully integrated health-monitoring systems regarding the entire track structure;
- solutions to drastically improve track capacity and decrease maintenance demands;
- intelligent integration of attenuation components including active solutions;
- integration of ducts for communication, signalling, power supply, maintenance (e.g. optical fibre for track condition monitoring);
- new assembly–disassembly systems (plug and play, different connectors).

Track support solutions

Innovations in the design of supporting layers, substructure and superstructure will be required to develop an integrated design, construction and maintenance process for the track support structure. This process will need to account for the soil type available – proposing, for example, soil stabilisation treatments for each single situation and showing the optimised dimensions of the support layers in design charts – and support component integration. Potential solutions include the following.

- Harmonised classification of existing natural soil and improvements of existing natural soil characteristics (such as bearing capacity or permeability) by the addition of new or existing materials including construction and demolition waste.
- Engineering of supporting layers with improved soil by the addition of new/existing materials (bituminous, cementations). This includes cross-sections and transition zone engineering;
- Improved analysis of required bearing capacities and settlement limits required by new track design and soil characteristics.
- Engineering of support components and their integration into existing and new track. This includes optimised drainage systems that can adapt to altered climate conditions.
- Improved new materials and combinations.

- Optimised innovative maintenance processes for remaining maintenance processes.

- Eradication of zones with 'track memory', which is manifested in the fact that track geometry faults tend to occur rapidly after mitigation. For a successful mitigation strategy, there is a need to understand the underlying causes, monitor the relevant identified root causes and intervene with effective actions.

- Improved and more maintenance-free drainage system.

Noise and vibration mitigation and prevention solutions

The research and development will concern new high-performance noise and vibration isolation systems. This includes the development of innovative environmental components that, in optimal combinations, can develop different levels of attenuation, particularly ground vibration and airborne noise (cf. Recytrack – Life Programme; Rivas – FP7). Solutions to be considered in the reduction of noise include the following.

- Improved methods for combined assessments of noise and vibration including solutions to derive toolboxes for an evaluation of the combined effect/cost of a range of different solutions to reach a target limit. The influence of renewed noise/vibration assessments, as a result of changes in legislation, will be assessed.

- High-performance noise and vibration mitigation and prevention solutions. This will incorporate integration of solutions at the design stage, but also individual solutions such as acoustic barriers and new materials to increase efficiency and durability and allow easy installation and low maintenance.

- Development of innovative methods for reducing the generation and growth of roughness and corrugation.

- Specific efforts to model and mitigate curve squeal, especially for light rail.

Integrated maintenance procedures

Maintenance is focused on the track structure. The solutions will provide:

- optimised methods to provide suitable track geometry,

- optimised methods to provide suitable running surface geometry,

- optimised methods to provide suitable friction between running surfaces,

- innovative intelligent maintenance activities to mitigate the replacement of track components.

The solutions must provide minimum disruption in traffic, be very LCC efficient and in principle provide the option of resetting operational conditions to 'as installed'. This relates to improvements in evaluation of needs for maintenance, decisions on required maintenance actions, methods and efficiency of required maintenance actions, and coordination of maintenance actions. TD3.4 will interact strongly with TD3.6, TD3.7 and TD3.8. TD3.4 will define key operational parameters to measure and analyse, derive models to predict deterioration, establish technical limits for acceptable deterioration levels, evaluate technical feasibility of improved maintenance procedures, and analyse consequences of different maintenance scenarios. In contrast, the focus in TD3.6, TD3.7 and TD3.8 is on overall data management, prioritisation and planning of maintenance actions.

Optimised condition monitoring

Technologies for early, high-precision track deterioration will be required in the long-term rail structures. Furthermore, the monitoring actions should provide real-time input to high-precision predictions of subsequent deterioration and provide real-time categorisation of the current condition of the track. The derived condition-monitoring solutions will be fully integrated into an asset management system that includes deterioration prediction, planning of maintenance actions and investment decisions. The development will build on the medium-term solutions in that they should provide a significant leverage over these. The development starts from the identification of key track performance indicators without requirements to relate to current track solutions. Monitoring solutions target, for example, running surface friction, crack detection, insufficient support of the running surface and improper track stiffness.

Interaction with train fleet

An important question for the railways is a functioning train–track, i.e. wheel–rail, interaction. In this question TD3.3 and TD3.4 will interact closely with both IP1 and IP5. There are also two sides of the question:

- Clearly and well defined and physically transparent and justified demands on vehicle characteristics are natural. The next step takes input from TD3.3.

- The different damage phenomena are taken into account to clearly improve the robustness. The knowledge has clearly increased understanding of the deterioration phenomena.

LCC and RAMS performance

LCC and RAMS, alongside technical capabilities and environmental impact, will be the main evaluation criteria for the developed solutions. The reason is to ensure that there will be a market demand (and a business case) for them.

Environmental impact and sustainability

The overall target in this TD is to eradicate the environmental footprint and provide sustainable track solutions. The fulfilment of these objectives is included in the solutions' evaluation criteria and also addressed in the design of the demonstrators. There is also scope for self-contained solutions to address influences of climate change and assess the consequences for the track, and to assess reuse of waste generated by the railways.

Product identification and link to asset management

In the long-term, the solutions will have integrated product identification capabilities to provide plug-in solutions for asset management systems. To further facilitate asset management, the TD will also prioritise solutions that can accommodate a module-based construction and building process.

Safety

Safety is, and will continue to be, the top priority of railways. Developed solutions will be provided with integral safety characteristics. However, this needs to be achieved without losing passengers and freight volume to road. Such a scenario would be sub-optimal, since road transport is some 50–100 times less safe. Consequently, a major increase in overall safety will also be obtained by the major improvement in attractiveness that the developed solutions will give the rail system.

The following table summarises some examples of how this TD will advance the state of the art and overcome existing limitations and difficulties.

Table 55 / ***Next generation track***

STATE OF THE ART	NEXT GENERATION TRACK
Although highly developed, current track structures are subjected to continuous increases in loads and demands on operational reliability	Radically optimised design, and maintenance of track to allow a long-time increase in loading at lower LCC and with high RAMS of the entire system
Damage epidemics occur regularly and cause high costs and operational disturbances	Significantly enhanced knowledge on influencing parameters for rail. Predictive models to foresee potential complications integrated with analyses of measured operational data. Seamless translation to operational procedures
Methods to evaluate track status and degradation rates exist, but are too crude to fulfil future demands	Seamlessly integrated monitoring concepts including accurate knowledge of what to monitor/measure, how to measure, and how to interpret gathered data and translate these – in real time – to maintenance/re-investment plans
The use of virgin material is widespread, but becoming more and more unsustainable	Large-scale introduction of reused/recycled materials into the design and construction process
Maintenance procedures are becoming more and more unsustainable as time on track decreases whereas maintenance demands increases	Improved precision in which maintenance to carry out when. Enhanced maintenance methods
Noise and vibration emissions are decreasing, but will require even further reductions	Innovative solutions to substantially remove noise and vibration issues
The track system deteriorates severely in specific sections	Knowledge on influencing parameters for local deterioration, online collection, analysis and predictions using relevant data. Locally tuned solutions to mitigate the deficiencies
Asset management is handled through elaborate processes including significant hands-on manipulations and limited precision	High-precision identification and real-time collection of relevant data, evaluation of health status and real-time prediction of deterioration from an overall system perspective
Every year tens of thousands of Europeans are killed on roads, compared with the much safer railways	Provide a large-scale shift to rail transports for regional and long-distance transport through significantly decreased costs, improve reliability and performance through TD3.4 solutions

Interaction with other TDs (of the same IP and/or of the other IPs)

This TD will interact with:

- TD1.2, Train Control and Monitoring System
- TD1.4, Running Gear
- TD2.1, Adaptable Communication System for All Railways – quality of service, interfaces to signalling
- TD2.9, Traffic Management Evolution
- TD2.10, Smart Radio-Connected All-in-All Wayside Objects
- TD3.1, Enhanced Switch and Crossing System
- TD3.2, Next Generation Switches and Crossings

- TD3.3, Optimised Track System
- TD3.5, bridges and tunnels
- TD3.6, TD3.7 and TD3.8, intelligence asset management
- TD5.3, Smart Freight Wagon Concepts
- Work Area 2, KPI method development and integrated assessment
- Work Area 3, Safety, standardisation, smart maintenance, smart materials and virtual authorisation

There is close integration with TD3.1, TD3.2 and TD3.3 and transversal action on noise and vibration. Furthermore, work in TD3.4 on deterioration, maintenance needs, etc. relates strongly to TD3.6, TD3.7 and TD3.8. Transition zones are an area in common with TD3.5. There is a very strong link with IP1 and IP5, physically manifested in the wheel–rail interface. In addition, there are indirect links to IP2 (and IP4 via IP2) in that any asset condition monitoring derived from TD3.4 feeds decisions made within traffic management.

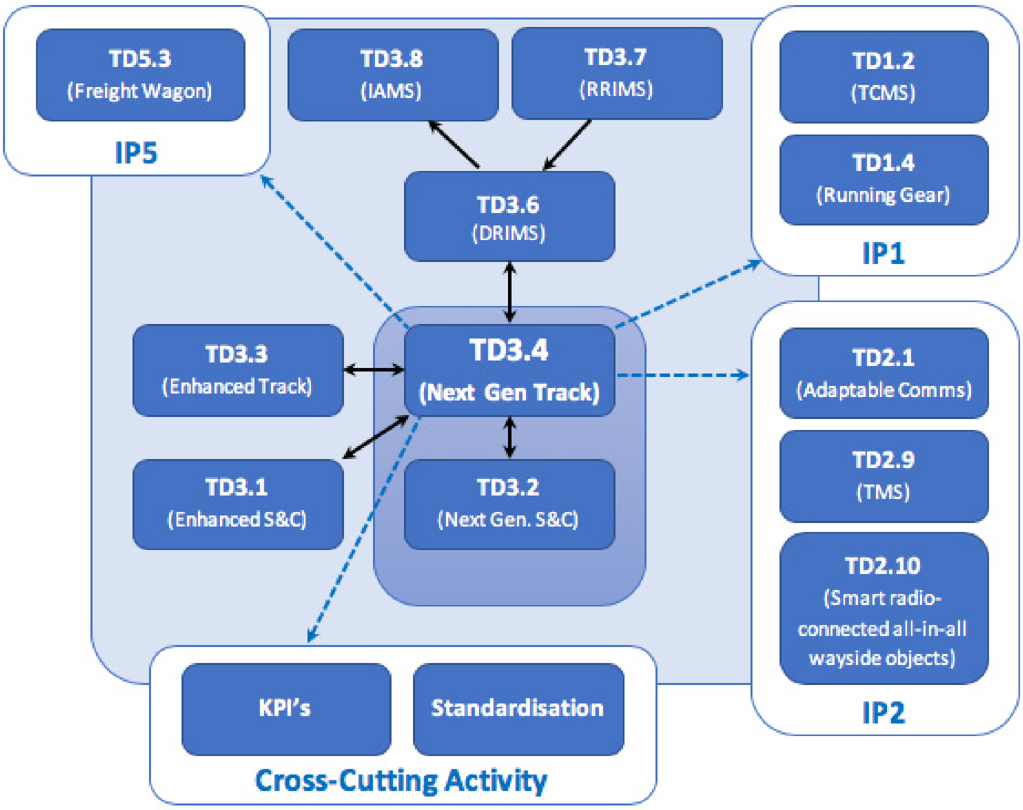


Figure 27 / ***Interaction with other TDs and IPs***

3.4.4. Impact and enabling innovation capabilities

The following technical impacts are envisaged from the implementation of TD3.2 and have been developed in the context of the three specific Shift2Rail global targets.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
100 % capacity increase	• Decreased track disturbances through less invasive construction, inspection and maintenance procedures • Reduction in failures/deterioration requiring service-affecting mitigation through more robust and reliable products, procedures and processes • Decreased noise and vibration impact that will allow more traffic in affected line sections
30 % reduction in LCC	• Extended operational life and decreased maintenance requirements through enhanced holistic track solutions • Harmonised assessment of solutions based to a larger degree on virtual testing that drastically reduces development costs and time to market • Extended use of recycled material that reduces investment and disposal costs • Decreased installation and replacement costs due to modular and installation-friendly solutions
50 % increase in reliability and punctuality	• Pre-validation of solutions to reduce tune-in problems and provide predictable levels of robustness • Reduction in unplanned maintenance through more robust track system solutions and increased use of predictive methods to plan optimal interventions • Reductions in operational disturbances of inspections and maintenance through less invasive inspection methods and a shift towards plug–and-play constructions • Optimised maintenance through intelligent monitoring and data analysis and prediction of deterioration rates

This TD will contribute to enabling European rail industry innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.4 NEXT GENERATION TRACK ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
1 – Automated train operation	Eliminating, or reducing to as low as reasonably practicable, existing failure modes that required maintenance intervention, to enable automated train operation by optimising whole-system RAMS performance. Reducing service-affecting failures by introducing a more resilient, reliable and smart infrastructure to unlock capacity and allow trains to run closer together. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data • BB3.4.2: Seamlessly integrated monitoring concepts
4 – More value from data	Whole-system remote condition monitoring for prognostic health monitoring to enable predictive maintenance and renewals. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data • BB3.4.2: Seamlessly integrated monitoring concepts
5 – Optimum energy use	Next generation design and materials to provide sustainable, whole-system solutions to minimise environmental impact and carbon footprint while ensuring sustainability. Relevant building blocks: • BB3.4.3: Large-scale introduction of optimised and sustainable materials
6 – Service operation timed to the second	Facilitating interoperability by very high-capacity and very reliable rail operations that enable close to seamless cross-modal transport. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data • BB3.4.2: Seamlessly integrated monitoring concepts

INNOVATION CAPABILITY	TD3.4 NEXT GENERATION TRACK ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
7 – Low-cost railway	Achieving a SERA through a very high degree of modularisation, standardised interfaces and a harmonised assessment methodology for innovative solutions. Increased attractiveness for end users through very high operational reliability; reduced costs for rail transports; and increased capacity. Simplified business processes through harmonised assessment methodology for innovative solutions. Increased societal safety by a modal shift from road to rail, which remains of an order of 50–100 times safer. Relevant building blocks: • BB3.4.2: Seamlessly integrated monitoring concepts • BB3.4_3 Large scale introduction of optimised and sustainable materials
8 – Guaranteed asset health and availability	Track forms with aligned component life cycles to promote a reduction in IMs' maintenance and renewal costs. Promotion of modal shift through highly reliable and efficient rail travel. Solutions towards zero maintenance and zero failure rates through tackling identified high-priority issues. Improved solutions that require less maintenance, improved precision in identifying exact maintenance targets and improved installation methods. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data • BB3.4.2: Seamlessly integrated monitoring concepts
9 – Intelligent trains	Infrastructure that communicates location and asset health data to trains to enable optimised predictive maintenance. Compatibility between next generation track systems and vehicle running gear to reduce wheel/rail interface related modes of degradation and failure. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data • BB3.4.2: Seamlessly integrated monitoring concepts • BB3.4.3: Large scale introduction of optimised and sustainable materials • BB3.4.4: High performance noise and vibration isolation systems
12 – Rapid and reliable R&D delivery	Employing a streamlined, well defined and highly virtualised validation processes that gives a smooth and efficient transition to implementation and world-wide marketing. Global technological leadership through highly innovative solutions and technical standards. Close interaction with end users in the development and validation of solutions, with a high degree of advanced virtual testing. Relevant building blocks: • BB3.4.1: Predictive models integrated with measured operational data

3.4.5. Demonstration activities and deployment

The objective is that the new technologies and innovations developed by Shift2Rail will be showcased (e.g. assembled, tested and validated) in real (physical) and/or simulated operational conditions by means of TDs, ITDs and SPDs.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Track System	Next generation track system	Next generation design and materials with optimised RAMS performance and LCC will be devised. Whole-system demonstrator may also form an ITD alongside TD3.2 for next generation S&C	Generic	5/6	Next generation design, materials and manufacturing will provide a step change in asset performance. A new track system designed from functional requirements as opposed to incremental improvements of existing systems. Bringing together of TD3.4 research and development work into a whole-system demonstration
	Rail for next generation track	Development will be carried out for the use of bainitic rail material in curves, to minimise head check defects, with optimisation of the rail production process for industrial quantities. This will be demonstrated and tested in an operational environment		6/7	As per specific activities
	Train-borne track stiffness monitoring	The rate of change of track stiffness and associated monitoring systems will be investigated, to deliver improvements in track geometry understanding and repair techniques.		4/5	As each component in the track system has its unique location and mechanical function, it has its unique vibrational modes/responses under train traffic. Such responses will change when the component degrades. This sub-task will develop the use of measurement of the dynamic responses of tracks to passing trains to understand and monitor the rate of change of track system stiffness, to provide a step change in whole-system asset management
	Rail defect monitoring	This task will develop a contactless ultrasonic method to identify rail-level defects using the electromagnetic acoustic transducer method		3/4	It will implement non-contact ultrasound methods and develop a laboratory prototype. Following the presentation of the results obtained with the bench, initiation of a study to carry out tests oriented on the problems of the faults that are difficult to detect with the system commonly used (piezo-ultrasonics)

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Track	Rail defect repair	An innovative solution for the discrete defect repair of rail using a low preheat process for the repair of defects will be developed		5/6	This sub-task will build on the initial work carried out to provide a demonstrator, with work to include thermocouple instrumentation trials and will enable development of the process for different rail steel grades
	Smart geo-grids and geo-textiles	Innovative geo-textile and smart fibre-based soil-, ballast- and concrete-reinforcing solutions will be developed, based on innovative fibrous materials		4/5	Smart geo-grids and geo-textiles for layer, soil and ballast composites will be developed. The mechanical properties (strength, stiffness and ductility) of these innovative materials can be optimised based on laboratory tests, including small-scale physical models. In addition, ground improvement using alkaline activation and a new environmentally friendly process to apply a geo-textile directly sprayed on the track, composed of cut fibreglass and binder, will be developed. A small-scale prototype will be provided and the performance evaluated in comparison with current products
	Asphalt track formation treatment	The use of asphalt as a formation treatment will be developed, as an alternative to more intrusive substructure remediation measures		4/5	An instrumented full-scale demonstrator will be provided, to enable validation of track deterioration and LCC modelling. The development of this activity will be supported by the work carried out in complementary activities, in which advanced numerical modelling of asphalt track solutions will be developed by Railenium

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Track	Innovative slab track solutions	Prototyping and testing will be carried out by manufacturing elements for a short track section, track laying and testing, and testing under real traffic conditions		6/7	Design optimisation of an innovative slab track concept through manufacturing and installation processes, monitoring and integration (S&C, transition zones, bridges, etc.). The development of these activities will be supported by the work carried out in complementary activities, namely in sub-task 4.3.4, in which advanced numerical modelling of slab tracks and transition zones will be developed by Railenium
	Cold spray additive manufacturing repair of rails	The concept of rail repair will be tested by cold spray additive manufacturing		3/4	A first step will be to repair a sample and obtain good geometry and mechanical properties before scaling up to a wheel–rail test rig and to a real rail if the first test is successful. Expected results are to detail the requirement specification for railway, find the suitable powder for the first tests, adapt powder and process parameters to realise cold spray coatings with good microstructure and properties, adapt the coating to the geometry of the rail and test the bonding of cold-sprayed coating
	Full-scale virtual demonstration of next generation track system	State-of-the-art whole-system modelling for next generation track system(s)		4/5	Advanced modelling of railway systems will be provided to support full-scale demonstrator planning and detailing of the design concept
	Track digital twin	Demonstration of track system digital twin providing an exact digital replica of an operational asset		5/6	Development of a track system digital twin will form part of the overall strategy for validation and demonstration of next generation track system concepts. The digital twin is a representation of a system that mimics its real-world behaviour and, in some cases, the surrounding environment. This may typically be a real-time updated collection of data, models, algorithms or analysis

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Next Generation Track	Automated inspection and repair	Prototype automated inspection and repair system using state-of-the-art technologies from within and external to the rail industry		4/5	This activity will seek to automate existing manual inspection and maintenance activities to improve the efficiency and quality of the activity undertaken

Planning and budget

TDs	TASKS	TRL up to
TD3.4	**Next Generation Track**	
	3.4.1 Demonstrator overview plan and design of next generation track system solutions	3
	3.4.2 Technology identification and development of next generation track system solutions	3
	3.4.3 Design and definition of demonstrators for next generation track system solutions	3-4
	3.4.4 Implementation of next generation track system demonstrators	6
	3.4.5 Technical recomendation and homologation	5-6
	3.4.6 Integration in system demonstration platforms	6

- ◆ milestone
- ○ quick win
- lighthouse projects
- contracted activities
- future activities

Table 56 / ***TD3.4 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Discrete defect rail process	Next generation rail defect repair processes
Q1 2020	Asphalt track formation treatment	Improved support conditions for next generation track solutions

Table 57 / ***TD3.2 milestones***

WHEN	WHAT
Q3 2018	Requirement setting and early designs for next generation track systems (up to TRL 3)
Q4 2018	Track technology identification and early conceptual design of feasible solutions (up to TRL3)
Q3 2019	Next generation track solution designs and experimental proof of concept in controlled environment (up to TRL 4)
Q3 2021	Integration of next generation track system solutions into whole-system demonstrations (up to TRL 4)
Q1 2022	Limited assessment of next generation track solutions (up to TRL 5)
Q1 2023	Demonstration of next generation track solutions within a relevant environment (up to TRL 6)

The estimated total budget for the Next Generation Track TD is EUR 13.5 million.

3.5. TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade

3.5.1. Concept

With increased traffic, deterioration may increase and the access time to bridges and tunnels for inspection and repair is reducing. However, performing fewer inspections or reducing the quality of the inspections can lead to wrong or inefficient structure management. This is due to delayed detection of damage, leading to more extensive time-consuming and costly repairs in the long run. This becomes critical and severely affects track availability because of extended track closures. With enhanced inspection methods and techniques, a reduction in inspection costs can be achieved while improving the quality of inspection and rationalising the costs for corrective maintenance actions.

Even if many of the existing structures are close to or past the end of their service life, it is not economically feasible to envisage their replacement on a large scale, since new standard bridges cost between EUR 0.5 million and EUR 2 million each. Similarly, the replacement of existing tunnels, quite apart from economic considerations, is not always a viable option owing to the lack of space, especially in densely populated areas. In view of this, the proactive and effective maintenance and upgrading of these structures to extend their service life is seen as a major priority to facilitate Europe's rail transport ambitions.

Today, and probably in the future, the ideal upgrading option is administrative upgrading, which means that tunnels and bridges are shown to be safe through calculations without any need for physical inspection. However, many of the existing structures were built to codes that did not take into account fatigue loading. The need for inspection and strengthening due to bigger traffic loads is increasing, while the ability to show the relevance of the calculations is becoming harder. As in other sectors, there is a need to use numerical simulation techniques that are closer to reality, coupled with physical inspection and maintenance data, with the aim of better managing uncertainties and reinforcing the administrative upgrading approaches and design of future structures.

The ability to rationalise and remove non-critical requirements from ageing codes and standards is a key requirement. This, coupled with improved inspection and maintenance techniques, reduces the implementation of non-standard and expensive solutions within the rail industry, leading to the optimisation of future structures' design and operation.

It is viable to reduce structural noise and vibrations due to today's traffic and also to meet future increased rail traffic.

3.5.2. Technical objectives

The main objective of TD3.5 is to improve the inspection methods and repair techniques for both reduction in costs and improvement in quality. With these methods and techniques, a proactive and more effective maintenance and upgrading of these structures to extend their service life is possible. Reduction in noise and vibrations related to these structures is also a prioritised objective. The objectives are specified by five categories and the key aims of TD3.5 are:

- develop new alternative inspection methods to allow faster and more accurate inspection of tunnels and bridges, including improved repeatability and reproducibility, allowing a 10 % extension of service life;
- develop new repairing, strengthening and upgrading methods that permit less traffic disturbance and fast installation with short track access time, and are stepwise in nature

to allow traffic movement between track operations, allowing another 10 % extension of service life;

- develop N&V-damping methods suitable for structures, reducing sound pressure by 50%;
- harmonise requirements in codes so uncertainties can be reduced and future new structures can be designed and constructed with 25 % reduced cost.

3.5.3. Technical vision

The following table summarises how TD3.5 will advance the state of the art and overcome today's limitations and difficulties.

STATE OF THE ART	ADVANCES BEYOND THE STATE OF THE ART
Inspections of tunnels are today very time-consuming and include long track closures. The inspections are quite subjective and will only find defects, i.e. measures can only be taken reactively to get rid of problems	Inspections will be faster, partly automatic and of enhanced quality. The inspections will be more objective and quantified, and detect deterioration before defects arise, and inspection results will be repeatable. With enhanced inspection, planning can be improved and actions can be planned well ahead at a lower cost with less traffic interruption
Inspections of bridges are subjective and costly, and include disturbance of traffic. Inspection results are of varying quality and will only find defects, i.e. measures can only be taken reactively to get rid of problems	Inspections will be partly automatic and of enhanced quality. The inspections will be more objective and quantified, and detect deterioration before defects arise. With enhanced inspection, planning can be improved and actions can be planned well ahead at a lower cost with less traffic interruption
Strengthening mostly covers improvement of ultimate limit state for semi-static loading and does not work completely in a number of cases	Strengthening methods can be used preventatively to reduce future problems. Strengthening methods will be enhanced to improving structural durability, structural ductility and bridge dynamic damping
Tunnel repairs are made in small degraded sections with a limited impact on the tunnel life span and do not typically allow a wider tunnel gauge	Concepts will be developed to improve old tunnels, including effectively used gauge, and meanwhile allow traffic to continue operating
Codes and standards are very prescriptive and reduce innovation and competition. Standards can also mean that the best solution based on a life-cycle analysis is not chosen	Codes will be more descriptive, allowing for innovation and for fair competition. Standards will promote the best solutions from a life-cycle analysis point of view

Interaction with other TDs (in the same IP and/or in other IPs)

Tunnel and bridge research needs interaction and research results from other TDs in IP3 to fully reach its potential. From TD3.3 and TD3.4, solutions for robust and functioning transition zones are needed in order to allow for increased payloads, and to reduce vibrations. From TD3.7 via TD3.6, data from on-board monitoring in usable format will be needed in order to monitor dynamic amplification of loads acting on bridges, to allow an extended service life of bridges regarding fatigue. The outcome of research on tunnels and bridges can be integrated into TD3.8 decision-making.

3.5.4. Impact and enabling innovation capabilities

With the suggested technology, it is estimated that expensive tunnel and bridge inspections can be reduced by 50 %, while improving safety and quality. This gives savings in the order of EUR 30 million every year. In addition, further savings are made by reducing the track closures caused by inspections. For tunnels, track closures for inspections are reduced by 50 %.

It is estimated that the remaining life of existing bridges will on average be extended by more than 10 years. Such an extension will make more effective use of existing structures and annually save in the order of EUR 1.0 billion to EUR 1.5 billion. With societal costs for traffic disruption on the same order as the construction cost, potential savings are doubled. Prolonged use of existing structures as suggested will also reduce line closure time for bridge replacement by an average of 10 %.

Based on today's traffic situation, noise and vibration intensity can be reduced by up to 50 % for selected and relevant frequencies.

New industrial methods and refined codes and standards are estimated to have the potential to reduce costs for bridge construction by 25 %.

A summary of the strategic impacts produced by the implementation of the TD results and discoveries is given below.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Refined philosophy for inspections allowing for further innovation
	Increased operational reliability (fewer service disruptions) through more robust systems based on proactive maintenance LCC reduction (through justified demands and longer use of structures)
	Increased passenger comfort from better maintained track geometry in transition zones Removal of limitations governed by poorly performing structures
Compliance with EU objectives	Promotion of modal shift: a big impact made by the implementation of these new technologies on avoiding service disruptions and adding new capabilities
	Support to capacity increase: by enhanced structural monitoring, structures can be utilised more efficiently
	Better utilisation of structures and longer use, significantly reducing emissions harmful to the environment
	Simplified business processes by setting functional well-justified demands and reducing detail in national standards
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRL 2 (principles observed and the possibility of using them formulated). Some concepts will be designed. At the end of Shift2Rail it is expected that many successful concepts will be brought to TRL 6 or 7

This TD will contribute to enabling seven innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.5 TUNNEL AND BRIDGE ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	Digitisation of tunnels and bridges includes models of individual assets and sensor data delivering real-time status indications on assets themselves and also on traffic passing them. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection
7 – Low-cost railway	Reduced tunnel and bridge life-cycle cost with ensured safety result from combining inspections. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection, and improvements • BB3.5.2: Enhanced tunnel repair to extend extended life at reduced costs • BB3.5.3: Prolonged bridge service life New bridges will be designed, constructed and subsequently maintained at significantly reduced costs. Relevant building blocks: • BB3.5.4: Bridge dynamics
8 – Guaranteed asset health and availability	The right decision at the right time is the backbone of maintenance defining the core of inspections. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection Tunnel repair will be developed towards moving relevant portions off site, allowing efficient improvements and availability. Relevant building blocks: • BB3.5.2: Enhanced tunnel repair Connected assets with continuously updated health information and reduced uncertainties will extend life and improve availability. Relevant building blocks: • BB3.5.3: Prolonged bridge service life
9 – Intelligent trains	Trains passing assets every day can provide useful information on assets, leading to reduced need for manual inspection, hence supporting the right preventative maintenance. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection
10 – Stations and smart city mobility	Modernised railways and stations typically require tunnels and bridges. Research on inspecting, improving and prolonging the life of tunnels and bridges indirectly contributes to stations. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection • BB3.5.2: Enhanced tunnel repair • BB3.5.3: Prolonged bridge service life • BB3.5.4: Bridge dynamics
11 – Environmental and social sustainability	A significant contribution to reducing the environmental impact will be ensured by postponing replacements. Relevant building blocks: • BB3.5.3: Prolonged bridge service life and designing and constructing more material-efficient structures • BB3.5.4: Bridge dynamics. Noise emitted from steel bridges, especially in urban environments, will be reduced. Relevant building blocks: • BB3.5.5: Reduction of noise and vibration

INNOVATION CAPABILITY	TD3.5 TUNNEL AND BRIDGE ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
12 – Rapid and reliable R&D delivery	The research in TD3.5 on tunnels and bridges is designed to reach implementation quickly, and the building blocks are all based on needs, transparency and reality. Relevant building blocks: • BB3.5.1: Enhanced bridge and tunnel inspection • BB3.5.2: Enhanced tunnel repair • BB3.5.3: Prolonged bridge service life • BB3.5.4: Bridge dynamics

3.5.5. Demonstration activities and deployment

Demonstrations are in line with technical objectives and will focus on inspections, improvements and motivated requirements. Assessment, which includes all kinds of inspections and structural health monitoring, will be demonstrated with enhanced quality requirements, while not disturbing traffic, and find deterioration early so measures can be taken in due time to eliminate long closures for maintenance. Together with TD3.3, improved transition zones between embankment and bridge will be demonstrated by making existing bridges less harmful to tracks and vehicles at the same time as making the traffic load less harmful to the bridge. Methods to reduce noise will be demonstrated. A more detailed code on dynamics will be developed and validated by demonstration activities.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Proactive Bridge and Tunnel Assessment, Repair and Upgrade	Tunnel health monitoring	Digitisation with high degree of objectivity and repeatability	High-speed passenger rail, regional passenger rail, urban/ suburban passenger rail, rail freight	5/7	On-board health-monitoring systems, tunnel drainage-monitoring system and tunnel integrity monitoring. Component testing of novel monitoring technology
	Tunnel improvement	Proactive maintenance and upgrading technologies		6/7	Improvement of tunnel drainage, replacement of damaged lining and tunnel gauge enlargement. Reducing track and tunnel closure through offsite manufacturing, and increasing quality through the factory environment
	Bridge health monitoring	Detection of early warnings and noise monitoring		7	Noise emission localisation and monitoring, optical monitoring methods for geometry and digitisation, and fatigue capability utilisation. Extending bridge service life and allowing more time for planning for construction work
	Bridge service capability improvement	Technologies to efficiently classify bridges, and real structural improvement		7	Noise reduction, extending bridge service life by lowering fatigue consumption, improved shear capacity of railway bridges, and classification capacity. Efficient monitoring of noise emission, and installation of passive noise dampers
	Bridge dynamics	Improved shear capacity of concrete bridges achieved with minimum of traffic disturbance installed	High-speed passenger rail, regional passenger rail	7	Damping and resonance under rapid cyclic loading, passive dampers to improve bridge damping, and proposal for improved design philosophy

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Proactive Bridge and Tunnel Assessment, Repair and Upgrade	up to	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	3.5.1 Tunnel inspection and condition data gathering	7													◆															
	3.5.2 Repair of tunnels	7																												
TD3.5	3.5.3 Implementation of tunnel technology	6														◆														
	3.5.4 Technology for bridge asessment	7													◆															
	3.5.5 Upgrade of bridges	7														◆														
	3.5.6 Implementation of bridge technology	5													○															

◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 58 / ***TD3.5 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
2018	Bridge exciter developed	Crucial equipment for research towards improving code on bridge dynamics

Table 59 / ***TD3.5 milestones***

WHEN	WHAT
2018	Enhanced tunnel laser scanning and optical bridge inspection methods developed
2019	Specific tunnels and bridges selected for planned demonstration activities

The estimated total budget for Proactive Bridge and Tunnel Assessment, Repair and Upgrade is around EUR 15 million.

3.6. TD3.6 Dynamic Railway Information Management System

3.6.1. Concept

The Dynamic Railway Information Management System (DRIMS) is aimed at defining an innovative approach to existing railway data management, processing and analysis to support the intelligent asset management system.

The huge number of individual information systems, each of them dealing with an isolated area of the maintenance process, shows the need for standardisation, in order to seamlessly and securely provide access to and manage heterogeneous data and information.

The increasing number of data provides the opportunity to apply data-mining and analytics tools to generate maintenance knowledge from data. The results will be used by the decision support tools.

To this end TD3.6 is offering:

- innovative open standard secure privacy–compliant interfaces to heterogeneous external systems;
- a smart analytics framework for automatic detection of anomalies,
- a smart analytics framework for discovering and describing the maintenance workflow processes,
- a smart analytics framework for railway assets decay prediction in support of prescriptive analytics for railway maintenance.

3.6.2. Technical objectives

The following represent the main technical objectives of this TD.

1. Increase asset status monitoring capabilities by 45 %: automatic anomaly detection algorithms will allow issues to be discovered faster.

2. Increase operational reliability (less service disruption) by 40 %: railway asset decay prediction will lead to more targeted maintenance interventions and fewer interventions due to sudden failures.

3. LCC reduction of 30 % based on condition-based maintenance of railway assets and continuous improvement of components/maintenance schedules.

3.6.3. Technical vision

TD3.6 aims to provide **open, standardised, seamless and secure access** to heterogeneous railway data and information, covering aspects such as transaction of intellectual property rights-protected business-to-business data, management of data with safety-critical impact, strict information assurance and related quality control procedures on data and quality gates, etc. DRIMS will also showcase how to generate **knowledge from data and/or information** – driven whenever necessary by the available domain knowledge – valid for life-cycle management and intelligent asset maintenance planning within the TD3.8 module, including:

- **automatic detection of anomalies** in the status of assets based on the analysis of measured data and their evolution over time in order to predict in advance (nowcast and forecast) potential failures or drifts and to define 'normal behaviour';
- **discovering and describing the maintenance workflow processes** (process mining) from workflow logs as they are actually being executed to infer actual workflow processes and, therefore, gather behavioural patterns, allowing the uncovering and measuring of the discrepancies between models derived from prescriptive approaches and actual process executions;
- **implementation of predictive models** of decaying infrastructure assets based on data/ information and relying on standard interfaces, potentially taking into account physical and statistical models, whenever available ([3]);
- **development of prescriptive analytics for maintenance** of railway assets based on the results of the analytical models;
- **contributing to the digitisation of the railway system** to manage maintenance activities.

DRIMS characteristics are extensive and complex, requiring a holistic approach and system-of-systems thinking in order to develop and provide generic solutions, which can easily be adapted to a specific context.

STATE OF THE ART	NEXT GENERATION DRIMS
A huge number of individual information systems are currently available in EU railways, each of them dealing with an individual and isolated areas of the maintenance process, thus not exploiting the potential of big data analysis	A seamless interface with the existing information and the required characteristics in the different EU railways contexts will be achieved

([3]) A lot of effort has been spent on finding physical-based models of degradation phenomena (e.g. sixth framework programme Innotrack project targeting track infrastructure), which can be exploited in synergy with data-driven models.

STATE OF THE ART	NEXT GENERATION DRIMS
Data mining and analytics algorithms require considerable manual inspections and manual adaptations by experts	Correlation analysis ensures credible detection of asset anomalies to evaluate current infrastructure performance reflecting the whole system and interactions
Asset behaviour and degradation models are not validated under naturalistic conditions, ignoring essential in-field operating parameters	Detailed understanding of asset behaviour provides a profound insight into root causes of asset failures. Design and damage models are adjusted to perfectly match the monitoring data
Isolated applications manage a limited volume of homogenous data	Heterogeneous data formats are incorporated. Railway and non-railway information will be incorporated
Applied maintenance is still periodic preventative maintenance based on good practices established a long time ago, simply integrated with targeted interventions when faults appear	Prescriptive analytics for maintenance are based on the results of the analytics framework

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and data and from that of information flow for usage in asset management systems, are:

- TD3.7, Railway Integrated Measuring and Monitoring System – using continuous monitoring information as an input for data analytic tools and platforms;
- TD3.8, Intelligent Asset Management Strategies – providing high-quality input to the IAM system;
- TD3.1, Enhanced Switch and Crossing System – processing S&C data;
- TD3.3, Optimised Track System – processing track data;
- TD3.5, Proactive Bridge and Tunnel Assessment, Repair and Upgrade – processing bridge and tunnel data
- TD3.10, Smart Metering for Railway Distributed Energy Resource Management System – manage high number of data from different sources and analyse them to provide support to the energy resource management system;
- TD2.9, Traffic Management Evolution – results on open standard interfaces, nowcasting and forecasting algorithms for TMS applications are the starting point for the development of new solutions for maintenance applications;
- TD5.2, Digital Transport Management – improved methods for timetable planning, real-time yard management and single-wagon load systems, real-time network management, intelligent video gate terminals;
- CCA Socio-economic & SPDs (WA1), KPI and reference parameter definition (WA2);
- CCA Supporting condition-based maintenance through analytics solutions (WA3).

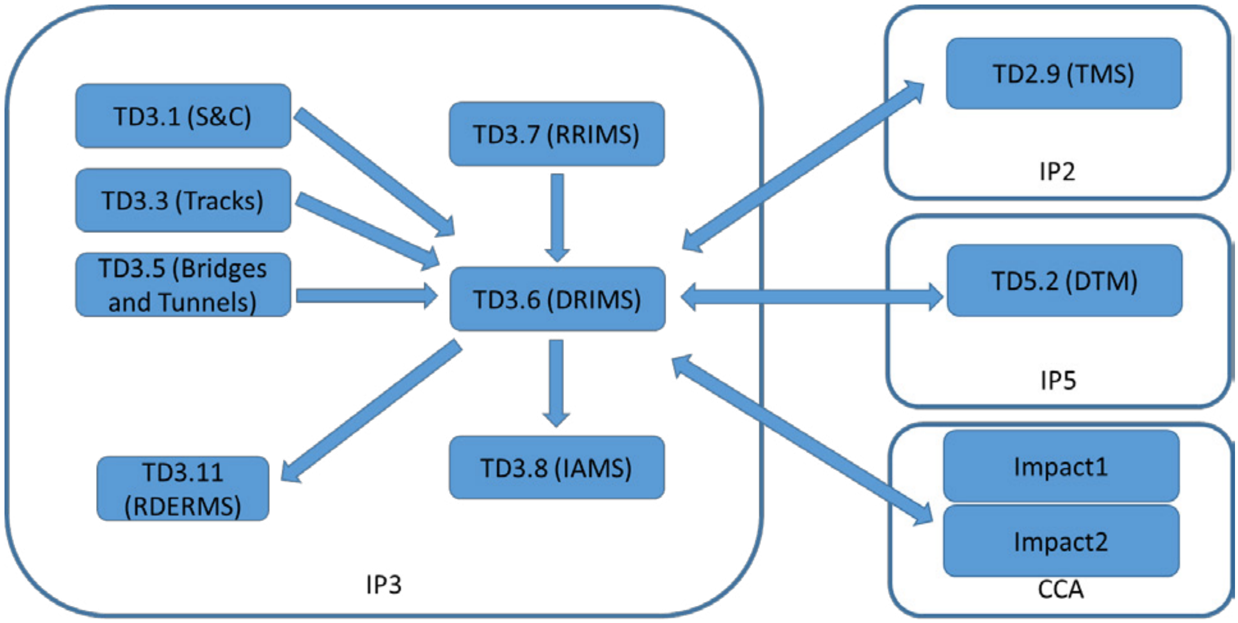


Figure 28 / ***Interaction with other TDs***

3.6.4. Impact and enabling innovation capabilities

DRIMS results have a major impact on the Shift2Rail system-level KPIs. The table below shows the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• **Support global technological leadership by a combination of innovation and technical standards, setting up an effective advantage for the European industry** TD3.6 DRIMS will contribute to the following TSIs and official or de facto standards: / the railML.org standardisation process to create a railway-specific universally applicable XML-based data exchange format / the ERA recommendation on specification of the register of infrastructure concerning the interfaces with asset registers (ERA/REC/04–2011/INT) / the ISO 55000 (Overview, principles and terminology), 55001 (Requirements) and 55002 (Guidelines for the application of ISO 55001) international standards for asset management / adoption of asset status information protocol compliant with ISO8000 (data quality) and ISO13374 (representation levels) The use of a set of standard open interfaces to access heterogeneous multi-owner maintenance-related data with the adequate degree of privacy, trustability, security and quality will help to improve the cooperation between the different stakeholders to achieve a win–win situation. TD3.6 DRIMS will contribute to introducing the internet of things and big data advanced analytics, which are considered among the IT-enabled business trends for the decade ahead. • **Increase operational reliability** (fewer service disruptions) through more robust systems based on less physical components, enhanced assessment and debugging concepts, and more flexible processing of information: predictive maintenance can noticeably reduce and better estimate the required occupation time and therefore greatly improve overall operational reliability • **Reduce cost:** predictive maintenance guarantees the optimisation of maintenance activities, guaranteeing a cost reduction both in terms of spare parts and in terms of effort • **Increase capacity:** besides increasing capacity, a modern and more cost-effective approach to maintenance can contribute to maintaining the target capacity of the network and, in certain specific cases, also to slightly increasing it
Compliance with EU objectives	• **Achieve a SERA:** a standardised approach to the maintenance information and activities such as the one developed within TD3.6 will reduce the technical obstacles to the proper interconnection of technical solutions • **Enhance interoperability:** the usage of an open standard interface to access data will guarantee that information can be accessed in a standard way; algorithms, based on a canonical data model, should be easily usable by different organisations to perform maintenance activities
Degree of maturity of the envisaged solutions	In other sectors, with more mature IT usage, such as banking, aerospace and finance, analytics approaches are at TRLs 7, 8 and, in some cases, 9, while in the rail sector they are currently at TRL2/3. Concerning the process mining, in all sectors approaches are currently at TRL2/3, except in the manufacturing sector, where there are results at TRL 5. At the end of Shift2Rail it is expected that the successful DRIMS concepts will be brought to a TRL from 5 to 7

This TD will contribute to enabling five innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.6 DRIMS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	Improved management of a high number of data available through an open standard interface. Usage of analytic tools to extract useful information from data. Relevant building blocks: • BB3.6.2: DRIMS data mining and analytics, from TRL 5 to TRL 7
7 – Low-cost railway	Automatic anomaly detection, discovery of workflow processes and prescriptive analysis providing the means for an intelligent and more efficient asset management system. Relevant building blocks: • BB3.6.1: DRIMS IT architecture, from TRL 5 to TRL 7 • BB3.6.2: DRIMS data mining and analytics, from TRL 5 to TRL 7
8 – Guaranteed asset health and availability	Results of the analytics framework leading to condition-based and predictive maintenance. Relevant building blocks: • BB3.6.2: DRIMS data mining and analytics, from TRL 5 to TRL 7
10 – Stations and smart city mobility	Management of high number of data and analysis to provide support to smart city mobility, with particular attention to human flow analysis. Relevant building blocks: • BB3.6.1: DRIMS IT architecture, from TRL 5 to TRL 7 • BB3.6.2: DRIMS data mining and analytics, from TRL 5 to TRL 7 • BB3.6.3: DRIMS open standard interfaces, from TRL 5 to TRL 7
12 – Rapid and reliable R&D delivery	Development of innovative algorithms and models, built in a standard way in order to be used by the different stakeholders, and contribution to a rapid development in the rail sector. Relevant building blocks: • BB3.6.1: DRIMS IT architecture, from TRL 5 to TRL 7 • BB3.6.2: DRIMS data mining and analytics, from TRL 5 to TRL 7

3.6.5. Demonstration activities and deployment

The following table summarises the contribution of TD 3.6 as part of the IAM ITD to the different SPDs of Shift2Rail.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
DRIMS	Strategic long-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long-term maintenance and operational decision needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6	Design and implement a data analytics platform using already developed algorithms for track degradation models. Design and implement a strategic decision support tool based on the tactical planning tool (simulation-based approach) to support the assessment of the IMs' asset management strategic KPIs. Develop a standard depot design, including the definition of basic requirements, sizing of elements and spaces, as well as a detailed design and technical specification of the building. The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance processes and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on long-term needs
	Tactical and operational short-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short-term and day-to-day maintenance and operational needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6/7	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance processes and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on short-term needs
	Metro/tram IAM ITD	Full demonstration of urban asset management including monitoring, data analysis and strategic planning, possibly including both long- and short-term maintenance and operational needs	Urban/suburban passenger rail	7	Define requirements for final demonstrator in close collaboration with IM. Install monitoring systems and fine-tune for obtaining good-quality measurements. Define and implement data platform and human-machine interface (HMI). Test final demonstrator. The final goal will be minimising maintenance costs, optimising the use of resources while maximising network availability and reliability

Three different demonstrators are planned for the IAM ITD, composed of building blocks from the following TDs:

- TD3.6, providing common interfaces and data modelling and analytics tools;
- TD3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD3.8, providing strategic and decision-making tools.

The first two demonstrators focus on a railway market, and the third one on a urban scenario. At least one installation site or area will be defined for each demonstrator, to allow hosting of newly developed technologies and building blocks.

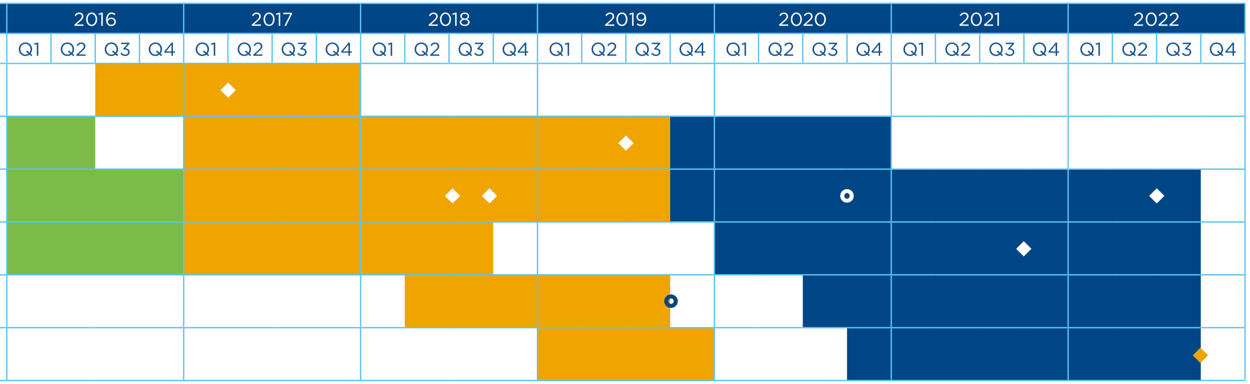
The first demonstrator refers to a long-term vision scenario, taking into consideration railway asset management for a period of 5 to 10 years. The demonstration will focus on the definition of a few strategic objectives, based on the usage of analytics tools and information mainly gathered from existing systems, and the initialisation of their development in practice.

The second demonstrator refers to a short-term vision scenario, taking into consideration railway asset management on an everyday basis for a period of up to 2 years. The demonstration will focus on the implementation of an intelligent asset management system, based on the usage of data analytics tools and information obtained from both existing monitoring systems and newly developed ones.

The third demonstrator will take into consideration aspects of both previous ones, with the difference that it focuses on an urban scenario, such as a metro or tram line. Indeed, urban scenarios present different characteristics and challenges from the mainline railway, such as the IM's ownership of the rolling stock and responsibility for maintaining it; higher requirements on service availability, punctuality and capacity (people per train per hour); and different environmental requirements (e.g. noise emissions).

Planning and budget

TDs	TASKS	TRL
	Dynamic Railway Information Management System	up to
TD3.6	3.6.1 DRIMS Specifications	-
	3.6.2 IT Architecture	6/7
	3.6.3 Data Mining and Analytics	6/7
	3.6.4 Open standard interfaces	6/7
	3.6.5 In-lab integration and testing	6/7
	3.6.6 Field prototype integration and testing	6/7



- milestone
- quick win
- lighthouse projects
- contracted activities
- future activities

Table 60 / ***TD3.6 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2019	Analytic solution test in lab	In-lab demonstration of an analytic solution to pave the way for In2Smart follow-up ITDs
Q3 2020	Analytic solution test on real data	Preliminary demonstration of analytic results based on real data

Table 61 / ***TD3.6 milestones***

WHEN	WHAT
Q1 2017	Asset management platform's first definition in In2Smart WP2, with an impact on In2Smart WP7–8
Q2 2018	Canonical data model and communication protocol definition in In2Smart WP7
Q3 2018	Test on canonical data model and communication protocols
Q2 2019	High-level architecture in In2Smart WP8
Q3 2021	Realisation of an architecture for data exchange, and final test of canonical data model and communication protocols for ITDs
Q2 2022	Analytics uncertainty evaluation solution coming from In2Dreams open call will be integrated into In2Smart WP8
Q3 2022	System validation on site for the architecture, canonical data model and analytics solutions for each ITDs

The estimated budget for the TD is around EUR 13 million.

3.7. TD3.7 Railway Integrated Measuring and Monitoring System

3.7.1. Concept

The Railway Integrated Measuring and Monitoring System (RIMMS) is aimed at defining an **integrated** set of **cutting-edge on-board** and **wayside** asset-specific **measuring** and **monitoring** subsystems in order to collect and deliver the status data of the railway system (infrastructure and rolling stock).

The need of improvement in technology and automation is clear from the several infrastructure inspection activities on an aged infrastructure, which are done manually by maintenance staff. These inspections take time and money, and generate a lot of risks for the personnel involved.

The following approach will be adapted: measuring relevant data using the most innovative techniques; processing data in order to generate relevant information related to maintenance infrastructure; and generating data/information to feed – using a standardised representation layer – both the TD3.6 and TD3.8 models/algorithms to support maintenance and asset management processes.

3.7.2. Technical objectives

The following represent the main technical objectives of this TD:

1. Increase operational reliability (30–40 % less service disruptions) and safety (10 % less incidents) through continuous and integrated monitoring of railway assets and rolling stocks impact.

2. Up to 30 % LCC reduction based on condition based maintenance of railway assets and continuous improvement of components/maintenance schedules.

3. Provide safer and faster ways of monitoring the infrastructure assets based on innovative technologies such as UAVs and satellites.

4. Provide straightforward, automatic and continuous monitoring of railway infrastructure through the equipment of many in-service trains with low cost monitoring and processing components.

5. Consider rolling stock impact on the railway infrastructure as a fundamental component in its overall monitoring.

3.7.3. Technical vision

The final target is to build an integrated set of **cutting-edge**, **on-board** and **wayside** asset-specific measuring and monitoring subsystems in strict coordination with the developments in TD3.6 (for what concerns the standardised representation layers) and TD3.8 (for what concerns the optimisation of maintenance processes). The development of measuring and monitoring tools for obtaining information about the state of the whole railway system will take into consideration:

- identification, within the most critical railway subsystems, of parameters and items that represent the greatest potential to improve asset utilisation;

- identification of the minimum set of parameters to be measured in order to obtain the necessary information to characterise the railway subsystems' and assets' statuses;

- filling the current technological gaps by applying cutting-edge technological instruments giving the most complete and precise information on the most critical infrastructure parameters;

- provision and integration of the data/information in an intelligent asset maintenance system, giving the possibility of using them in novel ways;

- continuous, cost-effective, safe and automatic monitoring will be provided by low-cost, commercial off-the-shelf components installed at the wayside, on in-service trains or on board satellites/drones.

STATE OF THE ART	NEXT GENERATION RIMMS
Inspection activities mainly performed manually by maintenance staff, requiring line possession and leading to personnel safety risks	Inspection activities carried on automatically by monitoring systems, eliminating or reducing line possession times and avoiding personnel safety risks
Non-integrated, expensive monitoring systems installed at a few points along the line or on a few equipped trains, providing information to different maintenance operators	Fully integrated, low-cost and highly distributed monitoring systems along the line or on many in-service trains providing overall line information to an asset management centre
Maintenance activities scheduled on the basis of single components' supplier-declared MTBF values and best practices, not taking into account line utilisation and operational impact	Condition-based maintenance for all railway assets, taking into account line utilisation and operational (rolling stock) impact
Signalling systems embedded monitoring not allowing agile modifications or upgrades because integrated in the safety case. Monitoring data provided via proprietary solutions	Signalling systems monitoring provided as an independent proxy module, allowing agile modifications/upgrades without violating the safety case. Monitoring data provided via a standard interface

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged with other TDs and/or IPs, both from the point of view of technologies employed and from that of data and information flow for usage in asset management systems, are:

- TD3.6, DRIMS – providing continuous monitoring information to data analytic tools and platforms via a common interface and canonical data model;
- TD3.8, IAMS – providing the low-level information necessary for an intelligent asset management approach;
- TD3.1, Enhanced Switch and Crossing System – sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the S&C monitoring needs;
- TD3.3, Optimised Track System – sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the track-monitoring needs;
- TD3.5, Proactive Bridge and Tunnel Assessment, Repair and Upgrade – sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the bridge- and tunnel-monitoring needs;
- TD5.1, Fleet Digitisation and Automation – sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the monitoring of rolling stock's impact on the railway infrastructure;
- WA3, smart maintenance – providing a comprehensive list of the infrastructure assets and parameters to be monitored for an overall railway condition-based maintenance system.

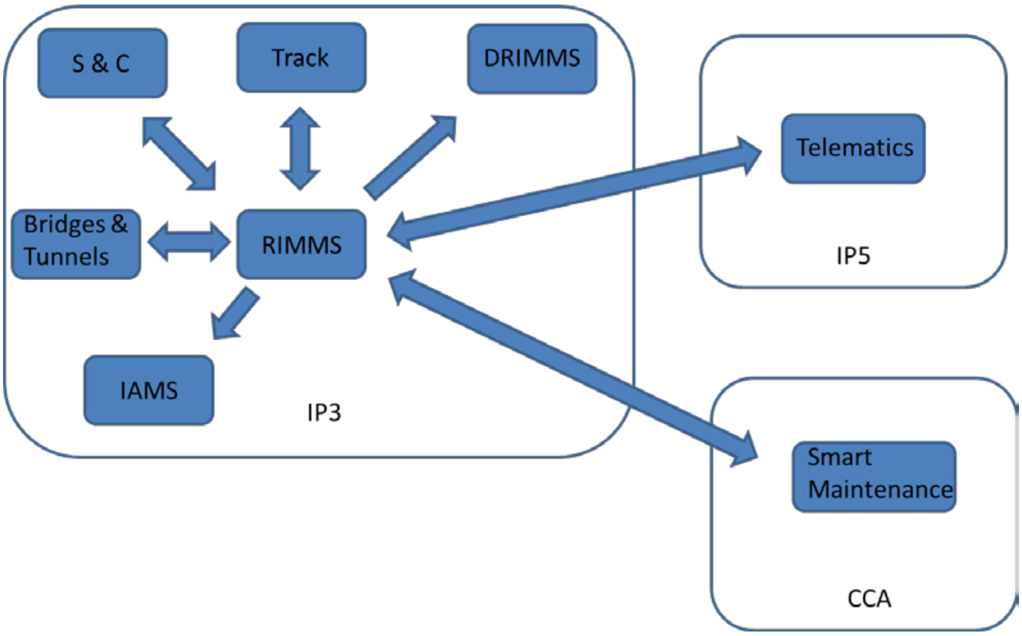


*Figure 29 / **Interaction with other TDs and IPs***

3.7.4. Impact and enabling innovation capabilities

The RIMMS-specific objectives have a major impact on the Shift2Rail system-level KPIs. The table below provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• **Global technological leadership supported by a combination of innovation and technical standards, setting up an effective advantage for the European industry:** / TD3.7 is highly focused on innovative technologies, which must be breakthrough, more robust and easy to use and integrate / The measuring and monitoring tools must be integrated in the IAMS, so they must send data through standard open interfaces (defined in TD3.6) • **Increase in operational reliability** (fewer service disruptions) through continuous and precise condition monitoring of key components leading to condition-based monitoring and more generally an effective asset management approach • **Reduce cost:** predictive maintenance through a condition-based approach
Compliance with EU objectives	• **Achieve a SERA:** a standardised approach to the maintenance information and activities, like the one developed within the IAMS, will reduce the technical obstacles for proper interconnection of technical solutions developed within TD3.7 • **Promotion of modal shift:** the impact of implementing these new technologies can enhance the attractiveness of the railway system by its being more reliable, more cost-effective and safer • **Simplified business processes:** a standard approach to the measuring and monitoring of railways' assets can simplify maintenance procedures
Degree of maturity of the envisaged solutions	The solutions developed within TD3.7 will have two main degrees of maturity: • TRL 4/5 if the technology used is very innovative in the rail context • TRL 6/7 if the solution is an improvement of existing tools

This TD will contribute to enabling six innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.7 RIMMS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
1 – Automated train operation	Support efficient and safe ATO through continuous monitoring of rolling stock assets and their impact on the infrastructure. Relevant building blocks: • BB3.7.4: RIMMS operations, TRL 6/7
4 – More value from data	High number of data available to support intelligent asset maintenance activities, as well as real-time TMS and logistics scheduling and planning. Relevant building blocks: • BB3.7.1: RIMMS tracks, TRL 6/7 • BB3.7.2: RIMMS switches and crossings, TRL 6/7 • BB3.7.3: RIMMS signalling, TRL 5/6 • BB3.7.4: RIMMS operations, TRL6/7
7 – Low-cost railway	Continuous monitoring of key infrastructure assets provides the means for an intelligent and more efficient asset management system. Relevant building blocks: • BB3.7.1: RIMMS tracks, TRL 6/7 • BB3.7.2: RIMMS switches and crossings, TRL 6/7 • BB3.7.3: RIMMS signalling, TRL 5/6 • BB3.7.4: RIMMS operations, TRL 6/7
8 – Guaranteed asset health and availability	Condition-based and predictive maintenance is enabled through continuous monitoring of relevant assets. Relevant building blocks: • BB3.7.1: RIMMS tracks, TRL 6/7 • BB3.7.2: RIMMS switches and crossings, TRL 6/7 • BB3.7.3: RIMMS signalling, TRL 5/6
10 – Stations and smart city mobility	Support the definition and evolution of smart cities where information on railways' current and predicted asset statuses is always available to people and services. Relevant building blocks: • BB3.7.1: RIMMS tracks, TRL 6/7 • BB3.7.2: RIMMS switches and crossings, TRL 6/7 • BB3.7.3: RIMMS signalling, TRL 5/6 • BB3.7.4: RIMMS operations, TRL 6/7
12 – Rapid and reliable R&D delivery	Monitoring data collected from railway assets could be used for continuous product development and future state prediction, using methodologies such as digital twins. Relevant building blocks: • BB3.7.1: RIMMS tracks, TRL 6/7 • BB3.7.2: RIMMS switches and crossings, TRL 6/7

3.7.5. Demonstration activities and deployment

The following table summarises the contribution of TD3.7 RIMMS as part of the IAM ITD to the different SPDs of Shift2Rail.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Railway Integrated Measuring and Monitoring Systems	Strategic long-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long-term maintenance and operational decision needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on long-term needs
	Tactical and operational short-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short-term and day-to-day maintenance and operational needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6/7	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on short-term needs
	Metro/tram IAM ITD	Full demonstration of urban asset management including monitoring, data analysis and strategic planning, possibly including both long- and short-term maintenance and operational needs	Urban/suburban passenger rail	7	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on urban network asset management

Three different demonstrators are planned for the IAM ITD, composed of building blocks from the following TDs:

- TD3.6, providing common interfaces and data modelling and analytics tools;
- TD3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD3.8, providing strategic and decision-making tools.

The first two demonstrators focus on a railway market, and the third one on an urban scenario. At least one installation site or area will be defined for each demonstrator, to allow hosting of newly developed technologies and building blocks.

The first demonstrator refers to a long-term vision scenario, taking into consideration railway asset management for a period of 5 to 10 years. The demonstration will focus on the definition of a few strategic objectives, based on the usage of analytics tools and information mainly gathered from existing systems, and the initialisation of their development in practice.

The second demonstrator refers to a short-term vision scenario, taking into consideration railway asset management on an everyday basis for a period of up to 2 years. The demonstration will focus on the implementation of an intelligent asset management system, based on the usage of data analytics tools and information obtained from both existing monitoring systems and newly developed ones.

The third demonstrator will take into consideration aspects of both previous ones, with the difference that it focuses on an urban scenario, such as a metro or tram line. Indeed, urban scenarios present different characteristics and challenges from the mainline railway, such as the IM's ownership of the rolling stock and responsibility for maintaining it; higher requirements on service availability, punctuality and capacity (people per train per hour); and different environmental requirements (e.g. noise emissions).

Planning and budget

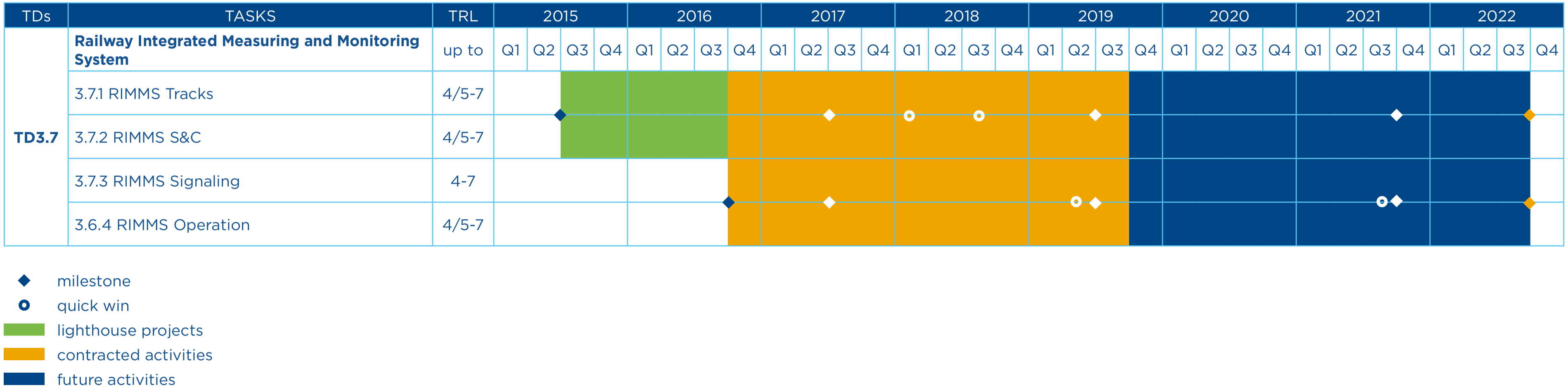


Table 62 / ***TD3.7 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q1 2018	Rail stress monitoring components' testing in the field	Allows selection of technology in a train operation scenario, opening the door to final architecture definition
Q3 2018	Track and S&C geometry monitoring through an equipped running train	Allows the testing of technology and elaboration algorithms in the field, in order to understand current limitations/problems
Q2 2019	Signalling and operations prototypes tested in laboratory	Defines the general approach and validates use cases in a laboratory scenario
Q3 2021	On-site data collection and limited validation of signalling and operations demonstrators	Brings TRL to a higher level, including installation of equipment in the field and reception of requirements from a real scenario. First step to obtain final field demonstrators

Table 63 / ***TD3.7 milestones***

WHEN	WHAT
Q2 2015	Start of the requirements definition and system specification activities for track and S&C monitoring
Q4 2016	Start of the requirements definition and system specification activities for signalling and operations monitoring
Q3 2017	Start of the prototype development activities for all demonstrators
Q2 2019	End of TRL4 prototype validation for all demonstrators
Q3 2021	End of installation and first results from field prototypes of all demonstrators
Q3 2022	Field demonstrators' final validation and inclusion in IAMS

The estimated total budget for the Railway Integrated Measuring and Monitoring System TD is around EUR 17.5 million.

3.8. TD3.8 Intelligent Asset Management Strategies

3.8.1. Concept

IAMS focus on the definition of concepts for maintenance planning and decision support; implementation of risk- and condition-based maintenance strategies; and decision support tools and system architectures for maintenance management, resource planning and deployment (including skilled staff, plant and possessions) and for LCC-based maintenance or system improvement, including state, age of asset and root causes of maintenance, supported by DRIMS.

A second stream of technical objectives is related to new and advanced working methods, tools and equipment, and logistics solutions, supporting the lean execution of intelligent maintenance processes. We intend to move mechanisation a step further with the development of multipurpose robots. The equipment is focused on the actual execution of maintenance activities. In this context, the safety precautions needed to carry out maintenance are also part of the work. The use of remote control technology will increase efficiency and safety.

IAMS will showcase substantial improvements of availability and reliability of railway infrastructure at the defined system platforms through:

- usage of decision support systems to adapt more effectively the most appropriate maintenance strategies (predictive, risk-based and condition-based),
- new and advanced working methods, tools and equipment, maintenance plant and logistical solutions.

In other words: make new maintenance approaches happen in a practical way. The IAMS TD creates a bridge from theoretical processes about asset behaviour and degradation, asset management theories and individual maintenance strategies for specific subsystems to the actual work outside in the operational process. The operational process is defined as the day-to-day maintenance and small- and medium-scale renewal work and how it is organised. Long-term strategies are often hampered by the day-to-day process with its own dynamics and therefore the intention of the bigger picture is sometimes not followed through. By putting long-term strategies in the context of the actual execution of the maintenance work in combination with other maintenance activities, instead of focusing on individual, simple (sub)systems, IAMS will look at it as a system of systems.

Decision support tools and systems for maintenance planning as a result of the developments in TD3.8 will provide a long-term benefit to the IMs in fulfilling their tasks/activities, in particular for capacity calculation, allocation and enhancement of the infrastructure. Decision-making processes will become more transparent and controllable, and their results will be directly accessible by railway service providers and customers.

Use of AI algorithms, blockchain for smart contracts and high-performance computing are among the technologies used to reach the TD objectives.

3.8.2. Technical objectives

The following represent the main technical objectives of this TD.

1. A shift towards a tailor-made maintenance approach by using the necessary tools for information management and decision support. Fifteen per cent of the assets can benefit from the new approach and are suitable for a tailor-made maintenance approach.
2. A scalable framework for asset management systems, containing the static and dynamic data from all relevant components of the rail infrastructure, enabling improved life-cycle management, efficient maintenance strategies and adequate operation planning, which includes logistical preparation, and deployment of staff, tools, equipment and plant, and possessions.
3. A holistic, whole-system approach in combination with the new methodologies and data-driven concepts provided by TD3.6 and TD3.7.
4. Using lean thinking to design new working methods and tools, making significant steps forward in reducing maintenance time and cost. Time saved should be 20 % or more.

3.8.3. Technical vision

The vision behind IAMS is to come to a **holistic** systems approach in combination with the **new methodologies**. In other words: make new maintenance approaches happen in a practical way. Intelligent system maintenance engineering and strategies form a bridge from the theoretical processes, asset management theories and individual maintenance strategies related to one specific subsystem, and based on its own behaviour and deterioration, to the actual work outside in the operational process, defined as day-to-day maintenance and small- and medium-scale renewal work and how it is organised. Long-term strategies are often hampered by the day-to-day process with its own dynamics and therefore the intention of the bigger picture is not followed through.

Making long-term strategies will be put in context the actual execution of the maintenance work in combination with other maintenance activities.

Instead of focusing on individual, simple systems (objects), IAMS will look at it as a system of systems.

Therefore IAMS focuses on the implementation of:

- support for risk-based or condition-based maintenance strategies;
- decision support for:
  - maintenance management, resource planning and deployment (including skilled staff, plant and possessions),
  - LCC-based maintenance or system improvement, including state and age of asset and root causes of maintenance, supported by DRIMS;
- new and advanced working methods, tools and equipment and logistic solutions.

The equipment mentioned in the last bullet point should be based on a **modular, reconfigurable, robotic platform** using sensing and perception to make its own decisions based on specific situations. The scope of the robot platform can be heavy equipment (on-track machines), covering both high-output equipment and express plant. The logistic solutions include possession management and worksite management systems.

STATE OF THE ART	ADVANCES BEYOND THE STATE OF THE ART
Individual discrete maintenance management systems	Integrated maintenance management system
Reactive maintenance	Predictive maintenance, and maintenance and decision support based on prescriptive analytics
‘Traditional’ maintenance failing to take full advantage of enhanced components built into the network	Advantages of new components identified and reflected in lower maintenance efforts
Infrastructure operators having isolated asset status information systems with customised decision support tools	Maintenance decision support tools with standardised interfaces enabling seamless integration of legacy asset status information systems, hence leading to increased interoperability
Maintenance decisions based mostly on static and pure geometric track quantities	Reliable maintenance decisions based on asset assessment drawing from vehicle–track–environment interaction
‘Preventative’ maintenance procedures not fully reflecting technology advances and interactions between components involved (e.g. corrugation treatment based only on surface condition)	Predictive maintenance building on total system view of infrastructure and leveraging on condition-based maintenance and life-cycle cost assessment
Lack of real failure data to carry out reliability analysis (RAMS)	Databases of failure and historical maintenance actions, which are the seed for RAMS analysis tools

STATE OF THE ART	ADVANCES BEYOND THE STATE OF THE ART
Immature predictive concepts using asset-specific degradation models that neglect uncertainties	Data-driven approach. Probabilistic information on condition and risk assessment as a basis for decision-making
Specific-purpose tools with limited applicability	Generic decision support tool derived from a general-purpose framework, thus easily adaptable
Lack of interaction with TMS	Integration into existing systems for logistics and traffic information
Use of heuristics based on experience for decision support	Use of mathematical optimisation in intelligent planning tools
Possession takes a lot of time to secure before work, and much hands-on tool time	Advanced work methods. Equipment to automatically secured workspaces within seconds, fast working methods, intelligent machinery on in-service trains
High-output machines needing operators and lots of small equipment that is heavy to use, leading to physical problems for staff using/operating the machines	Work methods, express maintenance machines (short time to get on and off the track, high production capacity and small profile – single track possessions), but also (automated) tools to use during rail operation utilising free time/space for short maintenance activities (plug and play, hit and run)

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and from that of data and information flow for usage in asset management systems, are:

- TD3.6, DRIMS – providing continuous monitoring information to data analytic tools and platforms via a common interface and canonical data model;
- TD3.7, RIMMS – railway data management, processing and analysis;
- TD3.1, Enhanced Switch and Crossing System – sharing requirements on maintenance requirements and approach;
- TD3.3, Optimised Track System – sharing requirements on maintenance requirements and approach;
- TD3.5, Proactive Bridge and Tunnel Assessment, Repair and Upgrade – sharing requirements on maintenance requirements and approach;
- IP1, various TDs covering the maintenance aspect – sharing maintenance and asset management approach applicable to rolling stock;
- IP2, TCMS – providing maintenance-related alerts and improvement of possession management;
- WA3, smart maintenance – sharing maintenance and asset management approach applicable to other types of assets (rolling stock).

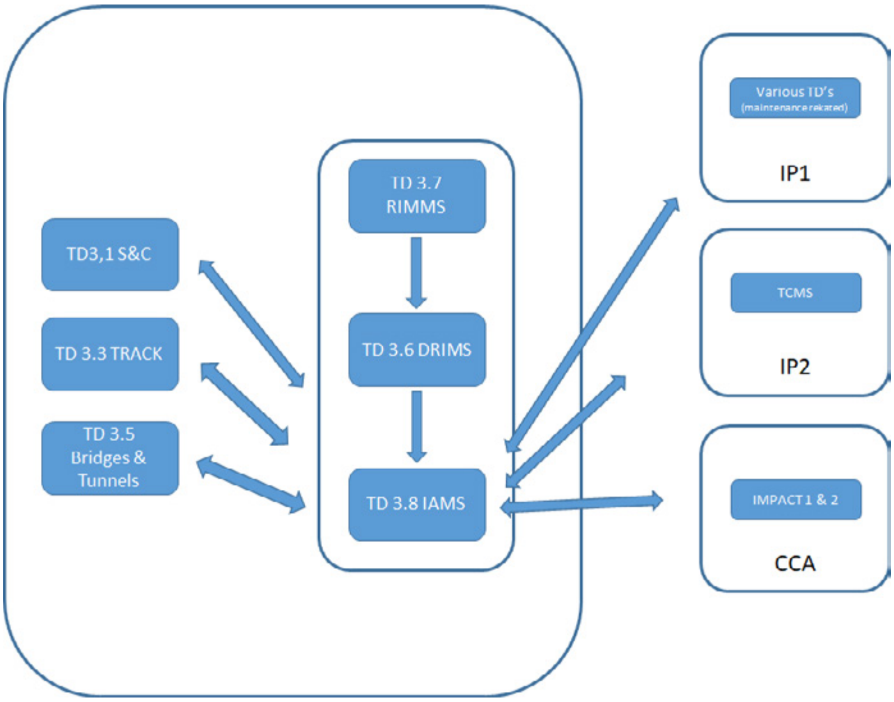


*Figure 30 / **Interaction with other TDs and IPs***

3.8.4. Impact and enabling innovation capabilities

The results of IAMS have a major impact on the Shift2Rail system-level KPIs. The relative weights of the benefits provided by the work are estimated in the table below, which provides an overview of the effects generated at a larger scale by the application of the TD results.

IMPACT TYPE	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Global technological leadership supported by a combination of innovation and technical standards, setting up an effective advantage for the European industry: • seamless migration of an innovative maintenance decision-making concept into daily practice • establishing a standardisation process in the area of infrastructure measuring, monitoring and maintenance • design and implementation of an ISO 55000-compliant data-driven concept for intelligent maintenance: the asset management framework
	Increased attractiveness and competitiveness: • increase in operational reliability (fewer service disruptions) through a progressive migration from corrective maintenance to predictive maintenance, which is less resource- and time-consuming and has less impact on train operation • reduced system cost by 40 % in the short term, due to better planned maintenance, the deployment of lean logistics and efficient execution procedures, and even more in the long term thanks to the low-maintenance-oriented design derived from the asset management framework engine • increase in infrastructure capacity of at least 20 % because of the reduction of downtimes due to unexpected failures and the optimisation of track possession for maintenance activities

Compliance with EU objectives	• Promotion of modal shift: a big impact made by the implementation of these new technologies • Achievement of a SERA due to a common understanding making long-term decisions based on an ISO 55000 framework, monitoring the effect across Europe of new technologies enabling further optimisation faster and for the whole of the European rail sector • Enhanced interoperability and simplified business process through the development of a general framework for asset management, defining new standards and contributing to existing ones across Europe
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRLs 2–4 (formulation and experimental proof of technology concepts). At the end of Shif2Rail it is expected that the successful concepts will be brought to TRL 6 or 7

This TD will contribute to enabling eight innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.8 IAMS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
1 – Automated train operation	Interaction between TMS for maintenance purposes. Relevant building blocks: • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance • BB3.8.4: Work methods and automated tools
3 – Logistics on demand	Maintenance is part of the logistics in the operational environment of the rail system. Through decision support, and clever and smart maintenance, the required maintenance can be delivered just in time. Relevant building blocks: • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance
4 – More value from data	Data are used as an integral part of the maintenance activities: for assigning risk and planning maintenance activities based on current status and available maintenance resources. The execution closes the loop by feeding data back into the system. Relevant building blocks: • BB3.8.2: Decision support tools, TRL 6/7 • BB3.8.3: Clever and smart maintenance, TRL 5/6 • BB3.8.4: Work methods and automated tools, TRL 5/6
6 – Service operation timed to the second	Maintenance can disrupt normal train operation. Avoiding disruptions and respecting maintenance timeslots benefits timely service operation. Relevant building blocks: • BB3.8.1: Risk- and asset-management-based strategy, TRL 5/6 • BB3.8.2: Decision support tools, TRL 5.6 • BB3.8.3: Clever and smart maintenance, TRL 6/7 • BB3.8.4: Work methods and automated tools, TRL 5/6
7 – Low-cost railway	Reliable asset status nowcasting and forecasting boost predictive maintenance and reduce unexpected maintenance interventions. Deployment of lean logistics and efficient work methods, development of guidelines for the design of low-maintenance and maintenance-free infrastructure systems, and efficient and effective maintenance will reduce cost. Relevant building blocks: • BB3.8.1: Risk- and asset-management-based strategy • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance • BB3.8.4: Work methods and automated tools
8 – Guaranteed asset health and availability	Improved integral performance of railway infrastructure by combining maintenance with optimised operation: enhanced integration with TMSs leads to balanced and controlled interventions between service and maintenance. Optimised working methods reduce the required downtime for maintenance activities. Predictive maintenance planning reduces downtime required for inspection and due to unexpected failures. Combined maintenance activities in a lean approach minimise track possession. Relevant building blocks: • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance • BB3.8.4: Work methods and automated tools

INNOVATION CAPABILITY	TD3.8 IAMS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
10 – Stations and smart city mobility	Stations are part of maintenance contingency plans. Relevant building blocks: • BB3.8.1: Risk and asset management based strategy • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance • BB3.8.4: Work methods and automated tools
11 – Environmental and social sustainability	Environmental and social sustainability considerations are the basis for maintenance actions, especially renewal actions. Circular economy principles are the basis for decisions concerning renewals. The use of emission-free machinery with low noise and vibration levels is the objective. Relevant building block: • BB3.8.2: Decision support tools
12 – Rapid and reliable R&D delivery	The developed examples covering all building blocks will be a showcase for further development. Relevant building blocks: • BB3.8.2: Decision support tools • BB3.8.3: Clever and smart maintenance

3.8.5. Demonstration activities and deployment

The following table summarises the contribution of TD3.8 IAMS as part of the IAM ITD to the different SPDs of Shift2Rail.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Intelligent Asset Management Strategies	Strategic long-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long-term maintenance and operational decision needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on long-term needs
	Tactical and operational short-term IAM ITD	Full demonstration of infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short-term and day-to-day maintenance and operation needs	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	6/7	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on short-term needs
	Metro/tram asset IAM ITD	Full demonstration of urban asset management including monitoring, data analysis and strategic planning, possibly including both long- and short-term maintenance and operation needs	Urban/suburban passenger rail	7	The ITD will guarantee the demonstrability of the overall concept, which is the demonstration of the improvement of maintenance process and strategies (TD3.8) through knowledge extracted from information (TD3.6) coming from available data, measuring and monitoring systems (TD3.7). The focus will be on urban network asset management

Three different demonstrators are planned for the IAM ITD, composed of building blocks from the following TDs:

- TD3.6, providing common interfaces and data modelling and analytics tools;
- TD3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD3.8, providing strategic and decision-making tools.

The first two demonstrators focus on a railway market, and the third one on an urban scenario. At least one installation site or area will be defined for each demonstrator, to allow hosting of newly developed technologies and building blocks.

The first demonstrator refers to a long-term vision scenario, taking into consideration railway asset management for a period of 5 to 10 years. The demonstration will focus on the definition of a few strategic objectives, based on the usage of analytics tools and information mainly gathered from existing systems, and the initialisation of their development in practice.

The second demonstrator refers to a short-term vision scenario, taking into consideration railway asset management on an everyday basis for a period of up to 2 years. The demonstration will focus on the implementation of an intelligent asset management system, based on the usage of data analytics tools and information obtained from both existing monitoring systems and newly developed ones.

The third demonstrator will take into consideration aspects of both previous ones, with the difference that it focuses on an urban scenario, such as a metro or tram line. Indeed, urban scenarios present different characteristics and challenges from the mainline railway, such as the IM's ownership of the rolling stock and responsibility for maintaining it; higher requirements on service availability, punctuality and capacity (people per train per hour); and different environmental requirements (e.g. noise emissions).

Planning and budget

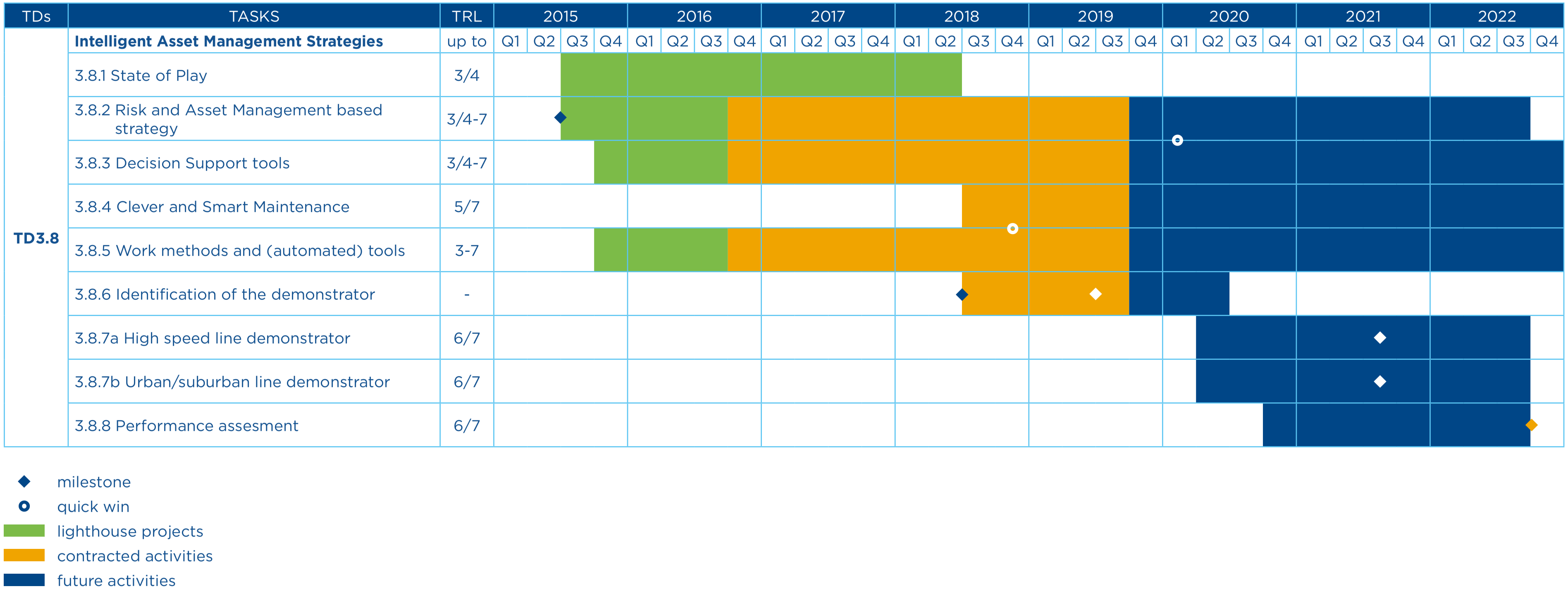


Table 64 / ***TD3.8 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q4 2018	First solution for the transformation of inspection data into data for tamping machines	Contribution to the building blocks: • BB3.8.3: Clever and smart maintenance • BB3.8.4: Work methods and automated tools
Q1 2020	Decision support tools, planning module	Contribution to the building blocks: • BB3.8.1: Risk- and asset-management-based strategy • BB3.8.2: Decision support tools

Table 65 / ***TD3.8 milestones***

WHEN	WHAT
Q2 2015	Start of the requirements definition for asset management framework
Q2 2015	Start of the requirements definition for lean tamping
Q3 2018	Start of the prototype development activities for all demonstrators
Q2 2019	End of TRL4 prototype validation for all demonstrators
Q3 2021	End of installation and first results from field prototypes of all demonstrators
Q3 2022	Field demonstrators' final validation and inclusion in an IAMS

The estimated budget for the TD is around EUR 16 million.

3.9. TD3.9 Smart Power Supply

3.9.1. Concept

The railway traction power supply system delivers the required electrical energy to the trains, giving consideration to quality and availability. The special characteristic of electrical traction power supply systems is that they interact with running trains, resulting in special load characteristics. That requires different solutions from standard power supply systems. For historical reasons a variety of systems with alternating current (AC) and direct current (DC) have been developed and are in use in different regions in Europe.

The power supply system is connected to the feeding public supply networks and will also act as a supply system for other energy consumers outside the railway traction system. The development of new sources of electricity, such as renewables or photovoltaics, requires different solutions for power infeed (e.g. small de-centralised systems).

The railway traction power grid of the future needs important smart functionalities.

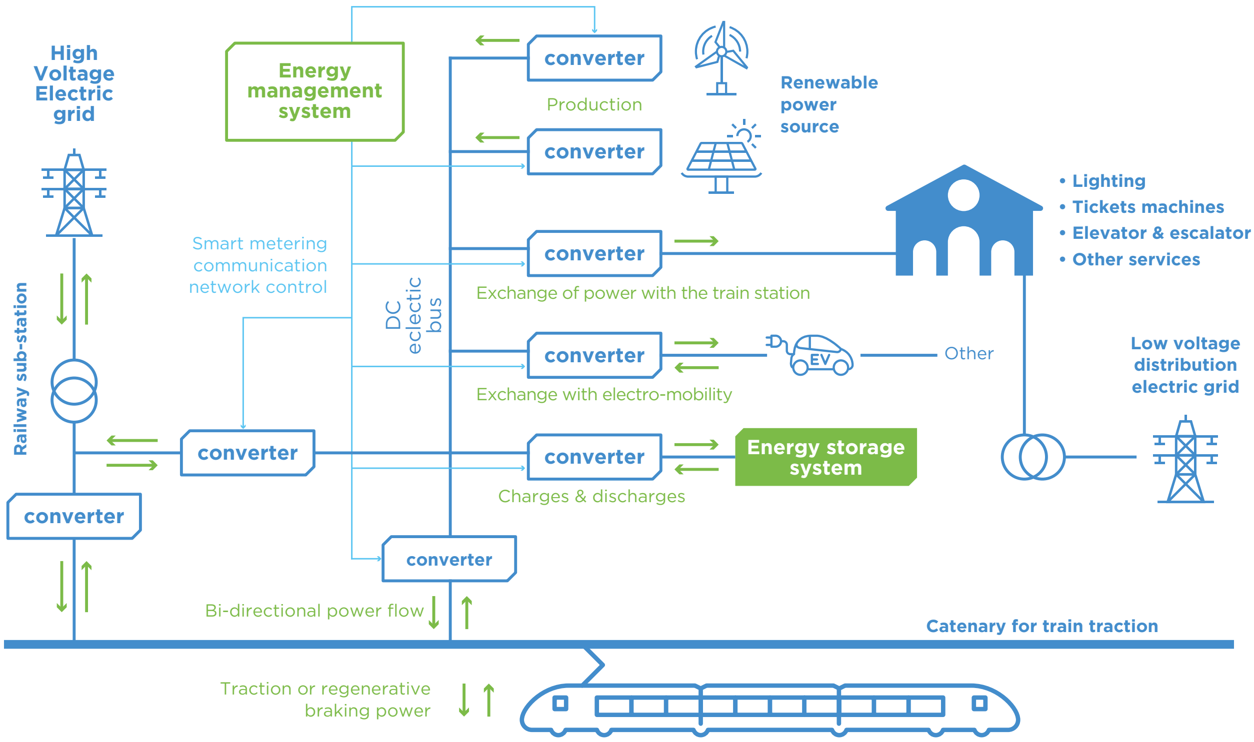


*Figure 31 / **Schematic view of rail traction power supply in a smart power environment***

Figure 31 shows the target railway traction power supply network. The basis is a connectable traction power supply system interacting with various sources and consumers of energy. This smart railway power grid (SRPG) requires active elements to regulate the power flow and the necessary sensors and methods to control these active elements, embedded in an overall network control concept.

TD3.9 covers the traction power supply system itself. The interaction capabilities are different for the several traction power supply systems. For example, for DC systems, active elements can be controlled rectifiers and inverters; for AC systems with special frequencies requiring a frequency shift, converters can be used.

In most cases, solutions equivalent to standard power grid elements will be used with improvements and adaptions for the specific requirements in the SRPG. The developments planned in Shift2Rail refer to unique railway-specific tasks inside this network and to railway-specific application of technologies under optimum use cases.

The implementation of the SRPG enables improvements and optimisations regarding train traffic capacity, energy losses and costs, power quality, energy supply security and availability for the railway system, and environmental impact.

3.9.2. Technical objectives

The following represent the main technical objectives of this TD.

1. Minimising energy losses by means of double side feeding in traction power supply systems, reducing the transmission losses by up to 50 %.

2. Optimal dimensioning of network equipment to minimise the difference between installed and used power, reducing the investment or increasing the line capacity for existing lines. Nominal power of installed equipment per line in substations can be reduced by up to 20 %.

3 Parallel connection of substations to allow elimination of phase separations on the line and reduce restrictions to operation for better operability and reduced maintenance costs. No power switch-off on trains every 20–40 km in 50 Hz systems will be necessary.

4 Ability to feed electrical traction systems from 'weaker' (lower short-circuit power) 3 AC supply networks with a lower voltage level for minimised investment. This will allow efficient electrification of railways in regions without the necessary improvements in the 3 AC grid.

5 Optimising control of the load flow between the connection points depending on the demand of the railway network, and feeding supply network to reduce load peaks for low energy costs and optimised dimensioning.

6 Capability to offer services to the grid operator such as frequency and voltage support, reactive power compensation and reduction in phase unbalance.

7 Increase in interoperability, availability, and control and protection functions in substation control systems by means of IEC 61850.

8 Reduction of costs by minimising the necessary copper wiring in substation control and protection equipment through the use of a process bus network.

3.9.3. Technical vision

The final target is the implementation of an SRPG. The SRPG allows bi-directional energy flow and the integration of other consumers and sources of electric power. Controlling this network will act to the internal behaviour of the grid and will consider the demands for power from trains and other consumers and also the capabilities of supplying elements. The target of the SRPG is to minimise the total LCC. The technical vision is based on the following developments:

- converters with semiconductors as active elements connecting networks with different characteristics;
- digital control and protection equipment in substations allowing management of complex networks;
- data acquisition and connectivity solutions to interact with the load control and energy measurement systems of adjacent networks;
- integration of operational data for interactive load control.

STATE OF THE ART	SMART POWER SUPPLY
Passive elements in substations (transformer, rectifier)	Active elements in substations allowing control of load flow and interaction with feeding grid
Substation dimensioning for peak power and energy demand in restricted-supply sections	Control of power peaks and distribution of load between substations in a grid
Single-side feeding of lines with high transmission losses. Phase separations between feeding sections in 50 Hz systems requiring shut-down of traction power at trains	Double-side feeding of line sections for uninterrupted traction power supply with reduced transmission losses

STATE OF THE ART	SMART POWER SUPPLY
Unbalance in 3 AC grid created by single-phase railway load	Load balancing for symmetric load energy consumption on the 3 AC grid
No control of reactive power	Control of reactive power in both grids, traction power supply grid and public supply grid
No interaction with asset and maintenance management systems	Condition monitoring and data support for maintenance management and traffic control
Copper wiring between instrument transformers and control and protection equipment	Decentralisation by using merging units at the instrument transformers and introducing a process bus network between the control and protection equipment

Interaction with other TDs (in the same IP and/or in other IPs)

The smart AC rail power supply system has the following interfaces inside the S2R project:

- IP1 – new traction systems (TD1.1) will change harmonics in the load characteristics and give more freedom to power supply designs.
- IP2 – control procedures will be influenced by the traffic management system (TD2.9). Integration in a TMS will be implemented with the demonstrator.
- IP3 – power supply equipment will be included in the asset management systems (TD3.8). The active equipment and the controls allow the use of load/stress characteristics for scheduling maintenance for the elements. This will interact with the DRIMS planned in TD3.6.
- IP3 – the results of the smart metering demonstrator will be used for the control and protection concepts in TD3.10.

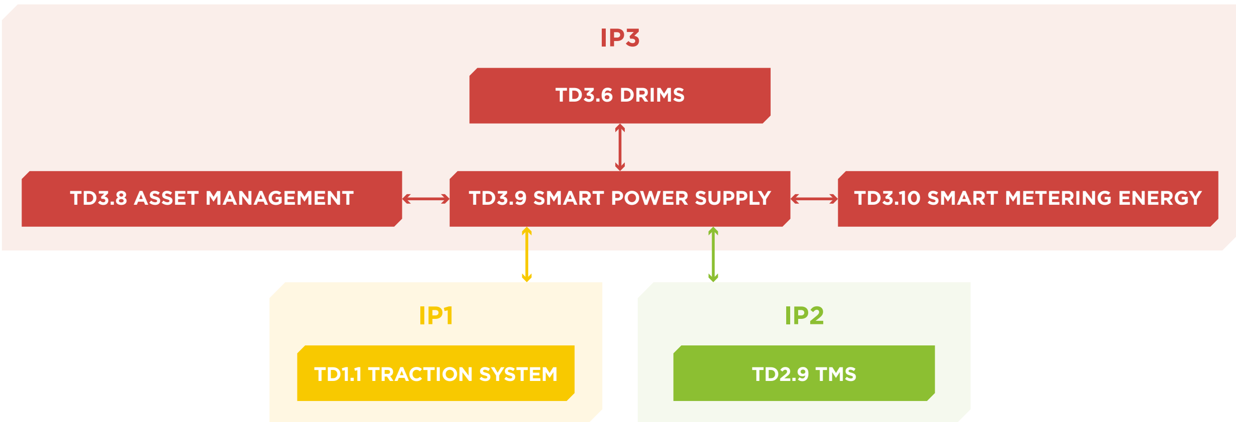


Figure 32 / ***Relationship of TD3.9 with other TDs***

3.9.4. Impact and enabling innovation capabilities

The smart power supply benefits will affect all the Shift2Rail system-level KPIs. TRLs achieved are defined for the demonstrated power supply system. The benefit differs depending on the power supply system used. The relative weights of the benefits provided by this work are estimated in the table below, which provides an overview of the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Technological leadership supported by a combination of innovative elements (flexible AC transmission system (FACTS) equipment, digital control and protection) with a whole-system approach for design and implementation of the smart railway power system. • Tangible benefits for the end user: / Energy efficiency: the implementation will reduce transmission losses in the power supply system by a significant factor (up to 50 % in contact lines) / Reduced investment: the electrification equipment installed at lineside can have significantly lower nominal power rating (up to 20%) / Capacity: the line capacity will increase by improving the transferable power along the line; the improved supply concept allows better power distribution to the train / Operational reliability: new protection concepts will improve the reliability and availability of the complete system
Compliance with EU objectives	• Support to capacity increase: as mentioned above, this is allowed by flexible unit coupling and fewer service disruptions due to lack of operational availability • Greening of transport through reduction of energy losses and integration of green energy sources
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies for railway application are in TRL 1–2 (principles observed and the possibility of using them formulated). At the end of Shif2Rail it is expected that the control and protection elements will be brought to TRL 5–6 and the system application will be brought to TRL 4

This TD will contribute to enabling six innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.9 SMART POWER SUPPLY ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	The use of data from the energy control and protection system in energy demand calculations will improve the quality of forecasts and improve the usability of datasets. Relevant building blocks: • BB3.9.1: Smart control and protection system
5 – Optimum energy use	Control of energy flow with knowledge of energy demands allows optimum use of electrical energy for railways. Relevant building blocks: • BB3.9.1: Smart control and protection system • BB3.9.2: Virtual demonstration of smart 50 Hz substation
7 – Low-cost railway	Control of energy flow with knowledge of energy demands gives the possibility of minimising investment for traction power supply systems. Control of energy flows to minimise losses and the use of stress-based maintenance to minimise LCC. Relevant building blocks: • BB3.9.1: Smart control and protection system • BB3.9.2: Virtual demonstration of smart 50 Hz substation
10 – Stations and smart city mobility	This TD plays an important part in integration between the several electric networks as a basis for the integration of railways into smart energy grids. Relevant building blocks: • BB3.9.1: Smart control and protection system • BB3.9.2: Virtual demonstration of smart 50 Hz substation

INNOVATION CAPABILITY	TD3.9 SMART POWER SUPPLY ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
11 – Environmental and social sustainability	Control of energy flow allows reduced energy losses and integration of green energy. Relevant building blocks: • BB3.9.1: Smart control and protection system
12 – Rapid and reliable R&D delivery	The demonstrators in TD3.9 are defined for relevant levels, with the benefit of maximum use of virtual technologies. The implementation of split demonstrators for control and for active elements facilitates the use of results in the different types of traction power supply systems. Relevant building blocks: • BB3.9.1: Smart control and protection system • BB3.9.2: Virtual demonstration of smart 50 Hz substation

3.9.5. Demonstration activities and deployment

TD3.9 will be demonstrated in parts, in different systems, to support the transfer of system solutions between the different power supply systems.

TD3.9 plans to implement two demonstrators to achieve the target functionalities described in the objectives. Using two demonstrators will allow the wider participation of existing experience in the fields of 16.7 Hz and 50 Hz traction power supply systems. This will also speed up the process of demonstrator implementation for the different functionalities and the transfer of results for DC rail power supply systems.

The achievement of TRL 5 requires the participation of railway infrastructure managers with the relevant basic hardware, and the possibility of hosting the enhancements as technology demonstrators. In addition, the functionality in the 50 Hz demonstrator is split into two sequential steps to allow results at an early stage, taking into consideration the risks from the outer interface to public grid operators.

TD3.9 will implement the two demonstrators in accordance with the following table.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Smart Power Supply	Smart control of rail power supply	Demonstration of digital control elements in rail power supply by paralleling an existing solution with a special improved switchgear station	All electrified railways in all market segments	5	Check and demonstration of functionality, capacity, application and integration in the systems
	FACTS demonstrator for 50 Hz rail power supply	Demonstration of integration of FACTS equipment in rail power supply networks	AC rail power supply systems	4	Evaluation and proof of concept for several implementations to find optimum solution for different use cases

In addition, TD 3.9 will rethink traction power supply systems, considering future demands from the integration of other modes of electric transport and new challenges from energy supply and the integration of green energy.

As TD 3.9 defines new applications, a revision of relevant standards and regulation may be considered. This covers the TSI Energy and TSI Locomotives and Passenger Rolling Stock for implementation and authorisation of the new system.

Different standards specifying active components, protection principles and systems, and for relevant interfaces such as EN 50388 and EN 50633 need to be improved.

Planning and budget

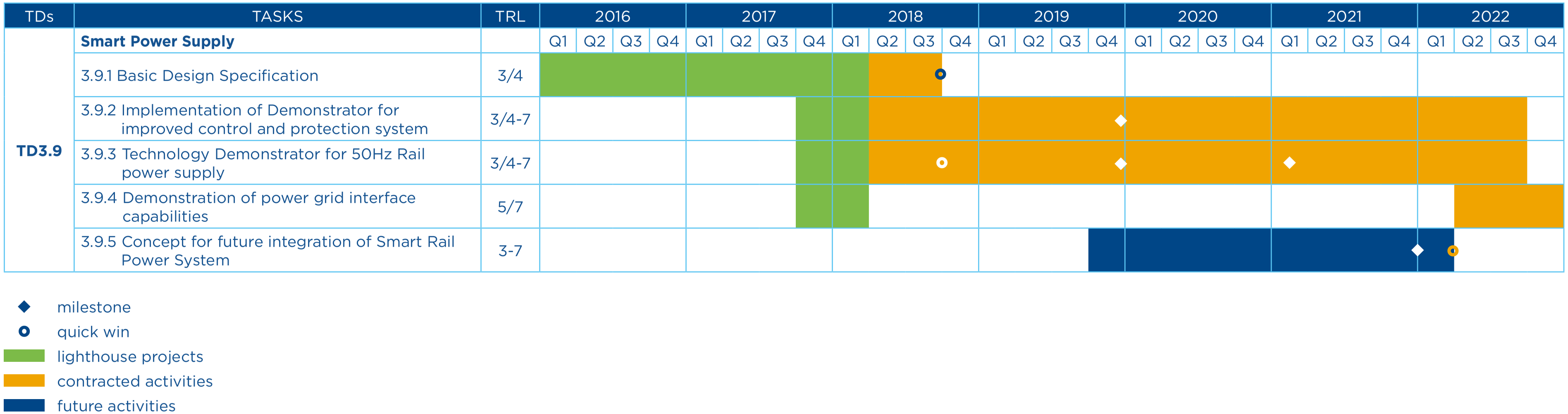


Table 66 / ***TD3.9 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2018	Control and protection specification	Main outcome of In2Rail allowing final design for demonstrator implementation in 16.7 Hz network
Q3 2018	Use case definition and interface specification for use of FACTS elements in 50 Hz AC rail power systems	Main outcome of In2Rail as start point for design specification
Q1 2022	Concept for future traction power supply system	Result from OC in AWP 2019 for future concept and operation of smart power supply

Table 67 / ***TD3.9 milestones***

WHEN	WHAT
Q4 2019	Final confirmed design for control and protection demonstrator implementation
Q4 2019	Final confirmed design for 50 Hz rail power supply demonstrator
Q1 2021	Use cases for virtual demonstrator defined
Q4 2021	Results from OC 'Future traction power supply for railways and public transport' to start demonstrator design for Shift2Rail 2

The estimated total budget for TD 3.9 available during Shft2Rail is around EUR 5 million.

3.10. TD3.10 Smart Metering for Railway Distributed Energy Resource Management System

3.10.1. Concept

The detailed mapping of energy consumption of a railway system is mandatory for energy efficiency analysis and management. The knowledge of load curves at rolling stock level, at traction substation level and at auxiliary services level will allow global system load prediction, peak shaving and energy cost optimisation. It will also highlight where the most effective actions could be implemented to give energy savings.

The concept of the demonstrator is represented in Figure 33 and the associated objectives are summarised as follows:

- To realise a non-intrusive smart metering sensor network at a railway system level.
- To realise an open system and interface for data collection, aggregation and analysis in an open source operational data management platform.
- To realise a set of user applications designs and specifications. The applications will exploit the energy analysis process with the aim of enhancing energy decision-making and line operation patterns; other possible applications include preventative maintenance plans, asset management and LCC dashboards, and energy market interfaces.

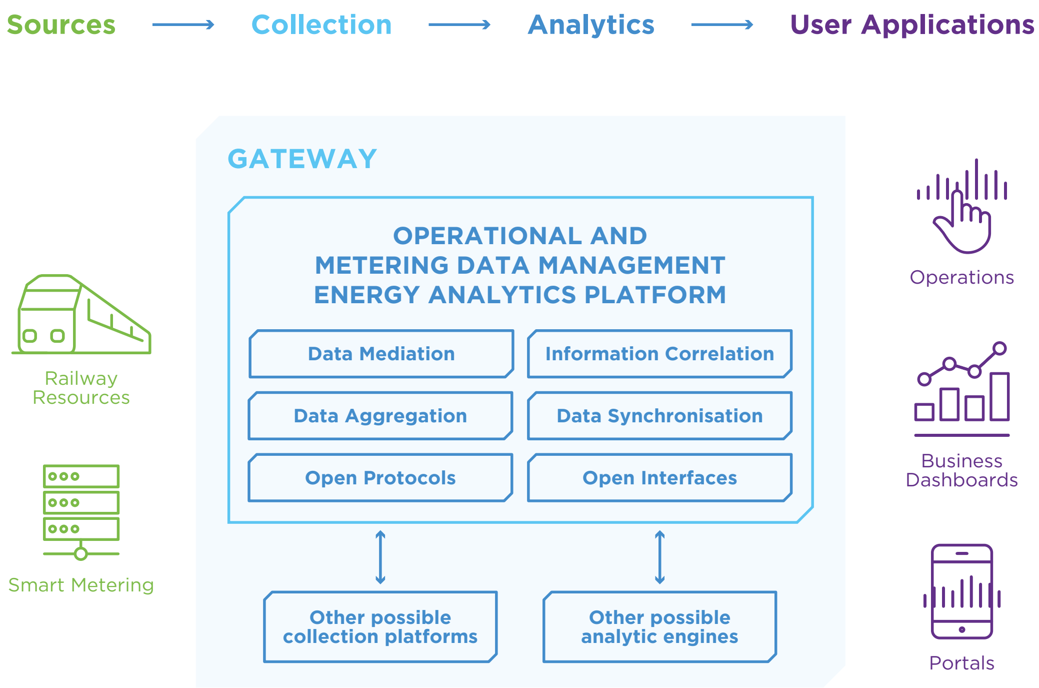


Figure 33 / ***Demonstrator concept***

3.10.2. Technical objectives

An analysis of the technical objectives of smart metering for energy management purposes can be highlighted for several use cases specific to the main rail transportation energy consumption profiles, for example the following.

Metro and suburban

- Valorisation of braking energy.
- Better management of train lighting and air conditioning/heating when not in revenue service.
- Better station energy management.

Regional passenger

- Providing an accurate energy measurement tool, leading to energy savings plans specific to each region (a variation of ± 20 % is expected in each region due to specific timetable constraints and climatic conditions).
- Allowing the optimisation of the energy mode choice (electric/diesel).
- Reducing the energy bill at a regional scale by adapting the best purchasing profile to the real-time consumption and allowing energy aggregation with regional consumers.

Freight

- Better valorisation of the off-peak hours used by the freight train.
- Better management of energy consumption when the freight train is stopped.

Inter-regional and high-speed passenger

- Valorisation of braking energy.
- Better management of train lighting and air conditioning/heating when not in revenue service.
- Better coordination between the energy hourly variation prices and the traffic operation.

Infrastructure

- Continuous supervision of power supply equipment states.
- Better knowledge of energy flows and consumers.
- Optimised ROI and a proven business plan, allowing optimal investment in local reversible DC substations or storage devices.
- Better identification of electric infrastructure losses.
- Better identification of auxiliary and station energy consumption and of opportunities for savings and demand-response.
- Improved reliability and LCC based on predictive maintenance by continuous supervision of energy consumption and identifying the abnormal variations.
- Increasing the power supply quality and optimising the line capacity.

3.10.3. Technical vision

In rail transport systems, smart metering can provide real-time information allowing the optimisation of energy consumption. Wireless and mobile devices can be used for railway metering. For example, a train-tracking system based on the Global Positioning System or the Global System for Mobile Communications can provide accurate, dependable and timely information to the controller. In addition, the train speed and dynamic status (accelerating, braking, maintaining speed, etc.) can be measured using an accelerometer, a common sensor that can be found in most smartphones. Based on the concept of data fusion, information can be gathered from different distributed sensors on board and at ground level (accelerometers, Global Positioning System, gyroscopes, voltmeter, ammeter) and combined to produce a comprehensive database with a common time and spatial reference. Once the database is ready, user-customised applications will evaluate the current situation and finally enhance the decision-making process.

Important scientific work will be performed in order to implement intelligent algorithms for energy consumption evaluation using as few sensors as possible. The measurements must be, as far as possible, non-intrusive and cost effective. The main effort will be concentrated on intelligent evaluation solutions rather than on measurement hardware (sensors, data loggers, etc.). For example, machine learning algorithms could be used in order to precisely evaluate the energy consumption by only measuring acceleration and speed. This will be a way to limit the usage of current and voltage sensors and their associated interface devices, which are costly and difficult to install on trains and substations already in commercial operation configuration.

Integration in the future smart grid allowing energy exchange between the railway and alternative generation modes such as renewables or locally distributed generation is conditional on the deployment of a smart metering network. At the infrastructure level, the functional architecture integrating the sensor network, the railway elements and the alternative energy sources is described in Figure 34.

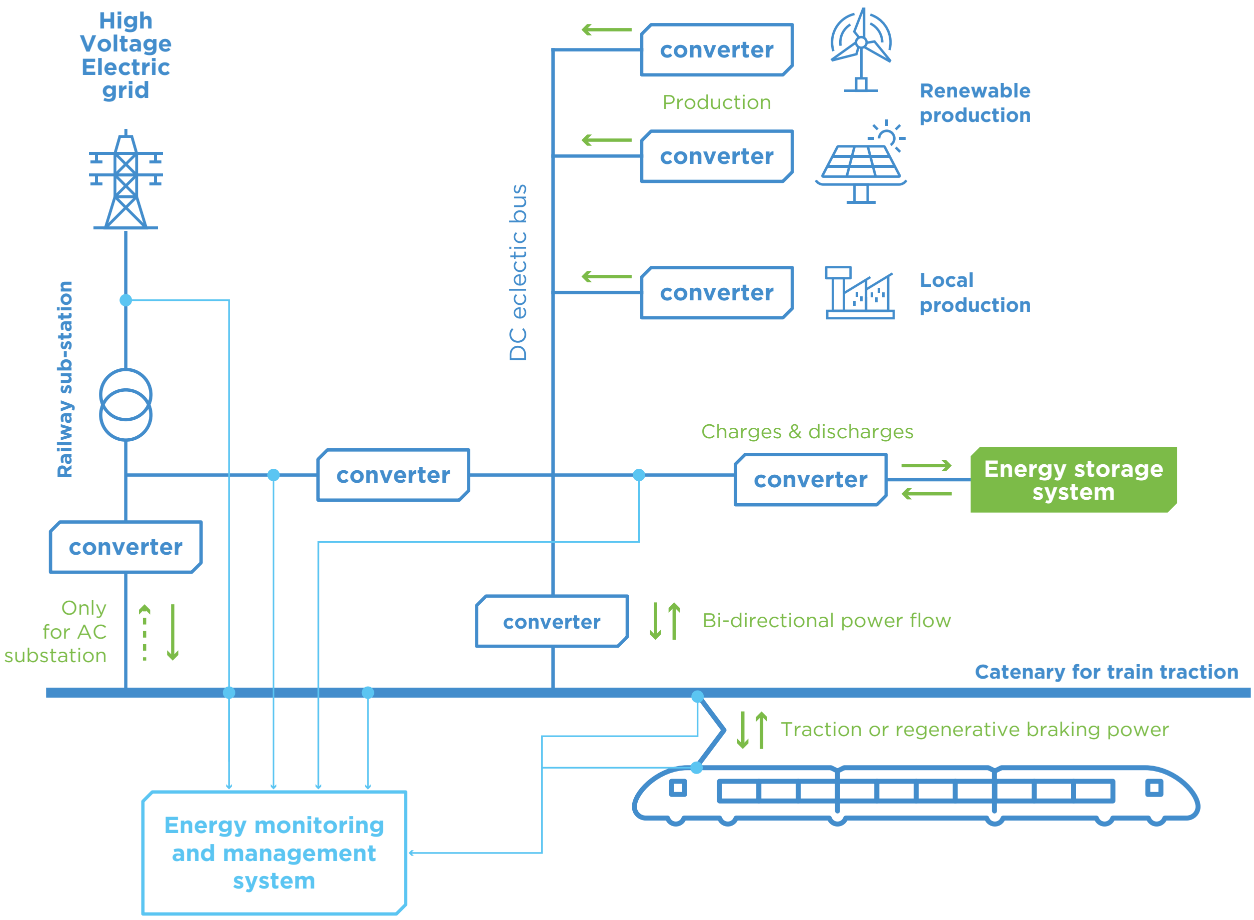


Figure 34 / ***Sensor network functional architecture applied to smart grid integration***

Currently, only customised on-board system measurement devices are available. They are mainly focused on the rolling stock's internal energy flow with the aim of measuring separately the energy used for the traction and the other auxiliary energy usages.

The concept's novelty comes from the system-level measurement integration, which provides synchronised measurements on board and on the ground. The other main feature is the path provided by the RDERMS to the energy market with an enhanced prediction capability.

Last but not least, today's mobile information technology makes affordable quite sophisticated mobile terminals such as smartphones and systems-on-chip mobile technologies to industrial applications such as sensor networks.

STATE OF THE ART	ADVANCES BEYOND THE STATE OF THE ART
The state of the art today shows a focus on rolling stock on-board energy meters at pantographs for energy-billing purposes. These measurements are not used in an integrated energy management process	Railway system-level measurement integration provides synchronised measurements, both on board and at trackside, of traction and non-traction energy flows. These measurements allow new business models such as a digitised access to a decentralised energy market, along with an enhanced prediction capability and flexibility

STATE OF THE ART	ADVANCES BEYOND THE STATE OF THE ART
System energy consumption is usually measured at the substations only and averaged over a defined period of time, which does not allow an exact energy analysis. This is currently done by simulation algorithms based on models that make simplified assumptions about real conditions. No correlation with train operations is made after measurements	Energy flows are mapped for the whole railway system, continuously and with refined granularity. The synchronisation, via a network time protocol server, of train and ground energy measurements, both traction and non-traction, will allow data analytics on a larger scale by correlating the data thus obtained. The user applications will then be based on real measurement data analytics, not only on simulation
The current rolling stock metering systems are quite intrusive, requiring relatively long implementation	The solution is based on non-intrusive technology and quite sophisticated, but off-the-shelf and mass-marketed, mobile terminals such as smartphones and systems-on-chip mobile technologies dedicated to industrial applications such as sensor networks. Embedded applications, combining measurements and modelling, open up a wide range of possibilities of locally processing data in order to enhance the sensor capabilities in non-intrusive measurement configurations

Interaction with other TDs (in the same IP and/or in other IPs)

This TD will interact with:

- TD2.10, Smart Radio-Connected All-in-All Wayside Objects – implementation of safe and reliable wireless-connected object controllers;
- TD3.6, Dynamic Railway Information Management System – implementation of data management, processing and analysis for energy-related data as an extension of the asset management data applications;
- TD3.9, Smart Power Supply – development of common gateways and energy-related data analytics;
- Sub-WA5.1, Energy – development of a standardised methodology for energy consumption estimation by measurements and simulations at railway system level.

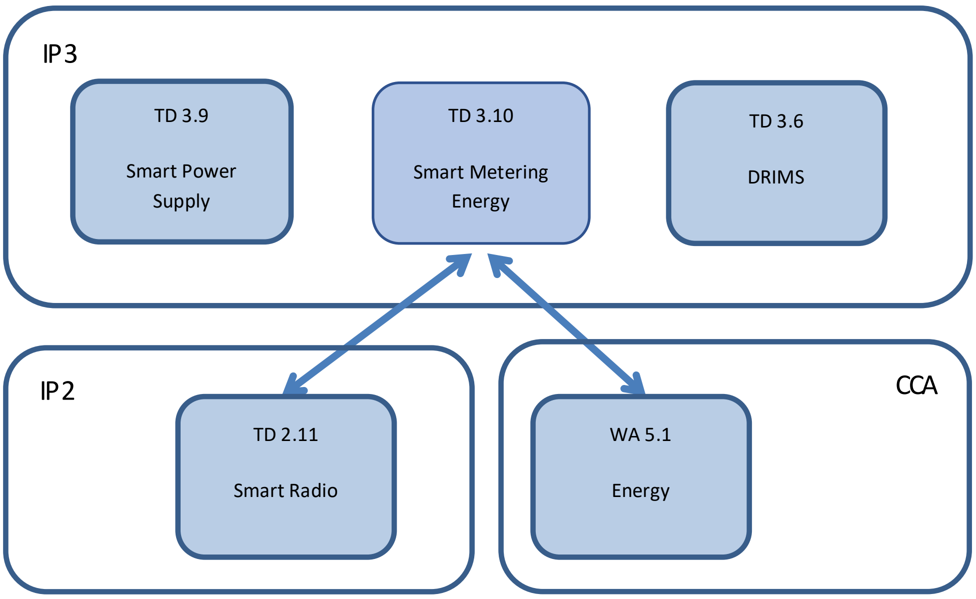


*Figure 35 / **Relationship of TD3.10 with other TDs***

3.10.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Global technological leadership supported by a combination of innovation and technical standards, setting up an effective advantage for the European industry: • enhancement of energy management at the level of the railway system • application of big data concept to railway energy data management and its extension to other data types such as maintenance and asset management
	Increased attractiveness and competitiveness: • increase in operational reliability: fewer service disruptions through continuous monitoring of subsystems' energy consumption • reduced cost: smart metering infrastructure cost reduction by using non-intrusive and standard components; energy cost reduction by using measurement results for energy management applications • increased capacity, by more rational energy usage, optimising asset management and new energy infrastructure dedicated to capacity increase
	Enhanced customer experience: end users can access through dedicated portals the energy data related to their own trips and thus contribute to energy savings by changing travel habits
Compliance with EU objectives	Promotion of modal shift: through customer-dedicated user applications using geolocation data and real-life measurements, and not only predefined timetables, an effective promotion of modal shift is achievable
	Greening of transport: using real energy consumption data and evaluating the environmental impact accordingly, the customer will act directly on transport greening
	Achieving a SERA by promoting data exchange formats and protocols
	Enhanced interoperability: facilitating detailed energy consumption knowledge will promote operational cost reductions for all operators
	Simplified business processes: sharing the data related to energy costs will simplify business case elaboration
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRLs 1 and 2 (principles observed and the possibility of using them formulated). At the end of S2R it is expected that the successful concepts will have been brought to TRL 5

This TD will contribute to enabling six innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.10 SMART METERING FOR RAILWAY DISTRIBUTED ENERGY RECOURSE MANAGEMENT SYSTEM ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
4 – More value from data	Data valorisation is part of the core activity of this TD. The operation data management platform will allow energy analytical engines to exploit the railway system field measurements in order to provide valuable operational and business decisions support. Relevant building blocks: • BB3.10.1: Smart electrical monitoring
5 – Optimum energy use	The knowledge of energy flows within a railway system is based on real operation measurements. This is one of the key drivers for taking appropriate actions in order not only to enhance the energy efficiency of a given system, but also to design and optimise the future investments for the whole electrical infrastructure of the system. Relevant building blocks: • BB3.10.1: Smart electrical monitoring

INNOVATION CAPABILITY	TD3.10 SMART METERING FOR RAILWAY DISTRIBUTED ENERGY RECOURSE MANAGEMENT SYSTEM ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
9 – Intelligent trains	This TD contributes to the train-to-ground communication services with a particular focus on data synchronisation between on-board and trackside energy measurements. Relevant building block: • BB3.10.1: Smart electrical monitoring
10 – Stations and smart mobility	The operational data platform will be able to receive data from heterogeneous sources such as trains, substations, passenger stations and control rooms, and to be interfaced with different analytical engines for building on demand user applications. Relevant building block: • BB3.10.1: Smart electrical monitoring
11 – Environmental and social sustainability	This demonstrator will give the opportunity of using real energy-related operational data for measuring the railway system's specific energy and CO_2 footprint at any time of the day, season and weather condition. These data can be published via specific portals and have a real influence on choosing rail as an environmentally friendly action. Relevant building block: • BB3.10.1: Smart electrical monitoring
12 – Rapid and reliable R&D delivery	Not only is the demonstrator itself based on a massive technology transfer from the IoT, big data and smart grid technologies to the railway domain, but also the data generated by the field measurements are contributing to a fast and reliable decision-making process for both the commercial and the technical management of a railway system. Relevant building block: • BB3.10.1: Smart electrical monitoring

3.10.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Smart Metering for Railway Distributed Energy Resource Management System	Commercially operated line use case	Demonstration of smart metering implementation with energy measurement on infrastructure and rolling stock in order to improve energy management in commercial operation. Demonstration of energy measurements of both on-board and trackside electrical equipment on a synchronised time basis. Data transmission, correlation and user applications building	Generic	5	Demonstration and assessment of the functional operation of the developed technology modules and user applications/ decision support tools for the line operation, highlighting the benefits of smart metering for the use case. Check and demonstration of functionality, capacity, application and integration of all field sensors
	Stationing and maintenance facilities operation use case	Demonstration of smart metering implementation in a tramway depot, in order to improve energy management in depot and maintenance facilities. Demonstration of energy measurements for both traction and non-traction electrical equipment in an operational depot	Generic	5	Demonstration and assessment of the functional operation of the developed technology modules and user applications/ decision support tools for the stationing and maintenance operation, highlighting the benefits of smart metering for the use case. Understanding the energy flows between trains and electrical infrastructure
	Electrical infrastructure monitoring use case	Demonstration of smart metering implementation in order to improve electrical infrastructure monitoring. Demonstration of electrical measurements dedicated to monitoring of electrical infrastructure critical values such as minimal voltage along the line, overvoltage and fault recording, etc.	Generic	5	Demonstration and assessment of the functional operation of the developed technology modules and user applications/decision support tools for electrical monitoring, highlighting the benefits of smart metering for the use case

Planning and budget

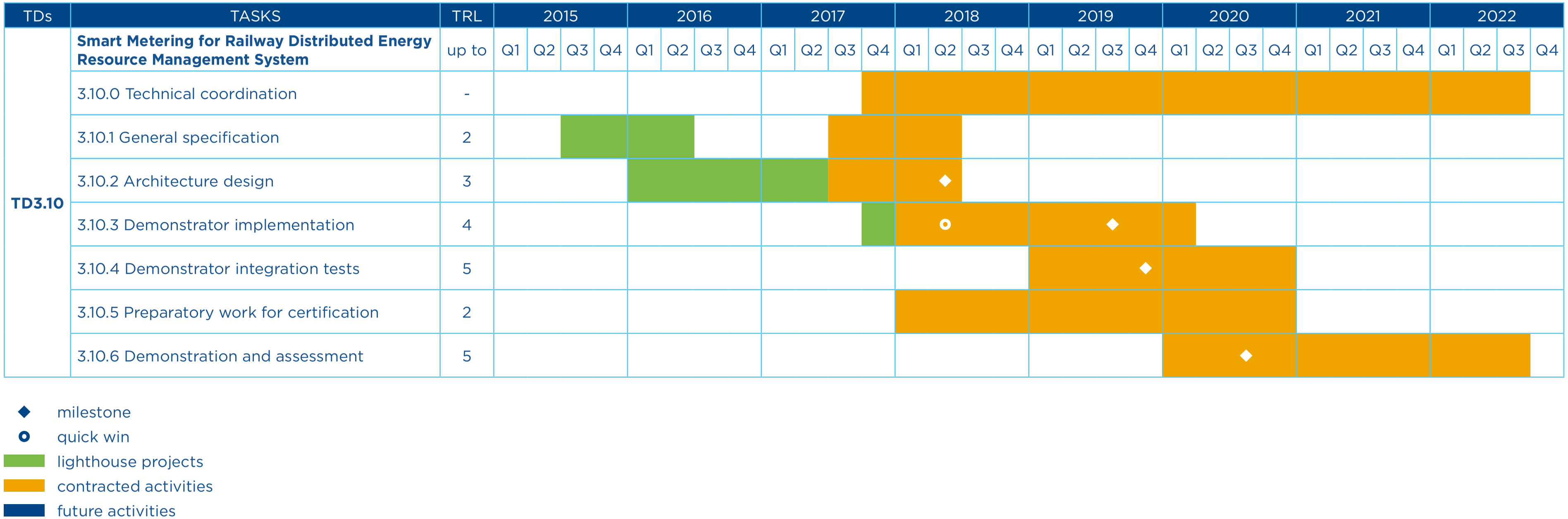


*Table 68 / **TD3.10 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Smart metering proof of concept implemented in Reims tramway	Tested hardware and data collection software platform in a real-life railway environment, as well as user application example

*Table 69 / **TD3.10 milestones***

WHEN	WHAT
Q2 2018	Handover from In2Rail
Q3 2018	Status report on relevant rolling stock and Eurotunnel and Network Rail electrical infrastructures
Q4 2019	Commercially operated line, stationing and maintenance facilities and electrical infrastructure monitoring operational use cases ready for operational test
Q3 2019	Sensors and telecommunications, and operational data management, ready for integration into use cases
Q3 2020	User applications and decision ready for integration into use cases

The estimated budget for the TD is around EUR 5.5 million.

3.11. TD3.11 Future Stations

3.11.1. Concept

From a major urban station to a provincial stop, stations are an important element of the railway system and one of the most complex. The major civic stations have become destinations in their own right and dynamic places of commercial, retail and social activity. Stations located in major urban areas are likely to have issues with congestion, orientation and security that are not experienced in more remote stations. Considering this as a starting point, the concept of TD3.11, Future Stations, is a plan to develop station design concepts optimising station management, creating cost-effective solutions and technologies so they can be applied in a variety of scenarios. The primary ambition is for customer experience at stations to be dramatically improved, increasing the number of customers that will use rail as their preferred transport mode.

In more detail, TD3.11 addresses the primary objective of improved customer experience by improving efficiency, cost-effectiveness and security through four parallel work streams considering future demands for large and small stations:

- work stream 1: crowd management and revenue protection in large stations;
- work stream 2: standardisation and prototypes for small stations;
- work stream 3: platform to train accessibility;
- work stream 4: emergency risk assessment of major stations.

3.11.2. Technical objectives

The technical objective of work stream 1, crowd management and revenue protection in large stations, is to improve flow between platforms and the concourse. It needs to investigate ways to increase station capacity with new ticketing technology that could potentially remove the need for gates in stations, encouraging seamless journeys while ensuring that operators do not lose revenue. This must be done in a way that will not compromise the security of the station and will consider alternative security measures if necessary. The same technology will also be considered for improving wayfinding in the station, looking for possible interfaces with IP4.

The technical objectives of work stream 2, standardisation and prototypes for small stations, are standardisation and prototypes to evaluate and demonstrate research activities linked with this typology of stations. An assessment of construction products that are available throughout Europe will seek to identify the most suitable materials and finishes for station components. This may include trials of innovative building materials and components in the station environment. Prototype station designs for small stations must be developed demonstrating a service-based approach to station design, and flexibility in adapting to future requirements. The study will conclude with recommendations on appropriate specifications and maintenance regimes depending on use and locality.

The technical objective of work stream 3, platform to train accessibility, is improvement of customer experience. The transition from the train to the platform is a major issue not only for wheelchair users but for the majority of users and especially those with prams and luggage. It is also a major safety concern, especially on curved platforms or on routes with varying train carriage heights. To address the above issue of platform–train interface (PTI), research activities will be undertaken that develop the optimum PTI configuration to achieve safe and consistent boarding and alighting. The study will then form the basis of which European countries can meet their PRM interoperability objectives and commitments and address them in a cost-effective manner.

The technical objective of work stream 4, emergency risk assessment of major stations, is the improvement of capacity and security. Research activities will utilise existing passenger flow software as a real-time means to understand the crowding issues in a station and control them with mitigating measures such as directing the crowds to alternative routes or exits. The work stream will seek to develop appropriate tools and procedures to assist large stations' operations.

3.11.3. Technical vision

Table 70 summarises how TD3.11 will advance the state of the art and overcome today's limitations and difficulties.

Table 70 / ***Technology for future stations***

STATE OF THE ART	ADVANCE BEYOND STATE OF THE ART
Barriers are gated for revenue control. Station staff rely on CCTV cameras to provide visual information and surveillance of the station	Removing gate barriers currently used for revenue control will increase capacity in busy stations. Revenue control will be integrated with crowd simulation software to allow managers of congested stations to manage peak periods as well as emergencies in a more efficient way. New communication technologies will replace traditional ticket sales and allow both users and operators to have real-time data at their fingertips. Passengers will be directed to their trains using real-time data

STATE OF THE ART	ADVANCE BEYOND STATE OF THE ART
There is confusion and lack of clarity within the industry regarding station products and materials that are safe and affordable to use and maintain. Standardisation of designs is not prevalent and sometimes does not even reflect local climatic and operational requirements	Clear guidance on products and materials suited to stations in differing scenarios will aid optimised selection and specification. Accessible, step-free routes to platforms and trains will be provided. Stations will guarantee independent mobility on platforms and in other areas, using way-finding solutions (apps) and visible, clear static signage. Passengers will have agreeable, accessible, safe spaces to wait for trains, with real-time information about timetables, disruptions and changes
The majority of existing platforms cater for a variety of rolling stock with varying floor heights. Curvature of existing platforms creates gaps between the train and platform. Reconstruction of existing platforms is very expensive and cannot be justified where rolling stock is variable	Solutions will allow safe and inclusive access to the train and will not be too demanding on maintenance; nor should they increase the dwell time of the train significantly
Station managers do not have sufficient data and tools to deal with emergencies, and depend very much on personal initiatives of the station staff in such situations. Security provisions are inconsistent and best practices are not shared	Element of surprise and unpredictability during emergencies will be countered with strategies and procedures worked out in advance for major stations

Interaction with other TDs (in the same IP and/or in other IPs)

Research activities linked with TD3.11 need interaction and research results from other IPs for the TD to fully reach its potential. Platform to train accessibility will not be solved only with new approaches on the infrastructure side but will also need innovative rolling stock solutions developed within IP1. In general, IP4 and future stations have extremely close connections regarding new and disruptive IT services with their only focus on improving customer experience, capacity and safety. Finally, future stations cannot be developed without taking into account issues linked to ATO, which is handled in IP2.

Table 71 / ***Interaction with other TDs and IPs***

	CROWD MANAGEMENT AND REVENUE PROTECTION IN LARGE STATIONS	STANDARDISATION AND PROTOTYPES FOR SMALL STATIONS	PLATFORM TO TRAIN ACCESSIBILITY	EMERGENCY RISK ASSESSMENT OF MAJOR STATIONS
Links to other work streams internally within TD3.11	Emergency risk assessment of major stations			Crowd management and revenue protection in large stations
Interaction with other IPs/TDs	IP4 Customer-focused IT services	IP2 Automated train operation (ATO) IP4 Customer-focused IT services	IP1 Cost-efficient and reliable trains IP2 ATO	IP4 Customer-focused IT services

3.11.4. Impact and enabling innovation capabilities

R&D activities within TD3.11 must have an impact on availability, reduction of disturbances, punctuality and cost-effectiveness in the operational management process as well as on the provisioning process of railway stations. Because railway stations are the way to enter the railway system as a passenger, it must be ensured that R&D activities within TD3.11 also have an impact on cutting-edge services for the customer and of course on customers directly. With this kept in mind, areas that now need optimisation and improvement are well addressed by R&D:

- consideration of the needs of passengers,
- crowd management as input for planning processes,
- equipment and quality standards including installation costs,
- subjectively perceived customer safety according to available public opinion polls,
- individualised services and customer information,
- individualised apps for intermodal access,
- sustainability and energy efficiency.

To achieve all this, a wide variety of instruments, methods and technologies will be used; for example:

- sensors for measuring and controlling changes in technical systems,
- data science, analytics, internet of things and artificial intelligence,
- predictive analytics and predictive maintenance,
- autonomous robot systems,
- simulation using digital twins,
- applied materials and structural research along with material and structural testing,
- applied comparative behavioural research, sociology and pedagogy,
- market research,
- open innovation.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Rail infrastructure becomes the available, trouble-free, punctual and cost-efficient backbone for mobility as a service and for future on-demand logistics	Results from work stream ‘crowd management and revenue protection in large stations’ will be used to optimise station design, improving the location and type of station assets to improve rail user experience and minimise congestion. Analysis and simulation of emergency and extreme events will also be undertaken to streamline and critically assess the station procedures and processes to ensure that the station infrastructure performs to its maximum in business as usual and in emergency situations Outputs from work stream ‘platform to train accessibility’ will also address the PTI issue from the platform perspective. Technical engineering as well as digital solutions will support a trouble-free and punctual service fit for PRM rail users

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Identification and establishing of new technologies and innovations to strengthen efficiency at all levels	The deliverables from the work stream 'standardisation and prototypes for small stations' will identify and validate new technologies in the rail environment. These will potentially include new materials, energy-efficient mechanical and electrical equipment, automated and intelligent building management systems to reduce carbon emissions, and digitisation of passenger information requirements through the use of phone apps and innovative tactile signage for PRM passengers. The work stream 'emergencies risk assessment of major stations' will also test and validate glazing and fixing materials to improve the safety and security of stations while analysing the whole-life cost of different combinations of materials and fixings. Cost–benefit analysis will also be carried out on results from blast testing to enable greater financial efficiency in future station design, construction and refurbishment
Optimising costs and increasing productivity and performance to improve rail's overall competitiveness by faster deployment of new system solutions and capabilities	The work stream 'standardisation and prototypes for small stations' will assess the entire customer journey or pathway chain in terms of how passengers use a medium-sized station. Improved ticketing solutions will be a key deliverable and will be validated in the rail environment. Whole-life cost analysis including construction, maintenance and disposal (life-cycle analysis) will be undertaken. Productivity and competitiveness against other forms of transport will be validated through stakeholder consultation with different station user groups including PRM, station infrastructure owners, rail passenger groups and also train-operating companies. Deployment of new technologies will be enabled through user validation of the digital and engineering solutions proposed in the work streams 'crowd management and revenue protection in large stations', 'standardisation and prototypes for small stations' and 'platform to train accessibility'.
Provision of sustainable mobility along the entire pathway chain	All work streams within TD3.11, Future Stations, will consider the latest definition of sustainable development and will include reference to environmental (decarbonisation/ low pollution), economic and social sustainability – known as the three pillars of sustainability. The work stream 'standardisation and prototypes for small stations' in particular will provide detailed sustainability information in the station design, in terms of both construction but also how the station is used, to ensure that the design ambition is achieved when the station is in use by the rail operator and passengers

This TD will contribute to enabling the following six innovation capabilities.

INNOVATION CAPABILITY	TD3.11 FUTURE STATIONS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
2 – Mobility as a service	Improve key elements of the transport chain in passenger door-to-door service process in MaaS model. Relevant building blocks: • BB3.11.1: Crowd management in high-capacity stations: improve passenger flow management in operation conditions through the use of simulation results to have fluid flows and avoid flow congestion inside high-capacity stations • BB3.11.2: Improved station designs and components: improve distribution and validation standards for ticketing systems with the use of new technologies to improve user experience • BB3.11.3: Improved accessibility to train–platform interface: ensure safe and inclusive access to trains from platforms for all passenger groups, including providing for the needs of PRM • BB3.11.4: Safety management in public areas: improve passenger flow management in standard operation conditions and in emergency situations; improve technical and organisational safety in all public areas for low-capacity small and medium-sized stations
4 – More value from data	Make better use of the data gathered in order to achieve better value from it in order to improve safety and more efficient management of passenger station (building and area) and passenger flows. Relevant building blocks: • BB3.11.1: Crowd management in high-capacity stations: use rich simulation capabilities to build a realistic synthetic world calibrated with real data and behaviour modelling, depending on use case (standard operation, emergency management) • BB3.11.2: Improved station designs and components: make better use of the data relating to passenger traffic on railway stations (station building and public areas) • BB3.11.4: Safety management in public areas: improve the use of CCTV systems on passenger stations (station building and public areas)
5 – Optimum energy use	Implement technologies to reduce energy consumption from non-renewable or difficult renewable sources in order to increase the use of solutions compatible with the concept of sustainable development. Relevant building blocks: • BB3.11.2: Improved station designs and components: improve components, optimise the types of materials used and use new technologies in order to ensure low emissions and energy demand in the railway station area during its whole life cycle (construction, operation and demolition)
7 – Low-cost railway	Improve standards for design solutions using a holistic approach to reduce operational costs of passenger stations during their whole life cycle while ensuring the expected level of service for the needs of passengers, including PRM. Relevant building blocks: • BB3.11.2: Improved station designs and components: use technical (components and materials), technology (digitisation, CCTV, service) and organisational (flexible service area) innovation solutions in order to optimise life-cycle cost • BB3.11.3: Improved accessibility to train–platform interface: improve organisational and technical methods to ensure access from platform to trains in order to reduce costs of passenger service (including service to PRM) by use of universal, common and readily available solutions

INNOVATION CAPABILITY	TD3.11 FUTURE STATIONS ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
10 – Stations and smart city mobility	Improve standards for design solutions in order to improve interoperability, accessibility, safety and security. Provide repeatable solutions to optimise the whole life-cycle costs of stations (station building and public areas) while keeping the expected level of user experience in the door-to-door transport chain. Relevant building blocks: • BB3.11.2: Improved station designs and components: improve standards for the scope of interoperability and accessibility for PRMs, and for safety in using new components, materials and digital solutions; improve standards of passenger service in stations in order to improve user experience while using universal design and non-discrimination rules; improve standards of distribution and validation in ticketing systems while using new technologies in order to improve user experience • BB3.11.3: Improved accessibility to train–platform interface: improve passenger boarding and alighting process in stations in order to improve user experience while using universal design rules; improve accessibility through implementation of universal technical and organisational solutions in scope to ensure accessibility from platform to train for all groups of passengers including PRM
11 – Environmental and social sustainability	Adapt the standards of the solutions to the requirements of sustainable development by reducing the demand for energy and the emissivity of the stations and increasing the sustainable mobility of all groups of travellers, including PRM. Relevant building blocks: • BB3.11.2: Improved station designs and components: improve standards of solutions oriented to sustainable development, and reduce emissivity and energy consumption of railway stations

3.11.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Future Stations	Safety management in public areas. Crowd management and revenue protection in large stations	Demonstration of the rail, security and vulnerability risk assessment model and the 3D visualisation tool linked with station security manual. Large-scale experiment at a high-capacity European station	Stations	5	Development of technical models including data inputs and probabilistic risk-based methodologies that will enable qualitative and quantitative outputs to inform IMs of security investment strategies and associated benefits 3D simulation tool: • simulates passengers flows • integrates passenger behaviour modelling and real data (video data) to solve the 'reality gap' problem between simulation and reality Results are used to help operators to manage stations and incidents: operator training, decision aid support with 'what if' scenarios

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Future Stations	Standardisation and prototypes for small stations	Improved small stations demonstrator	Stations	5	Innovative and economically viable solutions for small railway stations, as components, systems and modules ready to be duplicated at all types of railway station for improvement are expected to be delivered and demonstrated. Improved station designs and components thereof: develop standards and designs for small stations that will enable low energy impact and use of sustainable solutions, and will address the needs of passengers (design for all, including PRM). Intelligent solutions (systems and components) within the BIM (Building Information System) integrated with smart 3D (digital twin) will optimise station management throughout the whole life cycle. They will ensure interoperability, accessibility, flexibility in use, passenger safety and resistance to vandalism
	Platform to train accessibility	New approaches for platform-train interface design methods	Stations	5	Improve accessibility to trains for all traveller groups by addressing issues related to the PTI. Results will be an improvement in the ease of transfer as well as an improvement of the customer experience. On the basis of the current state description, the goal is to develop solutions that will allow safe and inclusive access to trains, not be too demanding on maintenance and not increase the dwell time of the trains significantly. They will ensure interoperability, accessibility, passenger safety and universal design
	Emergency risk assessment of major stations	Technical manual of options and associated benefits/ limitations for safety management	Stations	4	Simulate risk, develop basic decision support, ensure passenger safety and design for resistance against terrorism

Planning and budget

TDs	TASKS	TRL	2015				2016				2017				2018				2019				2020				2021				2022			
	Future Stations	up to	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD3.11	3.11.1 Crowd Management and Revenue Protection in large	5/6																																
	3.11.2 Standardisation and Prototypes for small stations	5																																
	3.11.3 Platform to Train Accessibility	5/6																																
	3.11.4 Emergencies Risk Assessment of major Station	4																																

◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

*Table 72 / **TD3.11 milestones***

WHEN	WHAT
Q2 2018	Work stream 1: reference use cases, scenarios and KPIs for standard and emergency operations – interim
Q1 2019	Work stream 1: in-depth technical review of best practices and latest research
Q1 2019	Work stream 3: new designs for platform-based solutions
Q4 2019	Work stream 1: reference use cases, scenarios and KPIs for standard and emergency operations – final
Q1 2020	Work stream 3: specifications
Q1 2020	Work stream 4: database
Q3 2021	Work stream 3: proposals of technical solutions to improve accessibility to trains for all groups of passengers and for PRM
Q3 2021	Work stream 2: catalogue of specifications with full methodology for existing situations
Q3 2021	Work stream 2: improvement of small stations regarding materials, components, life-cycle costs, energy impact
Q3 2021	Work stream 2: improvement of small stations regarding smart solutions, digitisation, ticketing technologies
Q3 2021	Work stream 2: demonstrators
Q1 2022	Work stream 3: final report
Q1 2022	Work stream 4: station security manual
Q1 2022	Work stream 4: model
Q1 2022	Work stream 4: technical manual
Q2 2022	Work stream 1: crowd management simulation system and tools
Q3 2022	Work stream 1: large-scale experiment at a high-capacity European station

The estimated total budget for TD3.11 is around EUR 6 million.

4. IP4 – IT solutions for attractive railway services

Context and motivation

A critical environmental challenge of the coming years is the reduction of carbon footprints, and citizens will be asked to reduce their car usage as much as possible. One of the effective contributions of S2R to support this challenge is to make travelling by rail a more attractive component of a lower-carbon mobility ecosystem.

The capacity to seamlessly integrate the rail transport modes into the overall mobility ecosystem, offering door-to-door journeys using multiple modes of transport, is a prerequisite to foster the use of rail over private vehicles, enabling reduction in traffic congestion and associated greenhouse gas emissions, among other benefits.

Currently travellers are faced with barriers when trying to plan a journey that mixes rail transport with other modes: these include needing to access multiple sources for timetables and planning information, needing to carry and purchase multiple tickets for the different parts of the journey, and adjusting to different means of paying fares, interfaces, devices, conventions, procedures and tools developed over the years by many retailers, operators and distributors.

In addition, different transport modes (air, main line rail, urban rail, buses, etc.) have grown independently at diverse speeds and over different periods of time, without any general plan, and are exploited by different operators. Even if there is some level of standardisation within each mode, a passenger using different modes of transport is confronted by the lack of interoperability.

This makes multimodality patchy and, as a consequence, travellers are unable to exploit the diversity of the marketplace easily and have little control in managing their travel. Without an end-to-end, one-stop shop experience, travellers have to manage for themselves how they search for their itineraries and purchase their tickets, by interacting with very different systems and interfaces that cover only parts of their trip. Current ticketing and validation systems vary greatly between transport modes and operators in terms of concepts, architectures and equipment, requiring conscious effort for travellers to combine them. Level of service, capability description, booking, pre-payment versus post-payment, validation media and profile of users vary greatly from one system to another. The consequences are that citizens must often switch between sites, ticketing devices or offices in order to shop for, book and pay for the components of their intended journeys, and must have multiple tickets to validate through a multimodal journey.

On top of this, there is little in-trip assistance for travellers when navigating transport nodes, encountering service disruption or wanting up-to-date status information on the subsequent legs of their journey.

This is why the European Commission in the *White Paper for Transport* (2011)([4]) identified this challenge as one of the 10 main goals of the coming years: ‘By 2020, establish the framework for a European multimodal transport information, management and payment system’.

With this overall objective in mind, there are a number of specific challenges that will need to be taken into consideration.

([4]) https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

Access to heterogeneous data

Among the challenges in the travel marketplace, an important one is access to data: timetables, fare products, prices, discounts, links with other modes, specific information related to traveller preferences, real-time information on the transport offer and others. In this context, a major trend in Europe, mainly coming from the public sector, is around open data.

Giving access to data is mainly a business problem: the operators must have an interest in sharing their data, they must have guarantees about the usage made by third parties and it must be clarified who is responsible to the final user for the quality and reliability of information provided. The market uptake will depend on the data available to support market growth.

But the challenge is not only access to data; it is also the heterogeneity of data format, which is critical in a multimodal context. Data standards exist in the rail sector: Telematics Applications for Passengers – Technical Specifications for Interoperability (TAP-TSI) and Service Interface for Real Time Information (SIRI), among others. Different ones exist for other transport sectors.

Because the objective is to facilitate multimodal transport for the benefit of the rail sector, bridges between these standards must be defined. The option that has been chosen in the S2R IP4 context is to develop an interoperability framework (based upon semantic technology), which offers ways to automate at the framework level (not at the application level) the translation between standards.

The main interest of an operator in using the interoperability framework is to become visible by means of an open-ended world of service resources on the marketplace, which is a condition for increasing business. Moreover, the technologies used in IP4 give some guarantees that can facilitate market uptake. The interoperability framework, using semantic technologies, proposes a more controlled environment (data access, usage control) than a complete open data approach. Annotation contributes to protecting data, as it permits the fixing of commercial conditions, or definition of specific mechanisms to enforce access control. Moreover, the interoperability framework overcomes the cost issue related to data format at application level, but also when publishing the data. These innovative technologies should make the operators be more prepared to share and publish their data. Although IP4 places the traveller at the centre and makes passengers' comfort the main target, by increasing the attractiveness of rail and other collective modes we also expect to increase the number of users of these modes and, therefore, improve operators' business. This means that, by joining the IP4 transport ecosystem, operators will benefit from multiple advantages such as making information about their services more accessible to users, or getting valuable insights into travellers' behaviour.

Data privacy, security of personal and financial data

Another challenge stems from the security issue. Personal information (in particular, traveller preferences and their planned and booked itineraries) is stored in the Travel Companion wallet, and so are assets with significant financial value (long-range aeroplane entitlement tokens, for instance), for which protection and resilience against cyberattack must be guaranteed. The opportunity offered to retailers and operators to access information in the wallet (e.g. to read preferences) must be carefully controlled, and adapting it to user profiles, must be subject to explicit consent. A security challenge also exists in the booking and ticketing processes, in which financial data are managed in order to support settlement payments and clearance.

Moreover, applicable from May 2018, the General Data Protection Regulation (GDPR, Regulation (EU) 2016/679) now regulates the processing of personal data relating to individuals in the EU. The relevant IP4 developments will have to comply with it.

Objectives of the IP and expected results

To support a modal shift, rail must become more attractive to the end user; this will come with additional comfort and better reliability of the rail system, but also from simplifying all the stages of the passenger journey and by ensuring better connection with travellers' daily life.

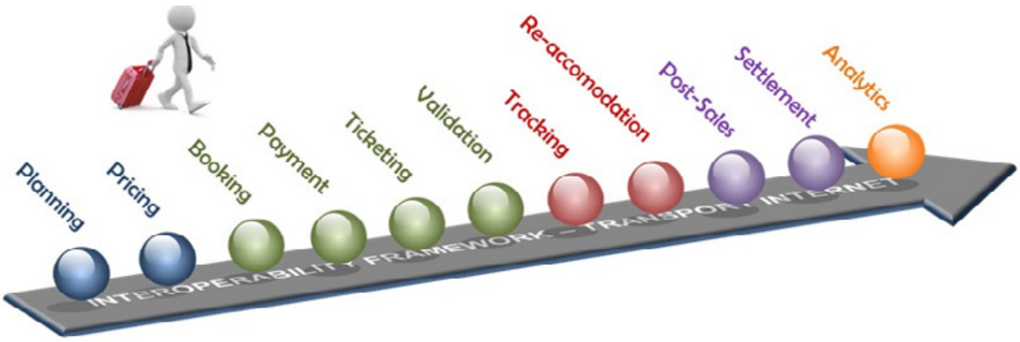
The target is to transform the European citizen's global travel interactions into a fully integrated and customised experience, rendering the entire European transportation system a natural extension of citizens' work and leisure environments, across all transport modes, local and long-distance.

This transformation, or digitalisation of the transport ecosystem, will also boost the expansion of new transport paradigms and concepts such as MaaS, based on giving individuals access to a packaged offer from travel service providers. To put MaaS concepts into practice, it is essential that the different parts of the transport system are seamlessly interoperable.

IP4 will lead to an increase in rail attractiveness, supporting a major shift to rail through:

- a seamless door-to-door travel experience, with a multimodal travel offer connecting the first and last miles in long-distance journeys, by combining air, rail, coach and local modes of transport;

- seamless access to all travel services, with the integration of all steps of a journey (from planning to aftersales).



This core objective of extended seamlessness will be delivered though the introduction of a ground-breaking technical enabler driven by two key concepts:

- The travel experience becomes the inclusive 'product', with the traveller placed at the very centre. This user-centric shift ensures that multimodal travel services mask the complexity of the transport system and offer a whole new door-to-door travelling experience with strong appeal, simplified access and trusted reliability.

- An open published interoperability framework (IF) will allow unprecedented service interoperability while limiting impacts on existing systems, without prerequisites for further centralised standardisation. Transport industry incumbents and newcomers will discover significant opportunities to provide new services, products and competitive business models, such as MaaS.

The overall strategy for IP4 developments can be summarised as follows

- IP4 will develop not a one-size-fits-all solution (or set of solutions) but a marketplace, where all transport stakeholders will find an open-ended world of data and service resources, which can be combined for improved services. IP4 is not about imposing solutions; it is about enabling market players and new entrants.

- Even though IP4 will encourage open data, it will accept any kind of data in any standards, interpreted by the IF. IP4 provides the mechanisms to access and orchestrate data and processes wherever they happen to be located. IP4 is completely agnostic about whether data and processing are centralised or distributed.

- Only parts of IP4 developments will be open source, but all specifications and interfaces will be open (access free), and every company can use them to develop equivalent (or additional) services. Reference implementations for the key services will be developed using the open specifications and will be presented as services hosted by the 'web of transportation'.

- IP4 is completely agnostic about whether products and services are directly or indirectly distributed.

- IP4 will be completely distributed (no centralisation of data or processes, no imposed technology) and modular. IP4 does not mean a centralised data and/or processing centre, or a single centralised platform for customers to get their multimodal travel plans and tickets. It is about facilitating these capabilities everywhere.

Table 73 summarises the main objectives of IP4 and provides an overview of some of the concrete deliverables that can be expected to result from the activities undertaken in the IP.

Table 73 / ***Objectives and challenges of IP4***

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Enhance the (capacity and) user demand of the European rail system	Provide a one-stop shop to the customer (able to handle any mobility query) and give visibility to all accessible trips	Travel shopping will propose specifications and reference implementation designed to be scalable to all transport modes and all operators and to support shopping over all types of distribution channel (direct, indirect, online, offline, etc.)
	Provide unified access to ticketing services for all transport modes, regardless of their location, access method or format, and validation process	Booking and ticketing will provide specifications and reference implementation covering 100 % of 'standard' entitlements (air, train, long-distance bus, daily/weekly/ passes, origin–destination/zonal, etc.)
	Provide a personal 'guardian angel' that gives access to all information and additional services, and simplify the user travel experience taking into account the user's preferences	Implementation of a 'Travel Companion' with innovative human–machine interfaces
	Better adaptation of supply to demand	Business Analytics will help operators adapt their services to the demands of the marketplace and deliver a more effective, optimised and satisfactory service

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Consolidate the (reliability and) quality of services	Increase the attractiveness and transparency of the rail system for the passengers	Trip Tracker will provide real-time information on all legs of the current trip, including access to alternative journey options and re-accommodation services if required
Improve LCC/competitiveness	Foster an extended competitive market of advanced applications and interoperability products and services	Open specifications, detailed open interfaces and access to the open interoperability framework will offer to any European travel industry player the tools to develop competitive and smart services, based on the framework defined in IP4. The amount and heterogeneity of data and the improved business analytics process allow more efficient operations and use of resources

Key performance indicators for IP4

The KPIs for IP4 are dissimilar to those used in other IPs (capacity, reliability, LCC). The increase in passengers, resulting from IP4 activities improving the attractiveness of the rail sector, is a prerequisite for the other IPs; we will only need additional capacity if we are able to attract more passengers.

The S2R initiative seeks to increase the capacity for a given infrastructure, by increasing the number of trains (control and command), while increasing the number of seats per train (rolling stock) and reducing the LCC (of the rolling stock and infrastructure). All of these constitute major steps. It is also essential, however, to increase the number of passengers (occupied seats) by providing them with better reliability and quality of service, including one-stop shopping and seamless travel, and through better integration of rail into the overall mobility ecosystem.

An in-depth analysis of the best way to quantify the increased attractiveness that IP4 brings is carried out for each CCA responsible for the KPIs for S2R. Starting with a list of obstacles to taking the train, derived from various inputs/projects, each IP4 TD assesses how the activities developed in the TD contribute to removing some of the obstacles, and this is used to derive KPIs for attractiveness, and possibly a quantification of the modal shift.

Strategic and business impacts

Travel service providers, both present and future, will benefit from IP4 by the elimination of the need for any common and scheduled platform interfaces developments. By supporting full semantic interoperability of interchangeable and loosely coupled tools, data and services, within a distributed web of transportation, multiple concurrent implementations can be developed independently by specialist suppliers and coexist competitively. This will apply downward market pressure to the cost of sourcing tools and technologies for travellers, retailers and operators, while allowing them to retain full control of the choice of business models through which their services are utilised or provide value.

Through the implementation of specific use cases, the traveller, the services retailer and transport operator will perceive beneficial impacts:

- Passenger services: the Travel Companion will give easy access to IT services adapted to passengers' profiles influenced by their preferences. Thanks to the connection between the preferences and the geo-localisation of the person, many innovative IT solutions can be developed covering all aspects of social life (culture, degree of mobility, aesthetic considerations, merchandising, etc.).

- The market for transport services (shopping, ticketing but also services related to guidance) will be opened up thanks to the interoperability framework. The fact that the heterogeneity of the transport market is now masked by the interoperability layer will decrease the investment costs for advanced IT solutions, and will open up a new competitive market.

Past and ongoing European and national research projects

The proposed approach will consider relevant major projects and initiatives running concurrently (see table below; additional projects are also listed in the various TDs). The identified liaison will allow the incorporation of external innovations while promoting the key concepts of S2R IP4 to other groups.

MAJOR PROJECTS	VALUABLE OUTPUTS FOR IP4
Telematics Applications for Passengers – Technical Specifications for Interoperability (TAP-TSI)	A common denominator set of standards for the rail industry designed to establish baseline standards for cross-border rail services, including reference data for location codes and company codes. This legislation is legally binding in the EU
Full Service Model (FSM)	Door-to-door rail product and service distribution across all distribution channels (domestic and cross-border)
All Ways Travelling (AWT)	European project: study and POCs showing that integration of long distance and local transport capabilities can be achieved without integration of standards
Smart Ticketing Alliance (STA)	Relevant trust schemes and specifications defining urban needs for cross-border ticketing technologies
EU-Spirit	A cross-border and Internet-based travel information service for customers of public transport
Mobiwallet	Integrating different payment means for multiple transport modes, fostering seamless travel and providing other added value services to improve intermodal journeys
IT2Rail	The S2R lighthouse project initiating IP4 activities
Co-Active and ATTRAcKTIVE	The two IP4 projects for members that started in September 2016, covering TD4.2, TD4.3, TD4.4 and TD4.5
GoF4R and ST4RT	The two IP4 open calls that started in September 2016, covering governance and some technical activities for the interoperability framework TD4.1
Connective	Call for Members (CFM) project (2017) continuing IT2Rail activities for TD4.1
Cohesive	CFM project (2017), the integration project (ITD) for IP4
MaaSive	CFM project (2018) covering TD4.2, TD4.3, TD4.4 and TD4.5
MOBiLus (EIT Urban Mobility)	Accelerating solutions that improve the collective use of urban spaces, while ensuring accessible, convenient, safe, efficient, sustainable and affordable multimodal mobility

Progress has been made on standardisation within the rail sector, epitomised by the TAP-TSI regulation (Commission Regulation (EU) No 454/2011) and implementation project together with the objectives of the FSM project. With regard to inter-transport mode standardisation, apart from the NeTEx/Transmodel CEN technical standard, objectives are arguably difficult to pursue since the pace of evolution of the transport industry outstrips the pace of such efforts. Given this, IP4 draws on current and emerging sectorial standards.

IT2Rail, the S2R lighthouse project initiating IP4 activities, is used as a ramp-up towards S2R IP4 full capabilities.

Set-up and structure of IP4

To achieve its objectives, IP4 will conduct work in three R&I areas listed in the Master Plan.

- Technical framework

Enforcing multimodal travel in a very diverse environment and with many transport modes is the role of the Interoperability Framework (TD4.1): the world of transportation service providers needs to be open-ended, evolves at its own pace, and uses multiple data formats and interfaces. Interoperability is positioned at the *semantic* level and defines formal and explicit models of the transportation domain in an open standard machine-readable language that will be exchanged automatically by computers.

All the services related to individual travels and to additional sensors will generate a lot of data, which have great value for the operators and the end users: an open-ended world of networked sensors, devices, social media, services and transactions that is not centrally coordinated. It will be the role of Business Analytics (TD4.6) to manage those data. Novel big data technologies such as intentional semantic information (denoting objects by properties rather than by values) will improve the capabilities to analyse distributed and heterogeneous linked data, creating huge possibilities to generate unprecedented insights for all the members of the ecosystem, and new intelligence for the benefit of operators and travellers.

- Customer experience applications

It is a key objective to provide travellers with seamless access to all travel services and enhance their travel experience. In IP4, the travel experience becomes the product, with the traveller placed at the heart of innovative solutions.

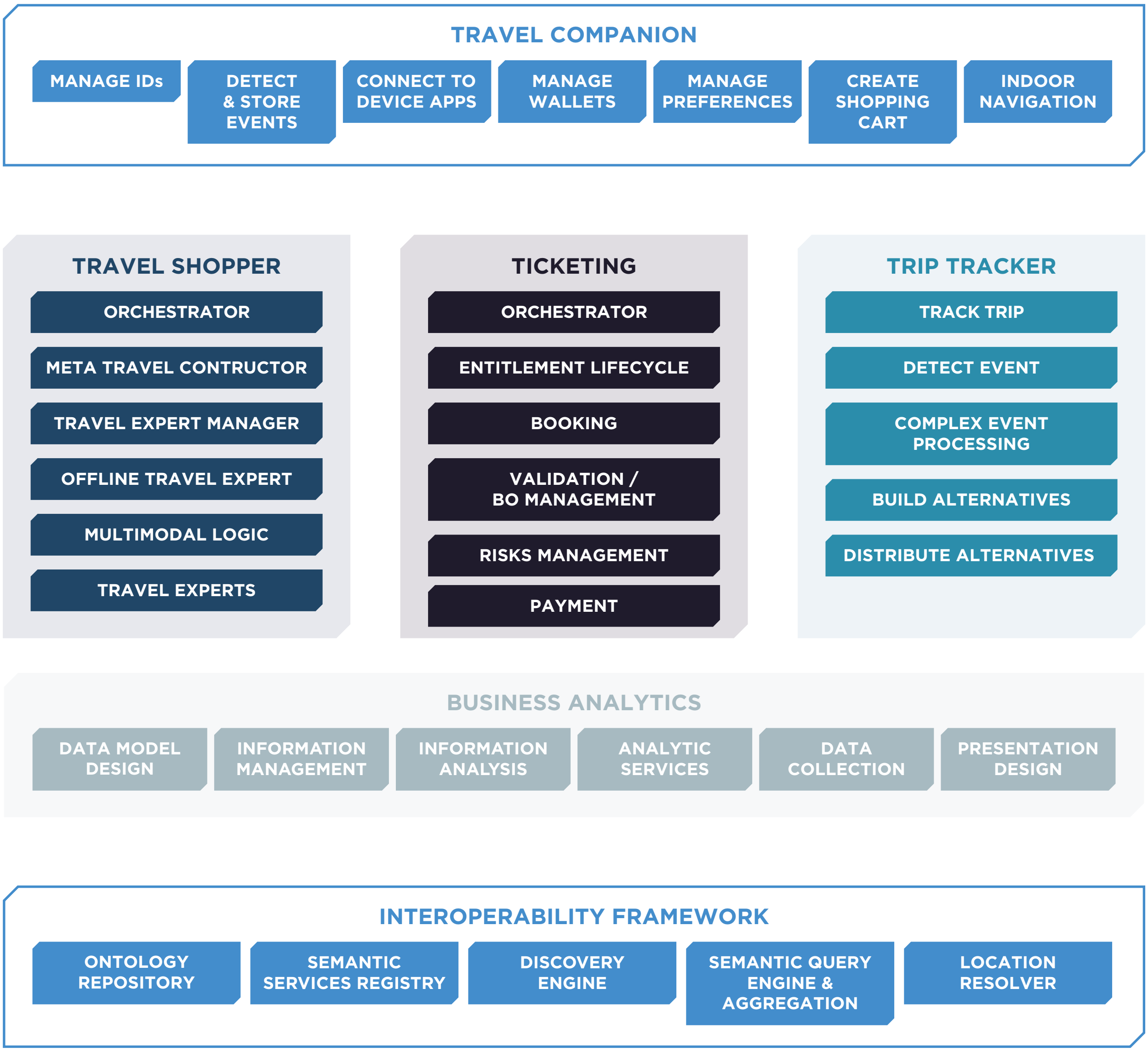
The traveller will have full control of the journey thanks to their own personal and secured Travel Companion (TD4.5), storing and sharing their personal preferences in a wallet. The Travel Companion gives access to all travel services needed for the journey, shopping and booking; allows storage of evidence of the right to travel; and provides guidance within stations. At the same time, retailers and operators are able to identify and authorise Travel Companion access to their own systems and networks. Through the Travel Companion, the traveller can also monitor their journey in real time. This is done by Trip Tracker (TD4.4) providing continuous monitoring of the journey, personalised information (related to preferences stored in the Travel Companion) and up-to-date status of the subsequent legs of the journey, and supporting the traveller in the event of disruption by proposing new travel alternatives with the possibility of booking and acquiring updated rights to travel.

- Multimodal travel services

To engage on a multimodal journey, the traveller today must switch between several websites, retailers and ticket offices in order to shop, book and pay, and must have fares and tickets in multiple media to validate through the journey. The IP4 approach aims to hide this complexity and enable one-click shopping and booking/payment and ticketing for complete multimodal itineraries. Travel shopping (TD4.2) will provide a comprehensive shopping application enabler that combines all modes of transport, all operators and all geographies, and provides a list of customer-relevant trip offers, which are all guaranteed available for booking, purchase and ticketing. Our approach will promote the integration of distributed travel operator data and the orchestration of services such as expert journey planning. The Interoperability framework facilitates both aspects by enabling applications based upon different standards or coding lists to communicate meaningfully but with no costly application adaptations.

Booking and Ticketing (TD4.3) will orchestrate multiple but parallel interactions with several booking, payment and ticketing engines, including the all-important roll-back activities should any single transaction fail, in order to eliminate risk. Thanks to the concepts of a unique traveller identifier and the Travel Companion wallet, the traveller will have easy access to the complete and integrated components of their journey, including easy production of the entitlement tokens required for all ticket validation controls encountered en route. The creation of a unified approach for entitlement life-cycle management will radically simplify the traveller's life by abolishing constraints associated with behind-the-scenes multiple booking, payment and ticket processes. Although downward compatibility with existing and legacy systems will be possible for operators joining the scheme without modifying existing equipment, our approach will promote new technologies such as NFC (near-field communication) and EMV (Eurocard, MasterCard and Visa) and smartphone integration.

The following picture depicts some of the functionalities that have to be developed.



Although IP4 is organised around TDs with clear and non-overlapping objectives, all the inputs are contributing to a specific IP4 integrated technical demonstrator (ITD4.7), which is the orchestrator of the TD developments and provides the whole-system approach to integrate the different TDs' results.

Approach within the IP

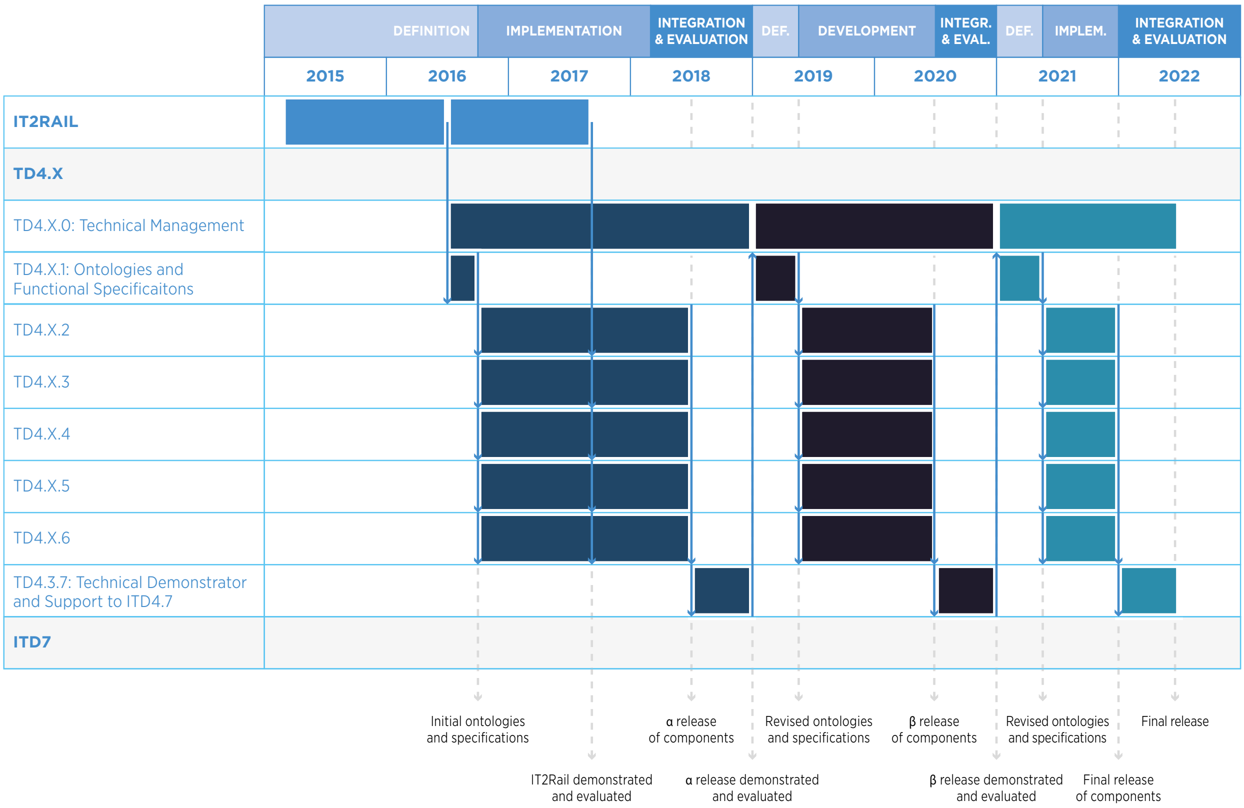
The overall method is to target a level of complexity and maturity for the system (scope and TRL), defined through releases at ITD4.7 level, and to identify the functions (at TD level) to achieve this objective.

The overall methodology for IP4 will be iterative, with releases, on a regular basis and for all TDs, of successive versions of enriched deliverables, from early conceptual prototypes to the final version.

There will be in total four releases: the first one is the final deliverable from the IT2Rail lighthouse H2020 project, which starts all activities with reduced complexity and a low TRL (TRL 4–5). Then the subsequent releases will (1) increase the maturity (TRL level) of the functions already developed in the previous releases, and (2) introduce new functions with lower maturity (TRL 4). Preliminary scope descriptions for each release are listed in (I)TD7.

The objectives are to target with the final release an almost complete set of functionalities answering to the Master Plan objectives (see above) and to achieve a maturity level of TRL 6 minimum.

As a consequence, all IP4 developments will be regular and developed in parallel in the different TDs, following the four system releases as shown in the scheme below.



Links to other IPs and ITDs

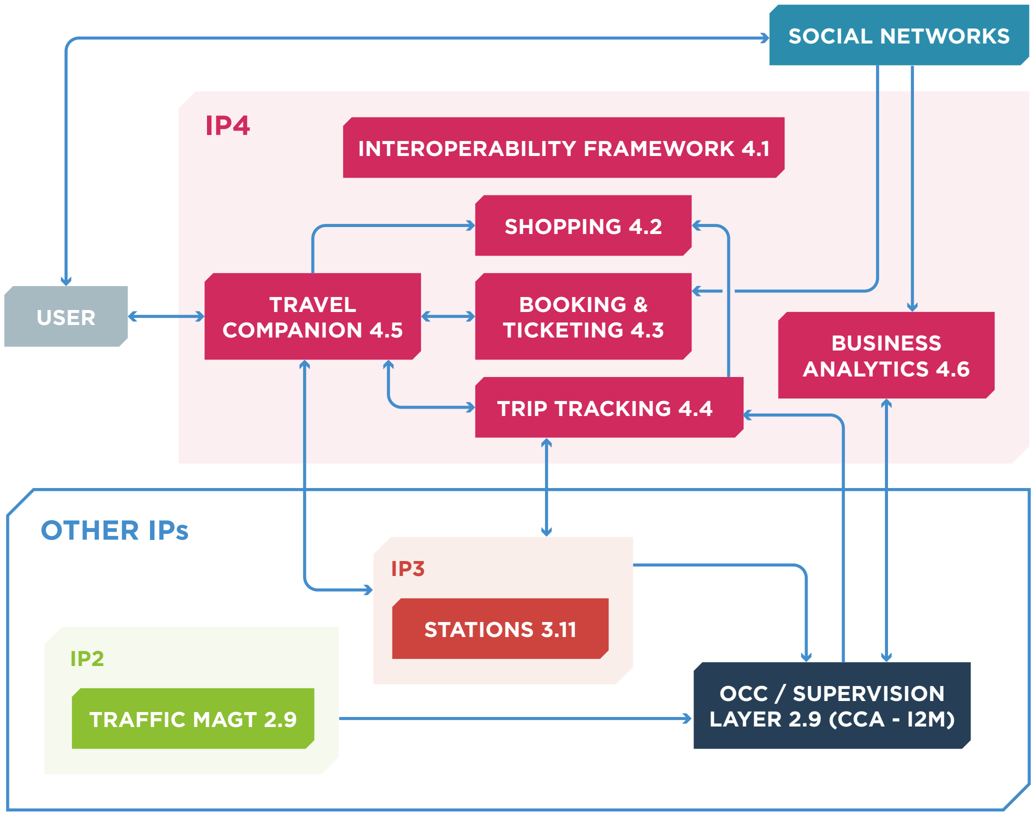
The coherence of IP4 with the other IPs comes mainly from one of its objectives, which is to give the user real-time information about traffic on the current and future legs of the journey. The status of operations is given through Trip Tracker, which monitors in real time the complete journey, and must be informed about any disruption, delay, cancellation and alternatives. Conversely, business analytics collects information about the flow of travellers, which allows the optimisation of the operations.

			S2R IP4						
			TD4.1	TD4.2	TD4.3	TD4.4	TD4.5	TD4.6	ITD4.7
S2R IP1	TD1.2	TCMS				->			
	TD1.6	Doors and access					->	<->	
S2R IP2	TD2.1	Communications				->	->		
	TD2.9	TMS	<-			->		<->	
	TD2.11	Cybersecurity	->			X	X		X
S2R IP3	TD3.6–8	Maintenance				->			
	TD3.11	Future stations			<->	<->	<->	<->	
S2R IP5	TD5.2	Access and operations	<-						
CCA	WA1	Social network				->	->	<->	
	WA2	KPI development						<->	
	WA4.1	Smart planning						<->	
	WA4.2	I2M	<-	->	->	->		<->	

The main interconnections are therefore with IP2/TMS, IP3/stations and I2M (integrated mobility management) CCA. Information coming from these TDs can potentially be monitored in real time by the Trip Tracker and used to inform the passengers and propose alternative solutions.

In addition, one of the main purposes of Business Analytics TD is to propose an adequate fit between the supply and the demand. Even when this feedback is not given in real time, the information collected is a key driver for the planning of traffic, and then gives back input to IP3 for infrastructure management and IP2 for traffic management.

In addition, the existing interactions with other IPs and within relevant TDs of IP4 take into account the work on the S2R rail Functional System Architecture and Conceptual Data Model (CDM) performed in IPx.



4.1. TD4.1 Interoperability Framework

4.1.1. Concept

The aim of this TD is to enable a complete digital transformation of the European transport ecosystem into a global services and data marketplace, liberated from technological barriers, where actors and business models will be able to emerge and prosper for the benefit of European travellers.

This TD will address the fundamental obstacles impeding the deployment of true multimodal IT systems, such as:

- the multitude of data formats across modes and services;
- the absence of connectivity standards for IT systems across modes and actors;
- low availability of good-quality data, including real-time data;
- high integration costs due to non-interoperable IT systems;
- the large number of specific solutions for different use cases;
- reluctance to share data and services on the part of those who benefit from the current fragmentation.

The Interoperability Framework should provide technical interoperability making possible the digital transformation of rail and, in general, the entire transport ecosystem, by enabling the creation of an open 'web of transportation': a shared distributed database of transportation data built using internet technologies. Linked data principles supported by the semantic web will be considered, besides ultimate advances in architectures and big data technologies for multiformat data management. It aims to provide a shared, fully described and machine-readable abstraction (ontologies) of transportation data and services, provided and consumed by information systems independently from their internal organisation and representation.

This semantic approach allows the Interoperability Framework to encapsulate the complexity of interoperability across heterogeneous distributed systems. It insulates customer applications such as shopping and booking from the heterogeneity of transport service provider (TSP) systems, removing the need to adapt TSP systems to make them part of a network of services available, minimising the need for static exchange of datasets, and giving these applications the capacity to interpret or understand the different data representations and concepts used by the different TSPs.

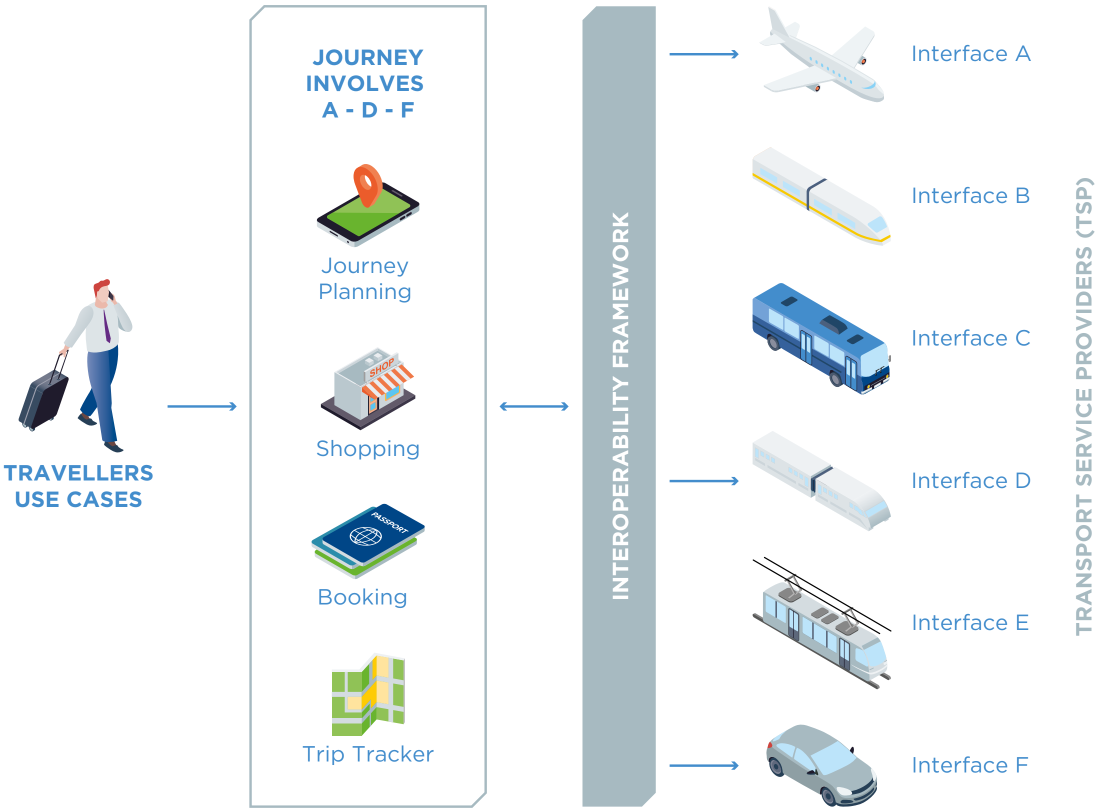


Figure 36 / ***IF within the IP4 transport ecosystem***

4.1.2. Technical objectives

It is possible to identify the following objectives for the implementation of the Interoperability Framework, in which business applications are rendered interoperable through the unified, machine-readable view of the travel and transportation domain realised as the web of transportation.

1. Share and distribute travel and transportation domain knowledge (ontologies) to facilitate automation of interoperability.

2. Harmonise approach to transport services. Provide business applications with a uniform view of all available data and service resources, regardless of their location, access method or format.

3 Provide software components that handle semantic interoperability, to be used by other IP4 applications for specific functionalities.

4 Allow multiple independent implementations and concurrent deployment of multiple instances.

5 Reduce development and integration costs of both legacy and new systems/actors. Foster an extended competitive market of advanced customer experience applications and interoperability products and services.

4.1.3. Technical vision

The main ambition of TD4.1 is the digital transformation of rail and all transport services through the provision of the framework, tools and technologies that will allow data exchange among different members of the transport ecosystem, providing mechanisms to separate data consumers from the complexity of varied data formats and non-integrated services, facilitating interoperability among systems and creating added value services to achieve a seamless multimodal door-to-door experience.

STATE OF THE ART	ADVANCES OF THE IF
Currently the transportation domain uses multiple syntactical schemas to represent the information. This is one of the main barriers that hinder the development of truly multimodal systems and seamless travel services, and results in a fragmented vision of the ecosystem	It will provide the framework, tools and technologies that will allow data exchange among different actors of the transport ecosystem, providing mechanisms to separate data consumers from the complexity of varied data formats and non-integrated services, facilitating interoperability among systems and creating added value services to achieve a seamless multimodal door-to-door experience
Specifically within the rail domain, several projects have tackled the challenge of integrating IT systems to make them interoperable, resulting in the development of many interfaces and data format standards, and sometimes in the generation of additional ad hoc solutions adopted through agreements by a small number of partners	It develops an open and extensible semantic web-based standard encapsulating interoperability problems and removing them from the IT assets' business logic. The IF will also constitute the 'reference' implementation of the specification, to be used as a compliance benchmark for alternate implementations. The plan is to develop a new concept map whereby integration and harmonisation are mandatory for building a complete transport ecosystem covering all the stages of the value chain. Moreover, mechanisms will be provided to ease and automate the publication of new travel service providers information, aiming to make the introduction of new actors easier and more seamless
The essential limiting feature of the approach to interoperability adopted in the past has been treating it as a matter of describing common formats or codes to describe data items to be exchanged. Although this could be sufficient for machine-to-machine exchange of data, the real meaning of this data is not understandable by computers. Therefore, cognitive effort is required to understand and interpret the digital representation of business entities and their associated context, meaning and assumptions	The common language for the decentralisation of management is defined by unambiguous semantics, based on the definition of a complete semantic model, using ontologies to identify the concepts representing the information. The semantics should support the underpinning legislation and European standards (such as TAP-TSI and NeTEx, but also ongoing initiatives such as FSM). This language based on semantics is highly flexible and reusable

Sharing such non-machine-readable knowledge assumes a relatively close and centrally coordinated community of participants who are already experts in the domain, limiting market uptake and the base of possible solution suppliers, and creating significant barriers to entry	The Interoperability Framework is an open specification based on open semantic web standards using linked data/linked services principles, with no predefined architecture and no mandatory centralised components. The provision of a web of transportation guarantees decoupling among systems and makes it easier to expand the model, allowing the fast integration of systems
Each stakeholder is an eager owner of its own information, bearing in mind the risk of sharing data beyond the potential benefits of new value chains	The IF minimises the need for static exchange of datasets. For example, the TSP can be reached by the customer applications at the time the multimodal ticket is being issued; there is no need for a centralised database that includes ticketing information from all the members of the ecosystem

Interaction with other TDs (in the same IP and/or in other IPs)

The Interoperability Framework involves the specification of generic capabilities to allow any compliant rail business application to interoperate. It provides other IP4 functionalities (such as Shopping, TD4.2, or Booking and Ticketing, TD4.3) with the ability to interoperate with legacy systems, and this approach could also be applicable to other IPs. Within IP4, TD4.1 acts as a 'horizontal' layer, and it is related to all other IP4 TDs.

At S2R level, TD2.9 TMS, CCA I2M or TD5.2, for example, entails an exchange of data among systems. The concepts and approach proposed for TD4.1 could also be applicable to these other domains, although in that case the required ontologies need to be defined to allow semantic interoperability of systems.

There is also a close connection with TD2.11, Cybersecurity, as TD4.1 is related to information exchange among systems, of which cybersecurity is an important component to preserve the privacy and integrity of the data exchanged.

4.1.4. Impact and enabling innovation capabilities

The main benefits that the Interoperability Framework will include:

- Enabling a complete digital transformation of the European transport ecosystem into a global service and a marketplace for third parties, including SMEs. Digitalisation will make it possible to create an environment that will facilitate the discovery, aggregation and use of information. Data available will foster the emergence of new market opportunities and services that exploit this information.

- Liberating from technological barriers. Actors and business models will be able to emerge and prosper for the benefit of European travellers.

- Promoting the development of a large competitive market of independent and autonomous suppliers of business services, applications, devices and systems to the travel and transportation industry by dramatically reducing the overhead, business and financial costs associated with making such services and applications interoperable.

- Promoting the development of a large competitive market of independent and autonomous suppliers of interoperability products and services to developers of travel and transportation devices, applications and systems, thus subjecting the cost of interoperability to downward market pressure.

In addition, TD4.1 developments will contribute to the following strategic aspects.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Cost reduction	Enhanced interoperability will make it possible to reduce the cost of interoperability between current systems and new ones; the costs of acquisition of customer experience systems for railway operators (and other TSPs); and the costs to railway operators of product distribution through third parties. It will also foster reusability and data harmonisation
Increased revenues	It will create new value chains, generating additional revenue to retailers and railway operators from richer product offerings and smart services to customers
More agility	The flexibility of the framework will reduce the time to market of advanced customer experience applications. Data available through the IF will foster the emergence of new market opportunities and services that exploit this information. Simplified integration of new entrants into the ecosystem and easy adaptation to market changes will accelerate market uptake
Better experience for customers	Travellers are shielded from fragmentation of services, modes and geographies. Integrating fragmented platforms and systems will contribute to a more attractive rail system as travellers enjoy continuous access to their personalised journey information systems and perceive their journey as a seamless extension of their working or leisure environment. In addition, by aggregating suppliers' systems into the offering, it will encourage the market of specialist suppliers of products and services to be compliant with the IF specification, thus putting additional downward pressure on the cost of interoperability for customer experience system developers

This TD will contribute to enabling two innovation capabilities as follows.

INNOVATION CAPABILITY	TD4.1 INTEROPERABILITY FRAMEWORK ENABLERS AND TECHNOLOGICAL BUILDING BLOCKS
2 – Mobility as a service	TD4.1 aims to move a step forward towards the digitalisation of the transport ecosystem and boost the expansion of new transport paradigms and concepts such as MaaS, based on delivering complete mobility solutions and packages to each individual, and integrated access to a complete offer from travel service providers. To put MaaS concepts into practice, it is essential that the different parts of the transport system are seamlessly interoperable, which is one of the core objectives of TD4.1. Moreover, TD4.1 contributes to ensuring connections between the different modes, including rail integrated with other modes, and ensures access to information along the travel chain, as defined in the MAAP Part A description for MaaS. Relevant building blocks: • BB4.1_1: Reference ontologies and resolvers • BB4.1_2: Services registry • BB4.1_3: Converter tools • BB4.1_4: Semantic discovery, query, aggregation engines
4 – More value from data	The IF facilitates the sharing of relevant information among systems, enabling the development of new services and applications to the benefit of the railway and its customers. Relevant building blocks: • BB4.1_1: Reference ontologies and resolvers • BB4.1_2: Services registry • BB4.1_3: Converter tools • BB4.1_4: Semantic discovery, query, aggregation engines

4.1.5. Demonstration activities and deployment

The Interoperability Framework demonstrator handles all interoperability tasks and is therefore the mediator of all interactions between technical demonstrators within IP4 and across data assets provided by multiple organisations. As it is a complex technical foundation for all technical demonstrators, it is important that the strategy for its development is provided with built-in capabilities adapted to minimise risks to the successful completion of the entire IP4 programme, and for it to be coherent with the consistency and convergence mechanisms designed in ITD4.7 to guarantee overall integration of the IP4 products.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Interoperability Framework	Definition of the framework and ontologies	Specification, ontologies	Generic	5	Identify, formalise and document requirements and global specifications for interoperability across IP4 TDs' applications, and integrate ontologies defined in other TDs
	Integrate travel service providers and resolvers	Specification, architecture and interface, software development	Generic	6/7	Deploy components for the integration of legacy systems of travel experts, including the mechanisms to register, annotate and discover the TSPs and their data. Provide resolvers based on semantic interoperability mechanisms
	Architecture and interface with other IP4 components	Specification, architecture and interface, software development	Generic	6/7	Integration with orchestrators and other IP4 components

The first release was the result of the IT2Rail project. It proposed an approach reduced to the scale of a specified use case without weakening any of the key concepts of IP4, such as the usage of semantic web technologies, and worked on starting to build the Interoperability Framework that will be completely settled in the context of the S2R IP4. The use case presented for IT2Rail was a selection from all the possible use cases that will be addressed by the S2R IP4. The use case was defined as a specific instantiation of the concepts, and laid the foundations for a completely scalable architecture fully instantiated in IP4.

As IP4 evolves, and extended functionalities, new approaches and new transport modes are included in new releases of the several TDs, TD4.1 developments are being extended to support the new functionalities required and the new information and services included. Furthermore, the platform will improve its performance through new tools and resolvers, and greater automation of processes. This will be reflected in the different releases (alpha, beta, final).

Planning and budget

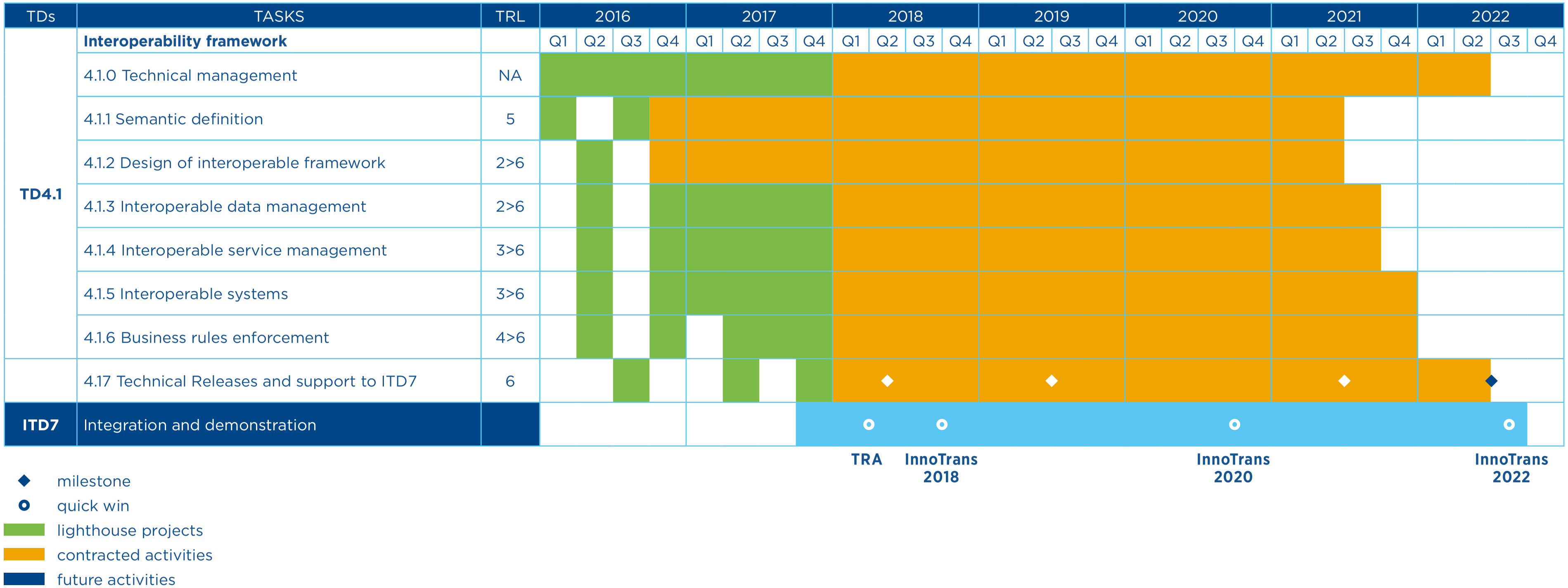


Table 74 / ***TD4.1 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q3 2018	Integration of existing relevant features to develop use cases during InnoTrans event: in live demonstration	The IF and its functionalities will support an end-to-end demonstration in a controlled environment. It will reflect the initial works within the Connective project, focused on integrating IF components based on IT2Rail results to cover the ATTRACkTIVE and Co-Active projects' requirements
Q3 2020	Integration of existing relevant features to develop use cases during InnoTrans event: following the MaaS concept	The IF will also be the backbone of a demonstrator following a MaaS approach, complementing the work of the MaaSive project with Connective developments in TD4.1. It will allow the performance of the IF to be demonstrated at a larger scale, including new types of travel experts, and adapting the interfaces to the new orchestrators and business applications deployed in the complementary TDs of IP4
Q3 2022	Integration of existing relevant features to develop use cases during InnoTrans event: enhancing the MaaS concept	The IF will interact with all the components developed in the IP4 ecosystem

Table 75 / ***TD4.1 milestones***

WHEN	WHAT
Q2 2018	Integration of all features developed in the IT2Rail project, May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRAcKTIVE project, September 2016 until May 2019
Q2 2021	Integration of all features developed in the MaaSive project
Q2 2022	Integration of all features developed in the last IP4 project

The estimated total budget for this TD is around EUR 9.4 million.

4.2. TD4.2 Travel Shopping

4.2.1. Concept

The concept of TD4.2, Travel Shopping, is both to enable and to respond to an emerging single European multimodal transport marketplace within a Single European Transport Area by setting up the fundamental information service for journey planning and offer building.

The prime characteristic of such a marketplace will be the capability of a critical mass of European travel/transport retail outlets to offer door-to-door travel solutions for customers' (European residents' and visitors') mobility needs and preferences with implications for any sort of travel within the Single European Transport Area.

TD4.2's technical enablement of this capability is fundamentally distribution channel agnostic, meaning that all retailer operations, whether belonging to third parties (indirect) or to specific transport undertakings (direct) can be supported by this technology.

Today's reality of multiple unimodal travel markets means that the onus for constructing multimodal travel solutions falls squarely on the shoulders of the customers themselves, mixing and matching transport products and services from a variety of travel retailers, both calculating if it is feasible to combine them and risking the possibility that it is not. Such products and services may be pre-paid, purchased en route, or even post-paid (as in a number of urban, regional or national smart ticketing systems). Given this, there is no single travel-shopping experience for customers today: each de facto multimodal journey is achieved by means of multiple shopping experiences before, during or indeed after the trip.

Thus, the customer directly confronts the fragmentation of the European travel market. The overwhelming majority of attempts to plan and purchase an entire door-to-door trip, in advance, fail. This is hardly surprising, since the fragmentation imposes unacceptable degrees of effort, patience, time consumption and risk.

The consequences for would-be travellers are manifold: travel intentions may be abandoned; the ease with which travel can be shopped for becomes a distorting factor influencing their travel choices; and, frequently, the customer defers travel purchase decision-making for most parts of their trip until they are en route, introducing elements of uncertainty and stress into their actual travel experience.

Overall, the current environment does not favour rail, which is poorly distributed in indirect channels and whose suburban services are sorely underutilised by customers arriving from outside the city.

This TD looks at how to reduce, radically, the risk and effort of travel shopping, while simultaneously facilitating the supply and distribution of comprehensive and combinable transport services. It consequently allows flexibility and increased choice between business models and distribution strategies for transport undertakings, leading to the optimisation of demand satisfaction, and increased take-up of greener forms of transport. Therefore, multimodal door-to-door travel-planning capabilities will be developed including all modes of transport.

It also addresses lowering the investment barriers, with respect to both market entrants and incumbent transport undertakings. Such barriers inhibit exploiting the business opportunities that commercial partnerships offering smart (intermodal) solutions for recognised or newly discovered passenger flows can provide.

4.2.2. Technical objectives

The main benefit of the Travel Shopping framework proposed within TD4.2 is to enable a one-stop shop travel-shopping experience despite the fragmentation of distributed travel data available only in different transport markets today, and so establish a single multimodal marketplace. The objectives are as follows.

1. Provide multimodal journey-planning and offer-building capabilities that can supply comprehensive coverage of the available transport products and services to meet any demand a retailer or Travel Companion makes of them.

2. Enable the cascading of customer preferences as parameters to drive the search for relevant travel solutions, as well as attaching the customer-specified attributes that enable comparison shopping and selection from the list of travel solutions so provided.

3. Provide checking/validation services for itineraries for which the customer has already purchased travel entitlements.

4. Take the effort and risk out of today's shopping experience, through the automated calculation of minimum connection times, and validation of the combinability of

products and services within the travel solutions/offers in terms of transport service provider business rules on pricing and availability, including intermodal ticketing agreements that emphasise intermodal products that can be purchased with a single payment and entitlements issued under a single integrated ticket.

5 Provide participating transport service providers with the certainty that their products and services always appear on the radar screen for customer travel queries to which they might be relevant.

4.2.3. Technical vision

STATE OF THE ART	NEW GENERATION TRAVEL SHOPPING
Multiple unimodal services between stop points	Multimodal door-to-door travel-planning capabilities with distributed journey-planning functionalities
Closed system with high barriers for new business opportunities	An integrated Interoperability Framework that can take into account every kind of TSP
Dedicated closed modal schemas	Open multimodal schema
Trips are not in accordance with preferences	Definition and taking into account of preference and search criteria to rate, sort and even filtering best-fitting travel solutions
Single person travel calculation only	Enabling group and family travel solutions

Interaction with other IPs

- TD1.2 → Any train-related data relevant to travellers
- TD1.6 → Occupancy rate of a train or wagon
- TD1.7 → Display the actual vehicle layout to the traveller
- TD2.9 → Usage of real-time information
- TD3.6 → Train-related information such as utilisation
- WA4.2 → Usage of real-time information

Interaction with other IP4 TDs

- TD4.1 → Get access to legacy system
  - / to journey-planning/offer-building capabilities
  - / to data (e.g. network data, real-time information)
- TD4.5 → Travel Companion – cloud wallet
  - / retrieve all traveller-related data
  - / store all kinds of travel-related information
- Called by
  - / TD4.5 → Journey planning/offer building for users

- TD4.4 → Alternative calculation
- TD4.3, TD4.4, TD4.5 → Itinerary validation

- Data provision for
  - TD4.6 → Business analysis

4.2.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
On the economics of the travel service providers ecosystem	Through its interface with TD4.1, Interoperability Framework, the enabled travel-shopping framework convertor technology introduces massive reductions in system and operating costs for all links in the travel supply chains: distributors and transport undertakings are able to communicate without having to invest in adapting interchange messaging between them. This should encourage a snowball effect of market uptake as retailers, distributors/aggregators and transport service providers realise that membership will allow mutual access in order to unlock and exploit a much larger consumer demand than was previously possible
On the creation of a (digital) SERA	The comprehensive and combined power of the travel-shopping framework will help not only ensure the emergence of a SERA, but to provide qualitative added value by enabling the SERA to interact and combine with the larger Single European Transport Area, liberating the inherent potential of rail products and services to link services from other – air, ground (including bus) and maritime – transport sectors as well as integrating long-distance and suburban rail with first-, middle- and last-mile transport provided by participating public transport authorities
On the resolution of TAP-TSI open points	TD4.2, Travel Shopping, will contribute to the business coverage of TAP-TSI and the identification of the remaining open points to achieve complete business interoperability both within the rail sector and with other transport sectors and distributors dominant in indirect distribution channels, by providing convertor technology that can understand and translate TAP-TSI messaging meaningfully without demanding compliance outside the rail sector. This in itself will encourage accelerated take-up and implementation of TAP-TSI thanks to the added value of this potential external connectivity

This TD will contribute to enabling two innovation capabilities as follows.

INNOVATION CAPABILITY	TD4.2 TRAVEL SHOPPING ENABLERS
2 – MaaS	TD4.2 develops a technical enabler for a one-stop shop that allows multimodal planning for itineraries and offers. As travellers need to be informed about all options for travelling (including all modes), these multimodal travel-shopping capabilities are key for any MaaS. Relevant building blocks: BB4.2_1: Travel shopping orchestrator BB4.2_2: Meta-travel solution constructor BB4.2_3: Travel expert managers BB4.4_1: Collection of static data BB4.4_2: Collection of dynamic data BB4.4_3: Real-time event processing BB4.6_1: Data management

<table>
<tr><th>INNOVATION CAPABILITY</th><th>TD4.2 TRAVEL SHOPPING ENABLERS</th></tr>
<tr><td>4 – More value from data</td><td>Spread over Europe, a huge number of data for travel services are available:
• timetable information (network and schedule)
• real-time information
• information from travellers provided through different internet channels
Travel Shopping will collect data about travel demands. Analysing these data with business analysis will allow the offer to be adapted to fit the real demand better. This includes both long-term planning and short-term adaptation. Relevant building blocks:
BB4.1_1: Collection of static data
BB4.4_2: Collection of dynamic data
BB4.4_3: Real-time event processing
BB4.6_1: Data management</td></tr>
</table>

4.2.5. Demonstration activities and deployment

<table>
<tr><th rowspan="2">RESEARCH AREA</th><th rowspan="2">OBJECTIVE</th><th rowspan="2">NATURE OF ACTIVITIES</th><th colspan="2">DEMONSTRATOR</th><th rowspan="2">FOCUS OF ACTIVITY</th></tr>
<tr><th>MARKET</th><th>TRL</th></tr>
<tr><td rowspan="4">Travel shopping</td><td>Define travel shopping</td><td>Specification, ontologies</td><td>Generic</td><td>6/7</td><td>Develop exhaustive vocabulary of common terms for every transport mode, with key objects, roles and concepts used in Travel Shopping, compatible with existing legal environment (e.g. TAP-TSI)</td></tr>
<tr><td rowspan="2">Multimodal travel shopping</td><td rowspan="2">Specification, architecture and interface, software development</td><td>Urban (MaaS)</td><td>6/7</td><td rowspan="2">Develop and establish a system that allows multimodal travel shopping Europe-wide, but for demonstration purpose on given long-distance corridors only
Therefore, interaction with the TC personal application, the TC cloud wallet and the IF will be established</td></tr>
<tr><td>Co-modal long-distance journeys</td><td>6/7</td></tr>
<tr><td>Co-modal agreements between TSPs</td><td>Specification, architecture and interface, software development</td><td>Generic</td><td>6/7</td><td>Develop a tool to manage co-modal agreements (contracts and business rules) between independent TSPs
Apply the business rules while shopping</td></tr>
</table>

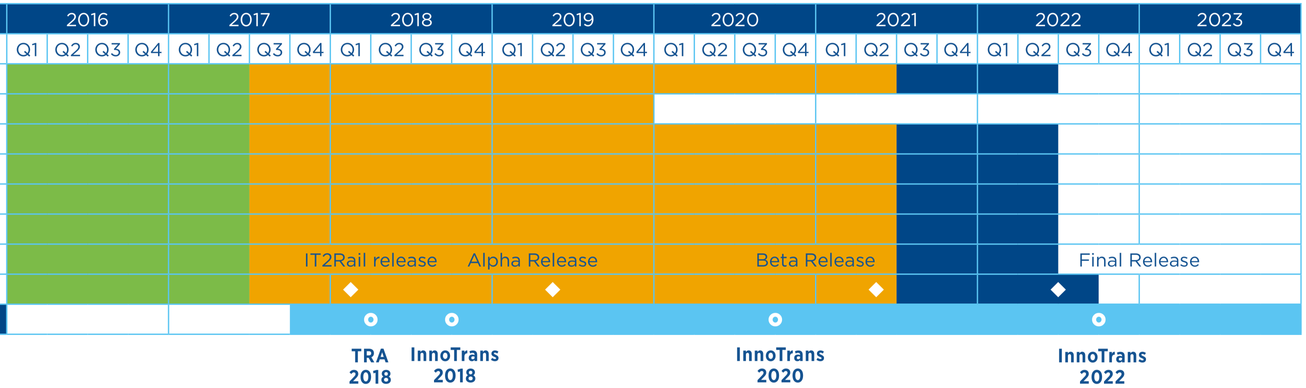
The activities of Travel Shopping will be developed in two contexts:

- the urban environment in the context of a MaaS approach;
- co-modal long-distance journeys in which the long-distance leg (e.g. air) is connected co-modally.

In these two contexts, the travel shopping needs are rather different (regular versus single journeys) and require different approaches.

Planning and budget

TDs	TASKS	TRL
TD4.2	**Travel Shopping**	
	4.2.0 Technical Management	NA
	4.2.1 Specifications and ontologies	5
	4.2.2 Travel retailer	6
	4.2.3 Travel shopping orchestrator	6
	4.2.4 Meta-Travel Solution constructor	6
	4.2.5 Trip travel expert manager	6
	4.2.6 Travel experts integration	6
	4.2.7 Technical Releases and support to ITD7	NA
ITD7	Integration and demonstration	



◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 76 / ***TD4.2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Integration of IT2Rail developments into the ITD7 demonstration	• Distributed offer building while using existing legacy systems • Interaction with legacy travel experts
Q3 2018	Integration of outcome of the CFM16 projects, mainly Co-Active	• Integration of new modes (e.g. private car, car and bike sharing) • Door-to-door capabilities • Working personal application following the entire shopping flow • Integration of management of contracts and business rules between travel experts
Q3 2020	Integration of the CFM17 project (Connective) and CFM18 project (MaaSive), and demonstration of an integrated approach to MaaS	• Integration of new modes (Demand Responsive Transport - DRT) • Support for group and family travels
Q3 2022	Integration of all the IP4 project features into ITD4.7	• Demonstration of the Travel Shopping features at InnoTrans 2022

Table 77 / ***TD4.2 milestones/projects***

WHEN	WHAT
Q1 2018	Integration of all features developed in the IT2Rail project (for detail, see in demonstration activities and deployment), May 2015 until April 2018
Q2 2019	Integration of all features developed in the Co-Active project (for detail, see in demonstration activities and deployment), September 2016 until May 2019
Q2 2021	Integration of all features developed in the MaaSive project and most of Connective (for detail, see in demonstration activities and deployment)
Q2 2022	Integration of all features developed in the last IP4 project (for detail, see in demonstration activities and deployment), CFM20

The estimated total budget for this TD is around EUR 6.7 million.

4.3. TD4.3 Booking and Ticketing

4.3.1. Concept

The concept of the Booking and Ticketing TD is to allow multimodality across Europe and across the modes. Today, even within a given mode (air, rail, urban, etc.), the rights to travel have at best a limited interoperability between various travel service operators within the same transport mode, and this interoperability is almost non-existent between different modes. From the Booking and Ticketing perspective, fostering multimodality therefore requires a grand unification of the way rights to travel are managed by the different TSPs. This TD will look at how to provide such interoperability across Europe. This includes cataloguing the entitlements, unifying the approach to describe their life cycles (as much as possible, specificities for various transport modes will be managed as such), defining principles to interact with the Ticketing framework and identifying the necessary use cases to demonstrate the functionalities included as part of this framework.

Therefore, the key concepts of the TD4.3 approach are as follows:

- **harmonise** terms and definitions of processes for the different services (such as ticketing, validation, settlement);
- **orchestrate** multiple but parallel interactions with several booking, issuing, payment and ticketing engines;
- **dematerialise** the entitlement: make access to entitlement ubiquitous, accelerate electronic ticketing and cloud wallets, and propose the most appropriate technology to allow seamless validation/inspection and interoperability.

This TD will go even a step beyond the traditional concept of intermodality, targeting a MaaS scenario too, which for example could entail the creation of mobility packs that integrate a bunch of transport services. Moreover, the contractual and business aspects behind the intermodal agreements will also be analysed as part of this TD.

4.3.2. Technical objectives

Based on this analysis, it is possible to identify the following objectives, which contribute to one-stop shop solutions/applications for multimodal ticketing.

1. Harmonise the management of rights to travel (entitlements).
2. Package entitlements to allow their storage in cloud wallets (Travel Companion).
3. Manage entitlements and tokens, ancillary services related to the trip (meals, Wi-Fi, etc.), and aftersales functionalities (cancellations etc.).
4. Reduce the gap between entitlement and embodiment.
5. Orchestrate processes involving multiple TSPs to allow multimodal booking, issuing, payment and ticketing.
6. Harmonise payment, clearing and settlement for entitlements.
7. Provide components and recommendations of technologies that could help to facilitate validation/inspection of tokens, including security measures.

4.3.3. Technical vision

By decoupling business and technical interoperability as different components within the ticketing framework, the ambiguous notion of the travel ticket will evolve towards the new triple concept of entitlement/token/embodiment (ETE) and allow greater interoperability of travel rights across the whole transport ecosystem.

- **The IP4 entitlement will capture the business value** within the ticketing framework, as it represents the right acquired (e.g. through travel shopping) or possessed (e.g. by virtue of being in possession of a credit card) by a potential traveller. This is the instantiation of a contractual agreement between the traveller and service providers, and can be understood ubiquitously by all actors participating in an intermodal scheme.
- **The IP4 token is the technical pendant of the entitlement,** as it permits a service provider to perform the due service. Because it is linked to the entitlement, the token enables interaction with the entitlement throughout the infrastructure of operators and service providers. Exclusively electronic and dematerialised, the token is an instantiation of the entitlement within a specific organisation, mapping dynamically the particulars of the

ticketing and validation environment for this organisation through the discovery capability of the Interoperability Framework (TD4.1).

- **The embodiment is the last element of the three.** It is essential to ensure that legacy ticketing systems can interact with the IP4 ticketing framework when electronic forms of tickets are not recognised. It is the fare medium, linked to an entitlement token, enabling interaction with the legacy devices and infrastructures of the operators and service providers (offering downward compatibility).

- **Benefiting from the complete dematerialisation of the entitlement,** the ticketing framework will provide interactions with electronic cloud wallets and unique identifiers to allow secure ubiquitous access to travellers' entitlements and itineraries. These mechanisms will provide the traveller with a global identity and associated rights accessible by European operators and service providers.

- **In addition, addressing the ticketing interoperability business angle,** TD4.3 will consider the criticality of the clearing and settlement functions and consider systematically the capacity to apportion and settle payment of every ticketing operation within the ecosystem and any contractual schemes.

STATE OF THE ART	NEW GENERATION BOOKING AND TICKETING
Electronic tickets have technical limitations: they are proprietary and not easy to manage in a multimodal context. Sometimes they need a transition to a physical embodiment (to be printed, for example)	The ETE chain will allow downward compatibility with existing systems, allowing willing operators to join the scheme without forcing them to modify all their existing systems. Components specialising in specific booking and ticketing functions for a given mode will be able to join the ticketing framework and to interface at their level with similar component of other modes, thus enabling deep components interoperability and modularity. Moreover, the IP will work towards the provision of ubiquitous access with consistent security and privacy, which will accelerate the movement towards electronic ticketing
In the shopping step, today, multimodality is mostly covered by multi-shopping, which in turns provides multi-tickets, with absolutely no link to each other, even in the niches where intermodal ticketing exists (as can be the case with air–rail, urban transit and some **rail–road transport** cases run by rail providers) but does not span all transport modes	IP4 supports a one-stop shop to perform intermodal travels, using all transport modes overcoming the current interoperability challenges, and proposing the harmonisation of the payment and settlement segments. Private and shared modes (own car, taxi, car sharing, public bicycle and, in the near future, fleet of shared autonomous cars) will also be considered as common modes used for the first mile, and with their own complexities and payment processes (e.g. tariffs based on time of use)
In general, there is no harmonisation of the payment and settlement segments either: as tickets are sold and managed separately, payments are very often quite different (and hard to track for the traveller), and the settlement follows only specific cases for the few cases of intermodal ticketing agreements already in place	The initial concept of the ticketing framework is to provide system-to-system interoperable rules and enabling technologies that allow every member of the ecosystem to communicate and interoperate at the business level without the need for a single European-wide global integration platform or for a central authority structuring and regulating the market

STATE OF THE ART	NEW GENERATION BOOKING AND TICKETING
The fare media offer today is very fragmented. A number of new technological advances are being made in terms of ETE, which are at different stages of operation/ experimentation (NFC, Be In Be Out, Bluetooth Low Energy, etc.)	One of the purposes of the ticketing TD is to investigate different technologies available, even those in the experimental phase, identify the most suitable to achieve interoperability, and describe how to integrate these technologies into the ticketing framework. In relation to TD4.5, Travel Companion, TD4.3 will introduce interaction between ticketing devices and fare media into a connected environment. Allowing a dynamic interface between the two items, it will enable seamless usage of the transportation system for the traveller while guaranteeing security and limiting the risk for the service provider

Interaction with other TDs (in the same IP and/or in other IPs)

TD4.3 has a close relationship with all the other IP4 TDs. Using the services of the Interoperability Framework (TD4.1), the Booking and Ticketing component locates and interacts with multiple booking engines and/or payment processors distributed across the network to generate bookings and entitlements for one or more of the itineraries selected by the citizen on the Travel Shopper (TD4.2). Ticketing also coordinates payments as requested, and stores created objects (e.g. entitlement references/tokens) in the citizen's Travel Companion (TD4.5). The entitlements stored make it possible to provide information relevant to the booked journey thanks to Trip Tracker (TD4.4). Moreover, Business Analytics techniques from TD4.6 could be applied to the ticketing data collected.

There could be also a link between this TD and IP3, which also tackles some activities related to ticketing validation and equipment at stations (TD3.11).

4.3.4. Impact and enabling innovation capabilities

The main benefit of the ticketing framework' proposed within TD4.3 is to remove the complexity of a ticketing scheme adapted to a multimodal heterogeneous environment.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
On the economics of the travel service providers ecosystem	Benefiting, through the Interoperability Framework (TD4.1), from access to an open-ended world of booking and ticketing resources and leveraging the Travel Companion (TD4.5) cloud-computing capabilities, TD4.3, Booking and Ticketing, will enable a sustainable ticketing framework, which will, in turn, allow market forces to accelerate the creation of multimodal products. By decoupling the business constraints from the technical ticketing interoperability issues, and offering global multimodal mechanisms for the latter, TD4.3 will indeed reduce investment costs for multimodal transport offers
On the creation of a (digital) SERA	The flexibility in the transport offers created by TD4.3, Booking and Ticketing, will allow better transport policy efficiency for TSPs. As the constitution and composition of existing products will integrate multimodal products, the coherence of public transport policy will be facilitated by the ability of the TSP to control and precisely define the way its products and prices will be integrated into multimodal offers. In the same way, the increasing availability of multimodal travel offers and especially the connectivity of urban and main-line railways will lead to an increase in rail attractiveness and, alongside, increase the use of rail transportation as the option becomes more available to the traveller

This TD will contribute to enabling one innovation capability as follows.

INNOVATION CAPABILITY	TD4.3 BOOKING AND TICKETING ENABLERS
2 – Mobility as a service	TD4.3 will contribute to the extension and consolidation of MaaS, integrating various forms of transport services into a single mobility service, allowing booking and ticketing for different modes, accessible through a unified gateway, and allowing a single payment channel instead of multiple ticketing and payment operations, contributing to increasing the customers' satisfaction and promoting the use of public transport systems through Europe. Relevant building blocks: • BB4.3_1: Orchestration of ticketing mechanisms for multimodal journeys • BB4.3_2: Operations of ticketing back office, including life cycle of parameters • BB4.3_3: Validation of entitlements (e.g. card-centric, EMV)

4.3.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Booking and ticketing	Design and specifications	Specifications, ontologies	Generic	5	Identify, formalise and document requirements and global specifications and ontologies related to booking and ticketing
	Entitlement, Token and Embodiment (ETE) life cycle	Specification, architecture and interface, software development	Generic	6/7	Establish a new concept of travel rights based on ETE to allow multimodal interoperability. Develop software components for entitlement life-cycle functions to manage acquisition, usage and disposal of travel rights
	Orchestration	Specification, architecture and interface, software development	Generic	6/7	Reference implementation of orchestration of multiple dialogues and required mechanisms to support co-modal and intermodal operations in the booking and ticketing environment (including ancillary services)
	Payment and clearing	Specification, architecture and interface, software development	Generic	6/7	Design and implementation of software components to support the operations of ticketing back offices in multimodal and multi-operator environments, including pricing, payment, clearing and settlement functions. This task will also include business and contractual management aspects

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Booking and ticketing	Validation and inspection	Specification, architecture and interface, software development	Generic	6/7	Focuses on the validation and inspection of the entitlement of the traveller throughout the multimodal transportation networks, closely related to TD4.5, Travel Companion, tapping activities. The task will propose software and hardware components for validation and inspection that facilitate operating in a variety of modal environments, following different approaches such as card-centric and account based. It will also aim to offer a more seamless experience for the users when accessing and travelling through the transport networks (e.g. less validation time, less media diversity, fewer physical barriers)
	Customer relationship management and passengers' rights	Specification, architecture and interface, software development	Generic	6/7	Components to manage customer relationships, passengers' rights and aftersales operations (refunds, cancellations, etc.)

The contributors will integrate in a common demonstrator all implemented software components and functions for Booking and Ticketing across the multiple modes involved in a relevant environment. By ensuring convergence of internal and external interfaces and verifying performances and functionalities, this work will build a reference implementation of Booking and Ticketing, which will guarantee the feasibility and scalability of the enabling technologies proposed. This integration will be monitored by ITD4.7, in charge of the system-level release, integrating all inputs from the different TDs.

Four main releases are expected at system level: IT2Rail release, alpha release, beta release and final release. The demonstration scenario will take the form of test campaigns for the different system releases. It will cover the full extent of the entitlement life cycle, and the use of multiple entitlement tokens demonstrating multiple validation schemes. Operational scenarios will envisage complex cross-provider processes such as refunds and claims on intermodal journeys as well as fallback scenarios (example given: provider did not meet its commitment when booking or issuing entitlement).

Planning and budget

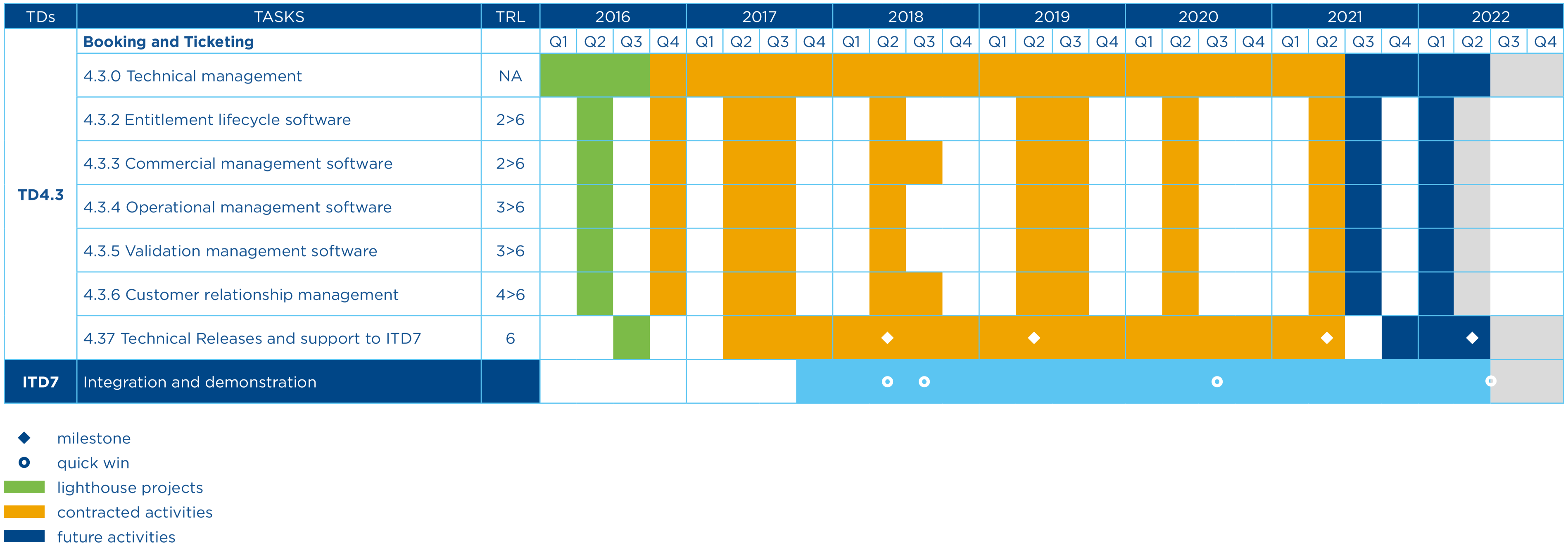


*Table 78 / **TD4.3 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Integration of IT2Rail developments to perform the IT2Rail final event	First presentation of the concept, and basic components deployed in IT2Rail, including booking orchestrator, integration with the cloud wallet and validation of proof of concept using NFC
Q3 2018	Integration of existing relevant features to develop use cases during InnoTrans event: in live demonstration	Presentation of the main results of the Co-Active project in relation to Booking and Ticketing, improving the components developed in IT2Rail and providing new functionalities, such as aftersales (cancellation, refund), ancillary services, and clearing and settlement functions
Q3 2020	Integration of existing relevant features to develop use cases during InnoTrans event: following the MaaS concept	Aims to demonstrate the evolution of the developments in TD4.3 to be compatible with the MaaS concept, as a result of the work to be accomplished in the MaaSive project. This quick win also expects to cover aspects such as customer relationship and travel rights management, and to propose the most appropriate technologies for validation in intermodal environments
Q3 2022	Integration of all the IP4 Booking and Ticketing features into ITD4.7	Demonstration at InnoTrans 2022

*Table 79 / **TD4.3 milestones***

WHEN	WHAT
Q2 2018	Integration of all features developed in the IT2Rail project (for detail, see in demonstration activities and deployment), May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRAcKTIVE project (for detail, see in demonstration activities and deployment), September 2016 until May 2019
Q2 2021	Integration of all features developed in the MaaSive project (for detail, see in demonstration activities and deployment)
Q2 2022	Integration of all features developed in the last IP4 project (for detail, see in demonstration activities and deployment)

The estimated total budget for this TD is around EUR 12.2 million.

4.4. TD4.4 Trip Tracker

4.4.1. Concept

We are living in a society that is characterised as a mobility world. For people today, it is absolutely normal to use the possibilities of private transport to travel from A to B or to use one's car to go to work in the morning and back home in the evening. It is also normal to be informed about the current situation on the streets. You switch on your radio and you will be informed about traffic jams, closed roads, closed exits and so on. In the same way, a driver will be informed when starting a navigation device in a car. The system proposes different routes, taking into account any kinds of obstacles and barriers. During the trip, push notifications inform the driver about upcoming jams, providing alternative routes. All this is normal for us, and we all expect systems to work like that.

In respect of public transport, we are only at the beginning of assistance for travellers of the kind we already have in private transport. Departure timetables presenting us with real-time information in stations and airports are working but the missing link is the combination of both. The attractiveness of the European railway lies fundamentally in its capability to contribute to the social infrastructure by providing smart and green travel services. With the ever increasing complexity of transport solutions, spanning regions, operators, infrastructures and modes, irregularities and anomalies in planed journeys need to be identified to provide the traveller with a seamless door-to-door and barrier-free travel experience. Door-to-door in this respect means using not only public transport instead of private transport but any kind of useful combination of them, whether car, bus, bicycle, aeroplane or train, although with more emphasis on public transport. This will be one of the most important steps forward to convince people to use public transport instead of private transport.

TD4.4, Trip Tracker, will be the task within the S2R ecosystem that will assist travellers throughout a multimodal journey with technologies that accurately and promptly notify travellers of any foreseen or unforeseen difficulties on their individual trips and offer rearrangement solutions by providing alternative routes to limit impacts of delays. By shielding travellers from disruptions, Trip Tracker will contribute to key objectives of the S2R Master Plan:

- improve perceived reliability:
  - / unprecedented level of comfort for the traveller;
  - / multimodal alternatives presenting best and most flexible choices;
  - / reliable ‘guardian angel’;
  - / customer experience;
  - / automated information of delays or disruptions;
  - / information regarding the next leg and the following ones in multi-leg journeys;
  - / increased trust of the traveller due to reliable real-time information;
- reduce operating costs:
  - / operators released from manually calculating and finding out new alternative multimodal routes;
  - / reduction of queues at helpdesks;
- minimise externalities:
  - / increased marketing effect, as it keeps the customer up to date, especially in the event of problems on cross-border trips;
  - / contribution to the objective of greener transport by promoting modal shifts;
- respect for and adaptations of TSI:
  - / adaptations to TAP-TSI proposed, to maximise journey-tracking capabilities,
  - / existing standards taken into account.

4.4.2. Technical objectives

Trip Tracker will be able to unify data from an open-ended range of sources through the Interoperability Framework (TD4.1). This allows not only scalability and dynamic reorganisation of planned timetables across modes but also access to near real-time traffic data. Trip Tracker will also take advantage of the emergence and availability of social media technologies that allow travellers to report events as they happen and therefore to act as valuable sources of information when conventional traffic control systems sources are unavailable. By applying complex event-processing technologies, Trip Tracker has the ambition to go much further than the association of static timetables with the current status of transportation means. The objective is to provide the following capabilities.

1. Identify patterns in the transportation operations and predict with accuracy future irregularities, thus pre-empting mitigation actions to safeguard the traveller's trip before the advent of the disruption itself.
2. Deduce complex consequences of associated events to identify the cascading effects on a particular individual trip, thus organising a timely response.
3. Take individual temporary preferences into account, resulting in a very complex process of calculating and offering optimal alternatives.
4. Work in near real time across a very large and open-ended set of data with potentially conflicting information, emanating from sources not necessarily intrinsically in real time; this requires simultaneous evaluation of multiple sources and complex decision-making algorithms.

4.4.3. Technical vision

STATE OF THE ART	NEW GENERATION TRIP TRACKING
Unimodal with services for each mode	Combined services for multimodal journeys
Closed system with high barriers for new business opportunities	Thanks to the integration of an Interoperability Framework, an 'unlimited' number of TSPs taken into account
Dedicated closed modal schemas	Open multimodal schema
Statistical information partly available for each mode	With the integration of Business Analytics, a complete picture of the travel situation is available
Disruptions to be handled by the traveller	Automatic handling of disruptions including the proposal of different alternatives
Entitlements, tokens and embodiments valid for a dedicated trip	In addition to proposing alternative journeys, checking if existing entitlements, tokens and embodiments for the journey are still valid

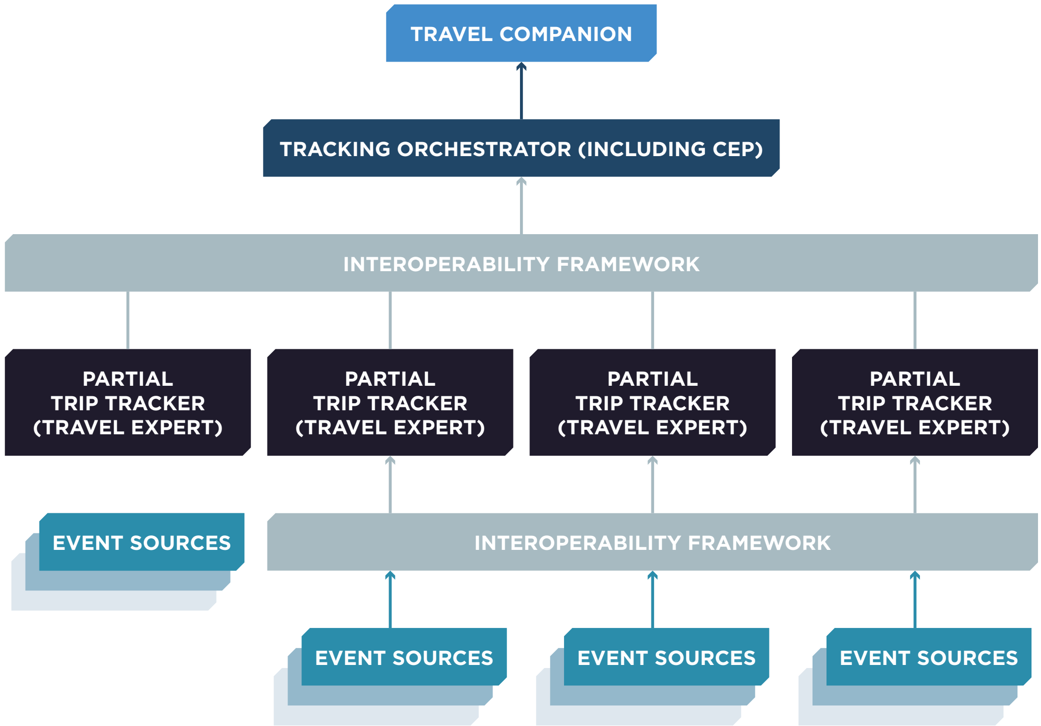


Figure 37 / ***Proposed TD4.4 architecture, including Complex Event Processing (CEP)***

Interaction with other TPs

- TD1.2 → Any train-related data that could be relevant to travellers while travelling
- TD1.6 → Detailed occupancy
- TD1.7 → Display the actual vehicle layout to the traveller
- TD2.9 → Information of high quality about real-time train arrivals

Interaction with other IP4 TDs

Usage of:

- TD4.1, IF, to get access to legacy system
  - / network data
  - / access to their JP/OB capabilities
- TD4.2, Travel Shopping
  - / to calculate alternative routes
- TD4.3, Booking and Ticketing
  - / to prove ETE for the original journey
  - / to provide necessary ETE for the chosen alternative route

- TD4.5, cloud wallet
  - to get traveller data
  - to store information
- TD4.6, Business Analytics
  - forward information to Business Analytics so that it can be taken into account to improve the S2R ecosystem and to provide better arrangements in the future

4.4.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Improve quality of service	Trip Tracker will contribute significantly to improving the quality of services offered to travellers on multimodal trips in Europe. By improving the perceived reliability of the transportation system, especially in the rail and urban modes, offering customer-targeted information and rearrangement mechanisms, and allowing operators to enhance the capacity of their infrastructure, Trip Tracker will promote the attractiveness of rail services and contribute to a modal shift to rail
Create business opportunities	Trip Tracker enabling technologies will create new business opportunities for service providers offering services dedicated to specific modes of transport (e.g. car sharing) and specific categories of travellers (e.g. PRM) in order to cope in the most efficient manner with disruptions. Disruptions could be considered opportunities, as they will trigger load balancing towards other modes of transport and generate revenues from travellers ready to pay a premium for re-accommodation
Widen the coverage of operators	As more travellers come to rely on the Trip Tracker services, operators and service providers will have to deal with an increasing number of re-accommodations potentially outside their own network and contracted arrangements. To benefit from this situation, intermodal agreements authorising rearrangements between operators could be put in place, offering travellers even more reassurance and less exposure to additional risks and costs
Use of business analytics to improve planning capabilities	Through the capability of Trip Tracker to identify disruption patterns and potentially through the feedback triggered by Trip Tracker to travellers and Business Analytics (TD4.6), a better understanding of network difficulties, bottlenecks and bypassing strategies will emerge. This will in turn allow operators, service providers and policymakers to optimise their offers and to propose fine tuning of planning capabilities within the Travel Shopping multimodal services (e.g. connection times between modes at a specific bottleneck station could be increased to cope with regular disruption)
Increase convenience of travel	This will release travellers from the need to find a new route by checking several sources and databases on their own; automatically calculated new routes will be optimal in respect of costs, time and convenience, taking into account personal preferences
Support the validation of tokens	The will release the traveller from the task of checking the validity of all embodiments, tokens and entitlements on a new selected route

This TD will contribute to enabling two innovation capabilities.

INNOVATION CAPABILITY	TD4.4 TRIP TRACKER ENABLERS
2 – Mobility as a Service	Trip Tracker will act as a guardian angel, taking travellers by the hand to guide them to their destination if any obstacle occurs. Taking the Interoperability Framework into account, door-to-door multimodal travel will observe the philosophy of MaaS. Relevant building blocks: • BB4.1_1: Collection of static data • BB4.4_2: Collection of dynamic data • BB4.4_3: Real-time event processing
4 – More value from data	Spread over Europe, a huge number of data on travel services are available, be they timetable information, real-time information or information collected by travellers and provided through different internet channels. Trip Tracker will collect all these data, combine them and thus generate new information to support travellers. Relevant building blocks: • BB4.1_1: Collection of static data • BB4.4_2: Collection of dynamic data • BB4.4_3: Real-time event processing

4.4.5. Demonstration activities and deployment

RESEARCH AREA	OBJECTIVE	NATURE OF ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Trip tracking	Define trip tracking	Specification, ontologies	Generic	5	Develop exhaustive vocabulary of common terms for every transport mode, with key objects, roles and concepts, used in the tracking of a passenger's journey, and compatible with existing legal environment (e.g. TAP-TSI)
	Collect and process data	Specification, architecture and interface, software development	Generic	6/7	Develop components to collect different kind of data – static (planning, scheduling, topology), dynamic (real-time traffic data), about passengers (itinerary, preferences, localisation) – and to publish or interact with Travel Companion and Interoperability Framework
	Implement real-time event processing	Specification, architecture and interface, software development	Urban (MaaS)	6/7	Analyse real-time changes compared with published data/schedules/ topologies, identify travel conflict and needs for alternatives, inform the traveller, all based on preferences
			Co-modal long-distance journey	6/7	
	Construct alternative itinerary	Specification, architecture and interface, software development	Urban (MaaS)	6/7	Implement alternative retrieval function, in order to obtain suggestions on alternative journeys in case of delays or disruption
			Co-modal long-distance journey	6/7	

The activities of Trip Tracker will be developed in two contexts:

- the urban environment in the context of a MaaS approach,
- co-modal long-distance journeys in which the long-distance leg (e.g. air) is connected co-modally (with an independent ticket).

In these two contexts, the impacts of a disruption are rather different (financially and legally) and require different approaches.

The first release was developed within the lighthouse project IT2Rail.

The second release was the alpha release delivered at the end of 2018.

The third release is the beta release allowing MaaS, which is expected at the end of 2020.

The fourth release is the final release, expected at the end of 2022.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Trip Tracker		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD4.4	4.4.0 Technical Management	NA																												
	4.4.1 Specifications and ontologies	5																												
	4.4.2 Static data interface	2>6																												
	4.4.3 Dynamic traffic data interface	2>6																												
	4.4.4 Passenger data interface	3>6																												
	4.4.5 Real-time event processing	3>6																												
	4.4.6 Alternative itinerary building	4>6																												
	4.4.7 Technical Releases and support to ITD7	6										◆				◆								◆				◆		
ITD7	Integration and demonstration										○		○								○									○

TRA 2018 · InnoTrans 2018 · InnoTrans 2020 · InnoTrans 2022

◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 80 / ***TD4.4 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Integration of IT2Rail to perform the IT2Rail final event	• Integration of real-time information from different TSPs mapped to one itinerary • Calculation of alternative routes in case of delays or disruptions • Alternative Manager to check if calculated alternative routes are compliant with real-time information
Q2 2019	New trip-tracking structure that integrates a trip-tracking orchestrator and several connected partial Trip Trackers	• Trip-tracking architecture split up into a tracking orchestrator and several connected partial Trip Trackers • Partial Trip Trackers to consider different methodologies with special event sources: / SIRI SX event source / GFTF-RT event source / prognosis event source component / mobile device event source • Providing alternative routes
Q3 2020	Realisation of MaaS concepts by integration of Interoperability Framework	• Integration of Interoperability Framework into the tracking orchestrator to include different partial Trip Trackers • Integration of Interoperability Framework into partial Trip Tracker to include different event sources • Checking if all ETEs are still valid on an alternative route
Q3 2022	Integration of the trip-tracking functionalities into ITD4.7	• Demonstration at InnoTrans 2022

Table 81 / ***TD4.4 milestones/projects***

WHEN	WHAT
Q2 2018	Integration of all features developed in the IT2Rail project (for detail, see in demonstration activities and deployment), May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRACkTIVE project (for detail, see in demonstration activities and deployment), September 2016 until May 2019
Q2 2021	Integration of all features developed in the MaaSive project (for detail, see in demonstration activities and deployment)
Q2 2022	Integration of all features developed in the last IP4 project (for detail, see in demonstration activities and deployment)

The estimated total budget for this TD is around EUR 8.4 million.

4.5. TD4.5 Travel Companion

4.5.1. Concept

Twenty-first-century travellers have high expectations for efficiency, and low tolerance for barriers to mobility. Information technology has recently made significant progress, especially in the field of mobile applications.

However, a more in-depth analysis reveals that these apps are actually very limited. They are very fragmented and do not bridge the gaps between services such as shopping, booking and ticketing. Global seamlessness for door-to-door multimodal travel at European scale, including public transport as well as personal transport, is hence not accessible.

This makes possible the emergence of new forms of travelling experiences enabled by an adaptive and engaging mobile, pervasive and interactive framework designed to guide, support, assist, inform or even entertain travellers during multimodal door-to-door journeys.

The Travel Companion includes an advanced personal application as well as allocated cloud-based services to store private user-specific information.

- The personal application is the client that travellers can use to access the whole ecosystem. In this way, travellers are able to access multimodal transport services through a unique user interface, allowing them to leverage all the capabilities of the system (shopping services, booking services, trip-tracking services). Furthermore, location-based experiences are integrated to present innovative entertainment or any other information that might enrich the travel journey in specific locations (stations, travel episodes). In addition, indoor/outdoor navigation location technology will be able to guide travellers to transit checkpoints along the journey.
- The online counterpart, the cloud wallet, serves as the secured repository for the users' personal information. Storing this information in the cloud not only prevents users from having to re-enter information multiple times but also enables them to use different devices. The cloud wallet also acts as a bridge between the personal application and all of the external services, allowing travellers to receive information affecting their journey and providing them with ubiquitous access to travel rights in electronic wallets.

4.5.2. Technical objectives

The following are the main technical objectives of this TD.

1. Provide a secure cloud-based platform hosting each traveller's virtual space, including ID, profile, preferences, payment means, tickets, etc.
2. Provide a homogeneous and innovative multimodal user interface enabling travellers to ubiquitously access heterogeneous services to the S2R IP4 services such as Travel Shopping, Ticketing and Booking, and Trip Tracker.
3. Provide new forms of location-based experiences, aiming to make travel more engaging and attractive for passengers.
4. Enable adaptive and seamless indoor/outdoor navigation for the users in transit between modes of transport at interchanges or within infrastructures and means of transport; the navigation function will take into consideration the traveller's preferences and any disabilities.

5 Allow device tapping that will use the travel rights stored in the travel wallets for validation and inspection purposes by field devices within heterogeneous operators' infrastructures.

4.5.3. Technical vision

STATE OF THE ART	NEW GENERATION TRAVEL COMPANION
Many fragmented applications covering a limited scope of services in a limited area	One single Travel Companion will be able to cover all services needed by the traveller all over Europe
Specific proprietary architecture for each application	An open and common architecture allows different suppliers to provide different Travel Companion applications based on the same ecosystem
Mobile applications are not exploiting all the potential of the new advances in the fields of human–machine interfaces, mixed realities and smart devices	New forms of location-based experiences aim to make travel more engaging and attractive, and homogeneous and innovative user interfaces enable travellers to ubiquitously access heterogeneous services such as Travel Shopping, Ticketing and Booking, and Trip Tracker
Not all basic services needed to organise a journey are covered	The Travel Companion provides access to all services provided by the S2R ecosystem
Applications are mostly dedicated to a specific transport provider	The Travel Companion is linked to the S2R ecosystem and not to a transport provider
Sharing information between operators for multimodal journeys is not available	A cloud wallet included in the Travel Companion serves as a secured repository for all information related to the user: personal information as well as journey information
Applications are independent from the traveller	The user experience is adapted to the traveller profile, which is updated based on the trajectories of the traveller
Public transport applications do not take into account the location of the traveller	The new generations will include a navigation app and the underlying positioning infrastructure supporting indoor and outdoor environments, as well as a seamless transition between them

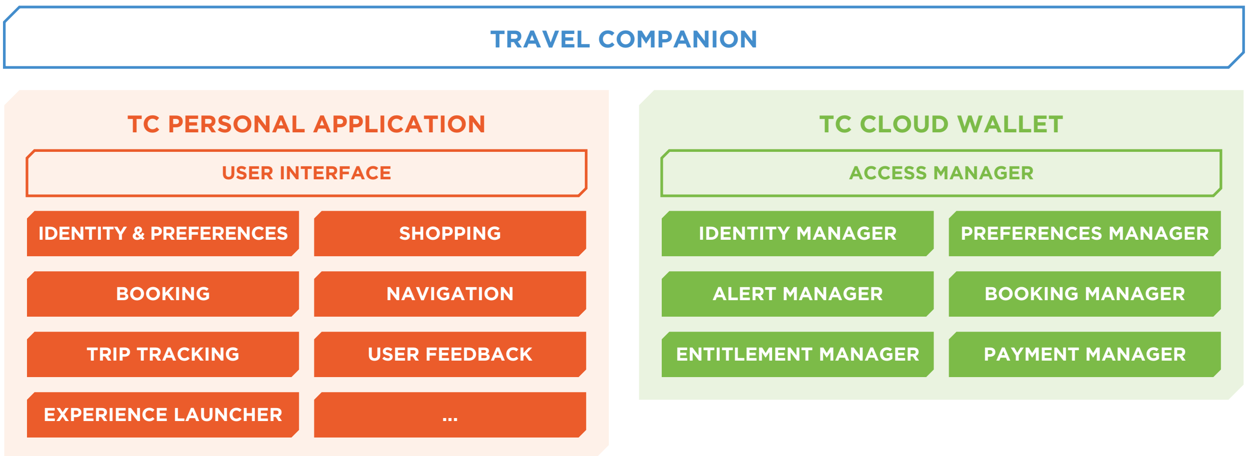


Figure 38 / ***Proposed Travel Companion architecture***

Interaction with other TDs (in the same IP and/or in other IPs)

The Travel Companion is the point of access to all services through a homogenised user interface, allowing the traveller to leverage all the capabilities of the system (shopping services, booking services, trip-tracking services, location-based services). On that point, TD4.5 interacts strongly with the other TDs of IP4:

- TD4.1, Interoperability Framework;
- TD4.2, Travel Shopping;
- TD4.3, Booking and Ticketing;
- TD4.4, Trip Tracker.

The interconnections with other IPs are with IP1, doors and access, and IP3, stations, and to some extent with the CCA 'social networks'. Information from these TDs can potentially be monitored and taken into account to improve the service provided to passengers.

4.5.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
On the economics of the travel service providers ecosystem	The capacity of the Travel Companion to alter for the better the traveller's perception of the transport ecosystem and improve the quality and attractiveness of the travelling experience, from door to door, is one of the most significant expected impacts. The enhancement of the traveller experience will result in an increase in the use of rail and collective transport, providing benefits to operators and accelerating the adoption of S2R solutions globally
On the creation of a (digital) SERA	New generation user-centric services enabled by the Travel Companion will not only help ensure the emergence of a SERA, but provide qualitative added value by enabling the SERA to interact and combine with the larger Single European Transport Area, liberating the inherent potential of rail products and services to link services from other air, ground (including bus) and maritime transport sectors as well as integrating long distance and suburban rail with first-, middle- and last-mile transport provided by participating public transport authorities

This TD will contribute to enabling two innovation capabilities as follows.

INNOVATION CAPABILITY	TD4.5 TRAVEL COMPANION ENABLERS
2 – Mobility as a service (MaaS)	Thanks to the Travel Companion (TD4.5) and the other relevant S2R services (TD4.x), the traveller will be able to access to all services needed to define and manage multimodal door-to-door travel as promoted by the MaaS philosophy. Relevant building blocks: • BB4.5_1: Secured cloud-based platform (e.g. preferences) • BB4.5_2: Interaction through smart devices • BB4.5_3: Geo-navigation functions • BB4.5_4: Device-tapping functions

4 – More value from data	The data related to the travels of the passenger are extensive and varied, including public, business and private data, and long-term as well as real-time data. Taking into account all these fragmented data for optimised use will generate an efficient service of high value for the passenger through the Travel Companion. Relevant building blocks: • BB4.5_1: Secured cloud-based platform (e.g. preferences) • BB4.5_2: Interaction through smart devices • BB4.5_3: Geo-navigation functions • BB4.5_4: Device-tapping functions

4.5.5. Demonstration activities and deployment

RESEARCH AREA	OBJECTIVE	NATURE OF ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Travel Companion	Define the services	Specification, ontologies	Generic	5	Identify, refine and analyse the end user requirements on a regular basis to foster the discussion with end users and stakeholders and make them understand the potential of the technology and the research directions that can be envisaged
	Develop the secured cloud-based platform	Specification, architecture and interface, software development	Generic	6/7	Develop the scalable and secured cloud-based platform that will be used to: • collect, aggregate and store information about each traveller in real time • process this information and perform services
	Develop the access to passenger services	Specification, architecture and interface, software development	Generic	6/7	Develop a wealth of components that will: • enable the interaction of the user with the S2R IP4 services throughout the journey • deliver personalised interactive experiences adapted to each traveller

RESEARCH AREA	OBJECTIVE	NATURE OF ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Travel Companion	Ensure external connectivity	Specification, architecture and interface, software development	Generic	6/7	Develop the components dedicated to the interaction between the travellers and the Travel Companion framework using smart devices as well as smart objects (e.g. smartwatch, augmented reality glasses, public displays, iBeacon) that populate their environment all along their journey
	Provide navigation	Specification, architecture and interface, software development	Generic	6/7	Develop the software components for geo-navigation functions available to users in transit between modes of transport at interchanges or within infrastructures and means of transport. These components will provide adaptive and seamless indoor/outdoor navigation functions taking into consideration the traveller's preferences and any disabilities
	Allow device tapping	Specification, architecture and interface, software development	Generic	6/7	Develop the software components that will use the travel rights stored in the travel wallets for validation and inspection by field devices within heterogeneous operators' infrastructures

The first release was the IT2Rail release.

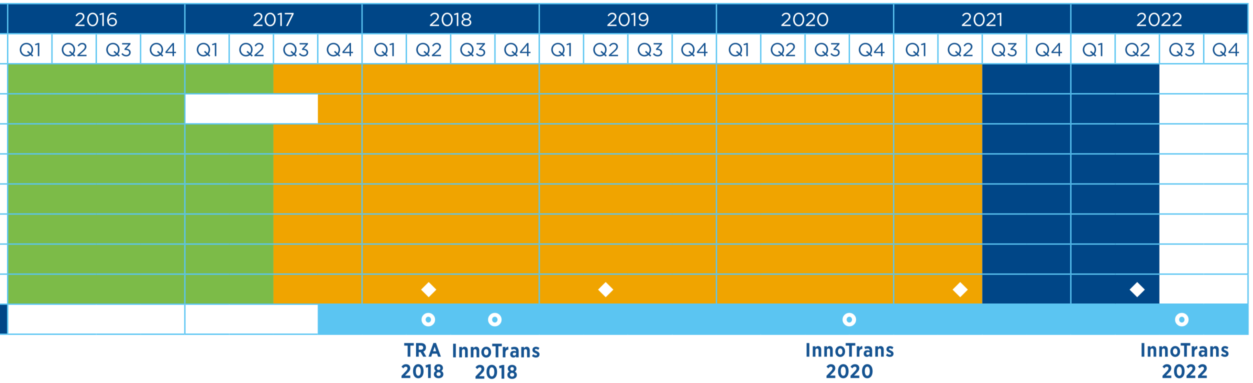
The second release was the alpha release (delivered at the end of 2018).

The third release is the beta release allowing MaaS (expected at the end of 2020).

The fourth release is the final release (expected at the end of 2022).

Planning and budget

TDs	TASKS	TRL
	Travel Companion	
	4.5.0 Technical Management	NA
	4.5.1 Specifications and ontologies	5
	4.5.2 Secured Cloud-based Platform	2>6
TD4.5	4.5.3 Passenger Services	2>6
	4.5.4 External Connectivity	3>6
	4.5.5 Navigation	3>6
	4.5.6 Device tapping	4>6
	4.5.7 Technical Releases and support to ITD7	6
ITD7	Integration and demonstration	



◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 82 / ***TD4.5 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP (SPECIFIC PER TD)
Q2 2018	Integration of IT2Rail developments to perform the IT2Rail final event	• User-centric application with unique transport account • Access to multimodal transportation offers • Indoor guidance (POC) • Trip tracking • NFC e-ticket
Q3 2018	Integration of existing relevant features to develop use cases during InnoTrans event: in live demonstration	InnoTrans 2018 demonstration will be based on the features of IT2Rail enhanced by the first release of ATTRACkTIVE. The following features will be demonstrated through the Travel Companion: • travel shopping • booking • ticket issuing • ticket validation • trip tracking • indoor navigation • location-based experience • user feedback
Q3 2020	Integration of existing relevant features to develop use cases during InnoTrans event: following the MaaS concept	InnoTrans 2020 demonstration will be based on the features of ATTRACkTIVE enhanced by the CREL (Core Software Release) of MaaSive
Q3 2022	Integration of all the functionalities of the Travel Companion into ITD4.7	Demonstration at InnoTrans 2022

Table 83 / ***TD4.5 milestones/projects***

WHEN	WHAT
Q2 2018	Integration of all features developed in the IT2Rail project (for detail, see in demonstration activities and deployment), May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRACkTIVE project (for detail, see in demonstration activities and deployment), September 2016 until May 2019
Q2 2021	Integration of all features developed in the MaaSive project (for detail, see in demonstration activities and deployment)
Q2 2022	Integration of all features developed in the last IP4 project (for detail, see in demonstration activities and deployment)

The estimated total budget for this TD is around EUR 12 million.

4.6. TD4.6 Business Analytics Platform

4.6.1. Concept

The rail sector, and more specifically urban mobility, is one area in which business analytics could soon be making a major difference. Public transport authorities and operators gather huge amounts of data, for instance generated by transport smartcards. Business analytics methods hold the key to getting more out of existing data and opening the doors to a more interconnected future, with deeper insights into passenger behaviour, passenger flows and the ways in which travellers make use of infrastructure and equipment. It can be used to plan better infrastructure, introduce new services, provide targeted passenger information, refine tariffs and even steer customer demand, with a far higher degree of certainty than has previously been possible.

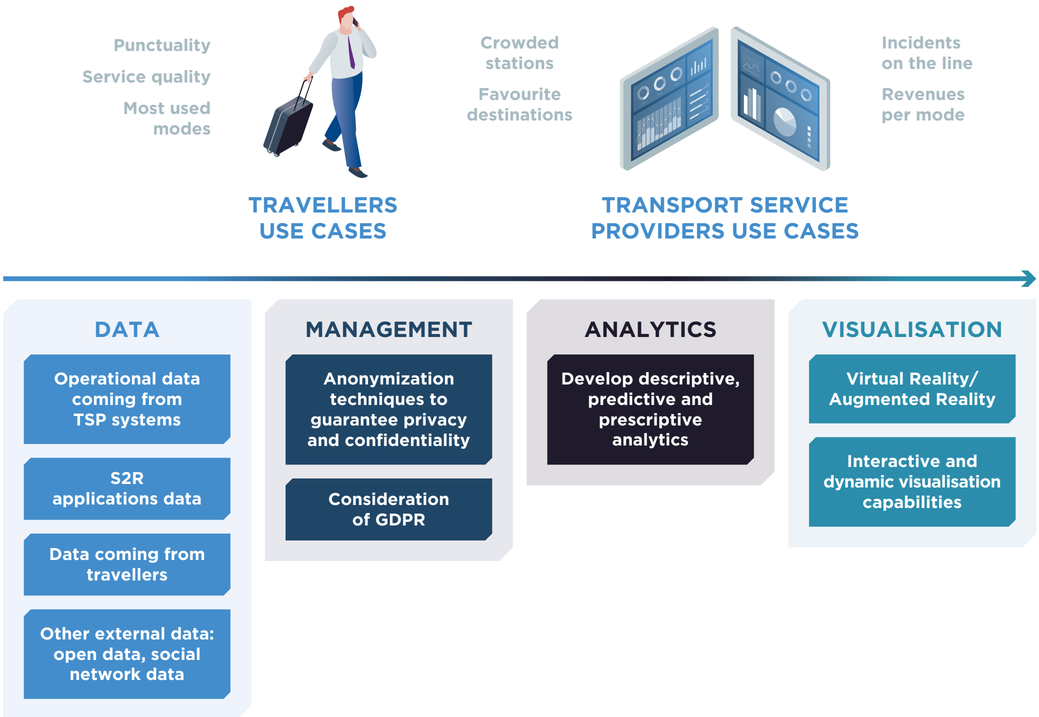


Figure 39 / ***Business analytics overview***

4.6.2. Technical objectives

TD4.6, Business Analytics Platform, part of the technical framework research area of IP4, will provide a common business intelligence foundation for all S2R transport product and service providers based on access to an open-ended web of transportation data offered by the Interoperability Framework (TD4.1). More specifically, the expected results are the following.

1. Provide to all S2R transport product/service providers a common business intelligence foundation to monitor IP4 target strategic indicators, structured in execution/ operational KPIs, and to manage service life cycle for continuous improvement of the rail-centric travel experience of European travellers.

2. Enable decision tools for rail and multi-transport operators (and all S2R ecosystem service providers), with planning, monitoring and reporting capabilities from data collection, filtering and analysis to build end user travel and transport intelligence.

3 Synthesise big data in travel and transport analytics over multisource channels for rail business executives (sales, marketing and customer service) and mobility and traffic management control rooms (operational support for passengers' mobility and freight logistics).

4 Collect historical business data (within IP4, from Ticketing and Booking) and data on travellers behaviour from all channels (mobile phones, social media, web) (within IP4, from Travel Shopping, Travel Companion, Travel Tracker, etc.) to allow a clearing house among operators, as well as dynamic personalised service in real time (in-memory computing).

4.6.3. Technical vision

The overall ambition of Business Analytics (TD4.6) is to propose a general platform and a set of tools allowing better analysis of the passenger flow in the network, in order to improve the operations with adapted means of transport, or with adapted offers (tickets less expensive at some hours, coupling of transport tickets with specific events, etc.).

Data warehouse, customer database and single-mode business optimisation strategies and tools exist today only within single transport operators (rail or public transport), making it impossible to obtain multimodal, door-to-door trans-European green mobility intelligence.

Furthermore, some recent and powerful tools such as big and open data capabilities by remote sensing and massive data analysis, and real-time traffic information, are not yet exploited, and are not correlated and transformed into usable travel knowledge for context-aware proactive suggestions to travellers, shipping enterprises and transport operators.

Critical operator infrastructure data security and privacy of travellers' information are not often guaranteed, and it is not possible to propose and deliver seamless journeys, as all partners work on different datasets.

STATE OF THE ART	ADVANCES IN BUSINESS ANALYTICS
Adoption of big data technologies is still a challenge: which platforms, technologies, tools	Propose a choice of big data platforms, tools and technologies that allow the loading, recovery, manipulation and analysis of data
Analysis of personal data not considering privacy issues carefully; many more constraints with GDPR, operational in 2018	Develop different anonymisation techniques and strategies to guarantee privacy
Data availability: in a multimodal environment, with different transport service providers, data collection is challenging	Develop a digital twin world based on a realistic synthetic world with data generation techniques based on machine learning
Analytics based mostly on KPIs and statistical computation	Develop descriptive, predictive and prescriptive analytics to create value through refining data into actionable information
Limited visual analytics-oriented dashboards	Develop novel visualisation techniques to show specific trends or as an alternative, intuitive way to increase human operators' understanding based in particular on virtual reality

Interaction with other TDs (in the same IP and/or in other IPs)

- TD4.1: access to open-ended web of transportation data offered by the Interoperability Framework
- TD4.5: access to data from Travel Companion

The following IPs/topics could also be addressed:

- TD3.11: Future Stations
  - manage people flow, accessibility, guidance or emergencies in stations;
  - with IP3, links with the TMS to gather useful information for passengers.

4.6.4. Impact and enabling innovation capabilities

The main benefits that the Business Analytics Platform will bring include the following.

- On the economics of the transport ecosystem: by providing a detailed and unprecedented understanding of the complex dependencies within the fragmented transport ecosystem, the Business Analytics Platform will allow public transport operators to better allocate their funds (to more specific items or to more efficient investments), resulting in lowering the costs of operations and increasing service availability. This will reinforce the capacity to anticipate potential crises and better prepare for events that temporarily increase the demand for mobility on a large scale, thanks to the business analytics tools (including predictive and prescriptive analysis) involved in planning and resource allocation.

- On the customer experience and the traveller–operator relationship: by allowing passenger feedback to be taken into account, the Business Analytics Platform will place the traveller at the centre of the transport ecosystem. Travellers' perceived influence on the ecosystem will foster a change in their attitude towards the transport services. In the same way the Business Analytics Platform will initiate a first answer to the complex environment of public relationship for public transport operators. Although public transport operators have customer relationship management that allows them to define their commercial policies, the social network-capable intelligent tools provided by the Business Analytics Platform will allow transport operators to leverage the social network capacity to involve their customers and build a smarter customer relationship.

- On access to top talent: business analytics technologies join together many complex technologies and IT services that are now being extensively developed in academic environments as an area of excellence and future major economic growth. Transport systems across Europe produce a very large number of data, making it natural to associate the transport ecosystem with business analytics to work with them. This will generate demand for innovative technology solutions and turn the rail travel industry into an attractor of top talents, which can produce a virtous circle. Creating intelligent mobility services and the IT applications to support them will become at least as gratifying as working in advanced 'pure internet' services.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Improved perceived reliability	By providing the tools for operators and service providers to monitor, analyse and understand global travel flows not only associated with their own services but, critically, across the entire ecosystem, Business Analytics will offer the capability to model resilient multimodal travel services, adapted to the wide variety of travellers' profiles and infrastructure environments, thus increasing confidence in the IP4 ecosystem services
Improved customer experience	As service providers and operators get better and more correlated feedback from the ecosystem, including from the travellers themselves, they will be in an optimised position to propose new services and adaptations of current offers to better suit the travellers' needs. Complete understanding of their users' typology, preferences, payment patterns, etc., will allow the transit agencies to offer innovative transport products better matched with demand

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Enhanced capacity	With better insights into the travel patterns and preferences of their customers, across their infrastructures and considering the relationships with adjacent networks and transportation modes, operators will be in a position to deploy more accurate capacity-planning tools and pre-emptive services to reduce congestion at stations and hubs
Lower investment costs	As business analytics platforms offer valuable insights and feedback on services provided, they provide a competitive edge and are fast becoming a necessary management and decision tool for the transport ecosystem. It is the objective of the IP4 Business Analytics to enable the emergence of commonalities in the platforms' technologies and data acquisition mechanisms to reduce the current high costs of investments necessary to benefit from those services
Reduced operating costs	With the Business Analytics providing the capability to perform predictive analysis on a vast amount of transport data, operators will foresee with greater accuracy the adaptations of their infrastructures required to meet demand and changes in travellers' behaviour. Exhaustive and enriched feedback will allow a more detailed base of KPIs and suggest operative actions/changes to services, based on the business needs to optimise LCC and increase revenues

This TD will contribute to enabling one **innovation capability** as follows.

INNOVATION CAPABILITY	TD4.6 BUSINESS ANALYTICS ENABLERS
4 – More value from data	Through its capabilities to analyse the European multimodal transport ecosystem globally, Business Analytics will provide an in-depth understanding of the usage of transport modes and allow precise KPI reporting. All analyses will take into account data privacy management. Business Analytics' objective is also to encourage the sharing of data between members of and competitors in the transport ecosystem. Through the adoption of coopetition (cooperation and competition) schemes between operators and service providers, data will gain in value through their correlation and enrichment with the analysis of the rest of the ecosystem. Relevant building blocks: BB4.6.1: Data management BB4.6.2: Descriptive and predictive analytics BB4.6.3: Visualisation

4.6.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Business analytics	Big data architecture	Specifications, architecture	Generic	5/6	Choice of big data platforms, technologies and tools
	Use cases definition	Specifications	Generic	5/6	Definition of TSP-oriented use cases and traveller-oriented use cases
	Anonymisation techniques	Algorithms	Generic	6/7	Development of anonymisation techniques to answer privacy issues
	Data generation	Algorithms	Generic	6/7	Development of data generation algorithms to produce realistic data
	Analytics	Algorithms	Generic	6/7	Development of algorithms for descriptive, predictive and prescriptive analytics
	Visual analytics	Software components	Generic	6/7	Development of software components for visual analytics and for virtual and augmented reality

The first release was IT2Rail. The first KPIs and statistics have been computed and some visualisation based on dashboards has been proposed. Three other releases will happen:

- the second release was the core release (at the end of 2019);
- the third release is the beta release (expected at the end of 2020);
- the fourth release is the final release (expected in 2022).

The demonstrator will provide an in-depth understanding of the usage of transport modes and will provide useful information for TSPs and users.

It will enhance capacity, providing TSPs with better insights into the travel patterns and preferences of their customers, across their infrastructures and considering the relationships with adjacent networks and transportation modes. Operators will be in a position to deploy more accurate capacity-planning tools and pre-emptive services to reduce congestion at stations and hubs.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Business Analytics		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	4.6.0 Technical Management	NA																												
	4.6.1 Specifications and ontologies	5																												
TD4.6	4.6.2 Data Management	2>6																												
	4.6.3 Descriptive and predictive Analytics	2>6																												
	4.6.4 Analytic Visualisation	3>6																												
	4.6.5 Technical releases and support to ITD7	3>6									◆				◆								◆				◆		
ITD7	Integration and demonstration										○	○							○								○	

◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 84 / ***TD4.6 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP (SPECIFIC PER TD)
Q2 2018	Integration of IT2Rail developments to perform the IT2Rail final event and TRA 2020	• KPI reporting and dashboards
Q3 2018	No features for live demonstration at InnoTrans 2018	Concepts developed in Connective will be illustrated with presentations: • privacy issues and anonymisation • big data architecture • visualisation
Q3 2020	Integration of existing relevant features to develop use cases during InnoTrans event: following the MaaS concept	InnoTrans 2020 demonstration will be based on the features of the Connective project
Q3 2022	Integration of Business Analytics features during InnoTrans event	InnoTrans 2022 demonstration will be based on the features of the Connective project, integrated into ITD4.7

Table 85 / ***TD6.4 milestones***

WHEN	WHAT
Q4 2018	Integration of all features developed in the IT2Rail project (for detail, see in demonstration activities and deployment), May 2015 until April 2018
Q2 2019	Integration of all features developed in the Connective project, September 2017 until June 2022
Q2 2021	Integration of all features developed in the Connective project, September 2017 until June 2022
Q2 2022	Integration of all features developed in the Connective project, September 2017 until June 2022

The estimated total budget for this TD is around EUR 9 million.

4.7. ITD4.7 Overall IP4 coordination and demonstration

4.7.1. Concept

The attractiveness of rail in Europe lies fundamentally in its capabilities to provide smart and green travel services as a way to engage in commercial, cooperative and leisure activities. It relies on an efficient railway network, but also on better integration of this network into the overall mobility ecosystem, by providing passengers with attractive and seamless access to all the services supporting their multimodal journey. While IP4 aims to offer this attractive and seamless access through six technical demonstrators encompassing all IP4 research areas, ITD4.7 ensures the overall technical synchronisation of IP4 and consistency of the developments made in the IP4 TDs, and maximises IP4's impact by proposing end-to-end demonstrations.

4.7.2. Technical objectives

ITD4.7 is significantly different from the other TDs, as it will not provide ground-breaking technologies or concepts, but will orchestrate implementation in a consistent, coherent and transparent manner, and will deliver an overall demonstrator that satisfies the IP4 community and meets the S2R Master Plan objectives.

The ambition of ITD4.7 is to foster a coordinated effort in the deployment of innovative IT solutions for the transport ecosystem: to bring together, through a global technical framework, multimodal travel services (such as Travel Shopping, Booking and Ticketing, Trip Tracker) at the European scale, and to integrate those into a Travel Companion that is unique to each user, providing end-to-end, multimodal, seamless capabilities for travellers.

This ITD will deliver the full benefit of the IP4 developments by addressing specifically the following objectives.

1. Support technical coordination: ensure smooth synchronisation and coordination of the different projects contributing to the IP4 objectives.

2. Ensure engineering consistency throughout IP4 technical demonstrators: consistent specifications and design architectures (functional, logical, applicative, technical) are key to ensure that the global concepts and principles of IP4 are cascaded throughout the TDs (via the projects), thus eradicating holes or overlaps in the design. The objective will be to ensure that common language, methodology, regulations, concepts, templates, tools etc. are disseminated throughout the TDs and shared by all participants.

3. Federate a community around the innovation concepts of IP4: a key objective is to ensure the appropriate dissemination of key concepts, progress and communication strategy within the S2R community and to the global ecosystem and future users of IP4.

4. Promote convergence of all IP4 technical demonstrators: IP4 will aim not only to specify core functions for a new transport ecosystem, but also to create a complete technical enabler encompassing the innovations of each TD in reference implementations. Given this, convergence of integration, testing and verification activities will make it possible to build a functional and representative IP4 ecosystem with the objective of reaching TRL 6 overall for the IP4 solutions compatible with mid-term market uptake.

5. Develop flagship demonstrations: the definition of relevant use-cases, adapted to the maturity of the running projects, will support the end-to-end integration of the constitutive building blocks developed in the TDs. These use-cases will be demonstrated in successive releases.

6. Open the market to new actors: at the core of ITD4.7, lies the objective of openness of the transportation ecosystem to new business actors, able to rejuvenate the transportation ecosystem technologies and business models, thus achieving the goals of European leadership in the market. ITD4.7 is the guarantor of the openness of new solutions and architecture specifications, allowing new entrants to benefit from enabling technologies and exhaustive specifications.

4.7.3. Technical vision

STATE-OF-THE-ART	IP4 CONTRIBUTION
Today although travel planning may cover different modes of transportation, it is still mostly one mode at a time and often over systems of different generations	The concept of an Interoperability Framework based on creating computer-readable, unambiguous, consistent and shared descriptions of the domain knowledge, based on a semantic interoperability approach, allowing any choice of the syntax to be used for representation of its terms and enabling exchanged messages to be unambiguously defined and understood by different systems
Interoperability is often handled by defining and agreeing on the data exchange method. This process becomes complex and tedious when dealing with the different technological aspects and generations of ticketing systems, especially in environments where each operator may define its own rules and interoperability is reduced or non-existent	Use of ontologies and semantic web to provide open components and interfaces to the registry, to connect elements and to standardise the way they interoperate with the IF
The variety and number of different systems and processes available, for example in a city of a reasonable size, makes it difficult to understand the transportation network as a whole and to extract information to better understand and improve it to the benefit of TSPs, authorities and travellers	Big analytics tools and decision support techniques to produce descriptive, predictive and prescriptive analyses, both in batch mode and in real time, allowing for example spatio-temporal analysis of mobility (mobility behaviours, users' habits, atypical situations), prediction of network loads and analysis of the impacts of particular situations

Interaction with other TDs (in the same IP and/or in other IPs)

Within IP4, ITD4.7 will mainly involve interactions with other TDs.

The interactions will in general cover roughly the same activities for all TDs and will consist of documentation and specifications.

The interaction with other IPs will be done at two different levels:

- through the other IP4 TDs for specific interfacing and interaction related to each TD;
- as an integrated solution, interacting consistently with the other IPs.

The following IPs/topics could be addressed:

- TD1.2, Train Control and Monitoring System:
  - on-board information management and distribution, and systems interaction;
  - use of train to ground communication for PIS interaction;
- TD1.6, Doors and Access Systems:
  - interaction for information exchange (counting, flow, occupancy);
  - information to support PRM;
- TD1.7, Train Modularity in Use:
  - in-train layout and mobility information for passengers;
- TD2.9, Traffic Management Evolution:

/ traffic status information to support passenger information services;

- TD3.11, Future Stations:

/ how to address information related to the station such as people flow, accessibility, guidance or emergency management.

Figure 40 depicts the main interactions between IP4 TDs and other IP TDs.

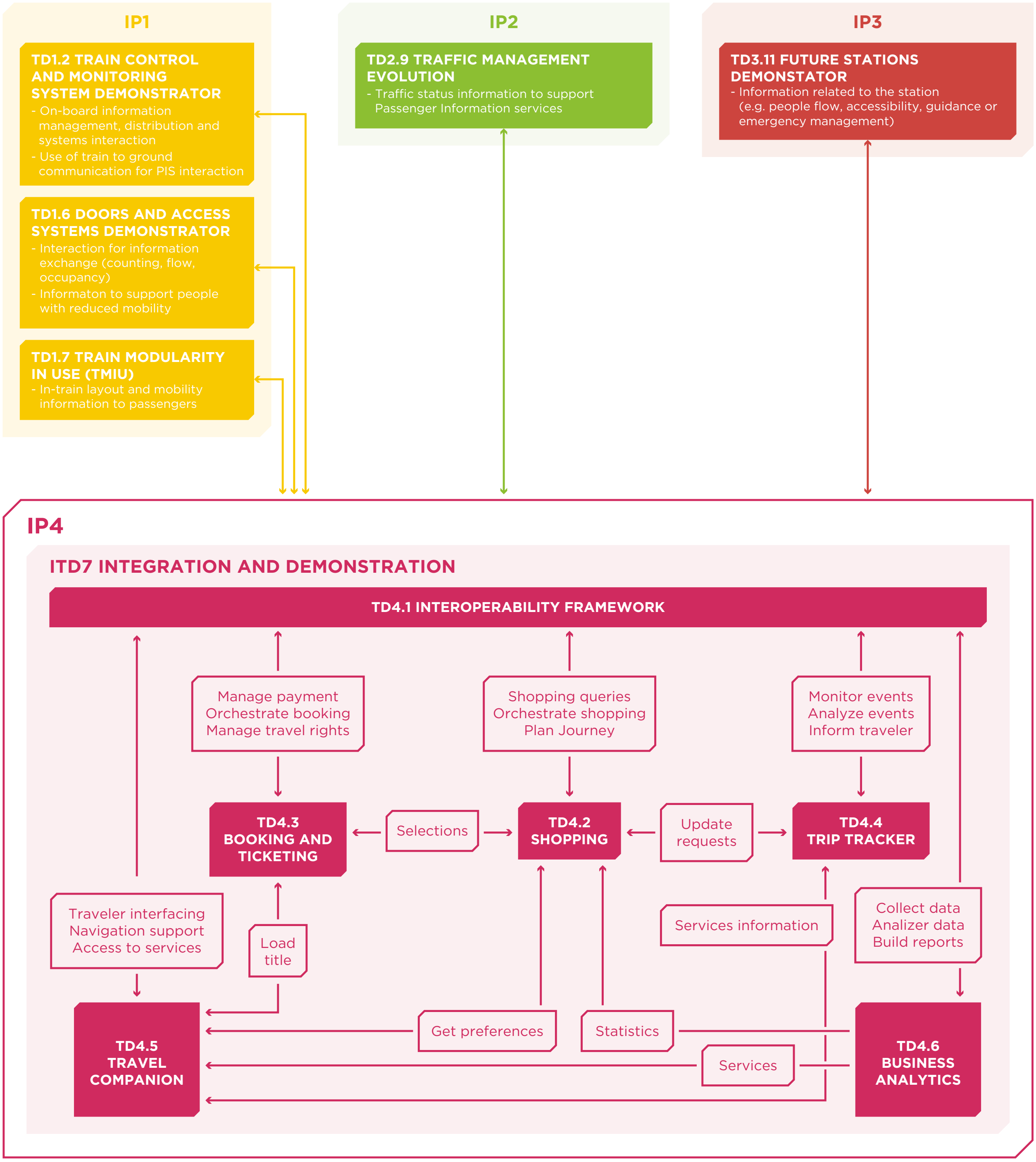


*Figure 40 / **Interaction with other TDs and IPs***

4.7.4. Impact and enabling innovation capabilities

- On the community adoption of IP4 concepts: although it is difficult to measure the level of adoption of the IP4 framework in the community, owing to the complexity and scale of the market, ITD4.7 will allow more effective transition of the transport ecosystem to IP4's disruptive and innovative technological concepts. By including a wide base of stakeholders in the work on consistency, principles will be shared and accepted in a much more effective manner. As ITD4.7 will be a guarantor of the production of open specification throughout the TDs of IP4, a good indicator of the openness of the specification produced will be the speed of adoption by the market. Moreover, the dissemination of the overall approach towards the transport community will be monitored by ITD4.7.

- On the consistency of engineering approach and deliverables: ITD4.7 will allow each technical demonstrator to take a common approach to the description and implementation of overall IP4's overall open specifications and conceptual architecture. This will result in a more effective, globalised engineering approach and consequently in the production of deliverables that are more widely recognised and accepted by stakeholders. Indicators of this impact could be standard engineering progress indicators (requirements, stability, etc.).

- On the convergence of a global IP4 technical demonstrator: to demonstrate the integrated, verified and validated satisfaction of the objective for an overall IP4 demonstrator, some indicators could be put in place, such as standard integration progress indicators (percentage of modules integrated, defects and change management, etc.), standard verification progress indicators (percentage of requirements tested, defects and change management, etc.) and standard validation progress indicators (percentage of use cases demonstrated, percentage of functions accepted, percentage of acceptance by stakeholders and by business requirements and implementation group).

- On the time to market for innovations: the availability of a structured and tested ecosystem will create a physical/logical environment that will enable faster entry for testing existing solutions and/or, thanks to a stable set of available rules and functional modules, for driving innovation by making the ecosystem available to innovation forces such as SMEs. This living lab approach across the community increases the innovation potential, which can be further streamlined through exchanges of information in the correct forums (such as those driven by the different IP4 projects) and the exploitation of data by local authorities and others.

- On the direct impact on travellers: the nature and scope of the ecosystem will be wider than current approaches, including not only multimodal travel information needed for routing from all over Europe but also knowledge from previous travellers and links to attraction centres. Since travellers will be directly linked to the system based on their own expectations and will receive personalised answers or alerts, they will clearly perceive that the information received is more accurate. The content will be reliable, since through the framework and operational modes the data providers will still have control over the interpretation and utilisation of their data.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Coordinated integration	The ITD will focus on the technical monitoring and synchronisation of the different CFM IP4 projects to guarantee aligned progress of the various TDs, enabling the different releases and demonstration phases to achieve the objectives

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Integrated consistency engineering management	ITD4.7 will focus on building an engineering methodology and on the strategies to ensure robust engineering processes and methods Associated with these processes, a set of documents will be produced to cover aspects shared by the different TDs, encompassing comprehensive lists of terms, acronyms and concepts By identifying high-level requirements and harmonising ontologies and interfaces, ambiguity and inconsistencies will be minimised, guaranteeing uniformity of integration, and the interoperability and openness needed for successful demonstration of the integrated concept

This TD will contribute to enabling three innovation capabilities as follows.

INNOVATION CAPABILITY	ITD4.7 ENABLERS
2 – Mobility as a service	The integrated environment opens up the opportunity to create seamless access to mobility services. This TD integrates all building blocks for the capability Mobility as a Service
4 – More value from data	The data acquired from traveller interactions, for example for trip planning, booking and follow-up, are a valuable source of information related to mobility. This TD integrates all building blocks for more value from data
10 – Stations and smart city mobility	Seamless travel does not end outside stations. Way guidance and flow management solutions will improve the traveller's experience

4.7.5. Demonstration activities and deployment

As explained already in the general IP4 description, ITD4.7 will release, on a regular basis, integrated batches of results from the IP4 TDs. To achieve this objective, IT4.7 must provide the framework as well as methods and tools to develop modern highly interactive IT systems.

For that purpose, the ITD4.7 iterative process offers:

- an effective software life cycle (timing different from the traditional V cycle) using rapid prototyping methods from early stages of the project;
- a continuous integration and test strategy;
- modern prototyping, rapid application development methodologies and agile software development approaches.

The initial phase of each release includes:

- evaluation results of the previous iteration, if any;
- identification of requested changes and/or corrections;
- identification, definition or refinement of specific use cases, which can be supported by the activities performed in parallel by the other projects.

The results of this initial phase are used to interact with the other IP4 projects, in order to serve as a basis for the technical specifications, the features and the technological choices.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Integration/ Demonstration	Use case definition	Specification of consistent use cases	Generic	6	Definition of consistent use cases that cover the different components and functionalities that will be used
	Component and interface specification	Coherent specification of interfaces	Generic	6/7	Definition of a coherent set of components' functionalities and appropriate specification of the interfaces needed
	Module and component integration	Consistent specification of interfaces and interactions	Generic	6/7	Integration of the different components to guarantee consistency of functional operation
	Testing and test results	Consistent specification of interfaces and interactions	Generic	6/7	Evaluation of the integrated components/system compliant with requirements and specifications

The content of the releases is defined by (the sum of) all the other IP4 TDs.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Integration and demonstration		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD4.7	4.7.1 Integrated Technical Coordination	5																												
	4.7.2 Integrated Community Management	2>6																												
	4.7.3 Integrated Engineering Consistency Management	2>6									IT2Rail				Alpha release								Beta release				Final release			
	4.7.4 Technical releases	3>6										◆				◆								◆				◆		
ITD7	Integration and demonstration										○		○							○	○							○ ○		
											TRA 2018		InnoTrans 2018								InnoTrans 2020								InnoTrans 2022	

◆ milestone
○ quick win
lighthouse projects
contracted activities
future activities

Table 86 / ***ITD4.7 milestones***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q2 2018	Integration of IT2Rail developments into the ITD7 demonstration. First presentation of the concept, aiming to raise awareness in the sector A prototyped version will be presented	Demonstration of the initial set of functionalities integrated into a stable environment
Q3 2019	De-Integrating the outcomes of the ATTRACkTIVE, Co-Active and Connective projects	Demonstration of the alpha release functionalities
Q2 2021	Integrating the Connective and MaaSive projects, aiming to demonstrate the evolution of the developments in IP4 towards a MaaS concept	Demonstration of the beta release functionalities
Q2 2022	Integration of all the outcomes of the IP4 projects. Demonstration in real-life environment	Demonstration of the final release functionalities

Table 87 / ***ITD4.7 quick wins***

WHEN	WHAT	
Q2 and Q3 2018	Seamless multimodal door-to-door travel	Demonstration of the first release with integrated functionalities at TRA 2018 and InnoTrans 2018
Q2 2020	Integrated multimodal ecosystem	Driven by the alpha release from ATTRACkTIVE, Co-Active and Connective ecosystem, which enables pan-European intermodal travel
Q3 2020	Towards the MaaS concept	With support of MaaSive and Shift2MaaS (use the content of the alpha release and MaaSive CREL) ecosystem, which also enables first set of MaaS features
Q2/Q3 2022	Towards the MaaS concept	With direct support of Connective and CFM2020, using the outcomes of the beta release and the software release previous to the final one (pre-final release)..Scalable ecosystems that enable pan-European intermodal travel and MaaS
Q3 2022	Fully dynamic door-to-door travel	With direct support of CONNECTIVE, and CFM2020), using the outcomes of the beta release and pre-final release. Scalable (near-)market-ready ecosystems that enable pan-European intermodal travel and MaaS, including cross-platform approaches

The estimated total budget for this TD is around EUR 7 million.

5. IP5 – Technologies for sustainable and attractive European rail freight

Context and motivation

Although rail freight markets within the EU have been open for a number of years, the modal share of intra-EU rail freight transport has slightly declined since 2010, so that the sector risks failing to fulfil the ambitious objectives that were set in the Transport White Paper in terms of developing rail freight, namely to almost double the use of rail freight compared with 2005 and to achieve a shift of 30 % of road freight over 300 km to modes such as rail or waterborne transport by 2030, and of more than 50 % by 2050.

The industry's stagnation can partly be explained by the existence of legal barriers restricting competition (including the infrastructure access regime, taxation, etc.), but also by problems of operational and technical natures, which affect the overall capacity and performance of the sector.

Today's main limiting factors are:

- problems with handling freight trains on mixed traffic lines during peak passenger train hours;
- long and unreliable lead times in terminals, hubs and marshalling yards accompanied with high operational costs and lack of synchronisation of different operations;
- low reliability and high operational costs due to manual handling processes and resource planning based on experience or stand-alone IT systems;
- reduced profitability, competitiveness and investment capabilities of railway undertakings/infrastructure managers and railway service providers due to the increase in operational costs and in LCC for assets and infrastructure;
- limited train weight, length and speed due to limits in the strength of standard couplers and traction distributed among several different locomotives in the freight convoy as well as due to limits in the railway infrastructure capabilities;
- low performance and lack of flexibility in serving the first and the last mile in single-wagon traffic;
- restricted payload–deadweight ratios, especially in the most emerging market segments of containerised single goods transport;
- unelectrified freight wagons, unable to benefit from intelligent sensors and communication systems;
- shippers and end-customers unable to track goods along the supply chain because data processing is not integrated'.

The members participating in IP5 are convinced that a significant proportion of the issues mentioned above are due to:

- insufficient optimisation of infrastructure and rolling stock capacity;
- low level of automation of the operational processes;
- limitations in wagon and locomotive technology;

- lack of communication, data management, data exchange, integrated IT systems/platforms;
- lack of TAF (Telematic Application for Freight) TSI implementation, which prescribes standardised data exchange platform between stakeholders;
- lacking or restricted interoperability among the different stakeholders that participate in international railway freight transport.

The cost competitiveness and the reliability of freight services need to be considerably improved so that rail freight can be in a position to offer a cost-effective, attractive service to shippers that helps to take freight away from the already congested road network.

The challenge is twofold:

- to acquire a new service-oriented profile for rail freight services based on excellence in on-time delivery at competitive costs, interweaving their operations with other transport modes, addressing the needs of the clientele by, among other things, incorporating innovative value-added services;
- to increase productivity, by addressing current operational and system weaknesses and limitations, including interoperability issues, and finding cost-effective solutions to these problems, including optimisation of existing infrastructure and fostering technology transfer from other sectors into rail freight.

For European rail freight to become more attractive, the rail freight sector must provide customer-tailored services to its clients and be more effectively integrated into the logistics value chain. Reliability, lead times, deliveries on time and in full, frequency and cost must meet customer requirements for different goods segments. Investments in rail innovations should be compatible with expected future needs and changes brought about by macro-level trends in trade and production patterns, goods types, shipment sizes and consumer behaviour.

The rail freight sector must also take advantage of and integrate new developments that are affecting other parts of the logistics chain, in particular digitisation, which can help to drastically reduce LCC and operation costs, as well as novel processes and technologies such as 3D printers or fabrication laboratory capacities, or blockchain.

Standardised digital data exchange and automated, condition-based processes are key to the vision of IP5. Therefore, IP5 recognises that the development of an efficient, capable and powerful IT infrastructure is an important precondition. To make use of innovative applications, technologies and processes, and for the profitable combination of different solutions, the IT backbone has to be a focus of development. Hence, IP5 aims to develop the overall IT infrastructure to make use of the potentials of the targeted results of IP5.

Action in the rail freight sector is urgent, as it risks losing its position as the most environmentally friendly transport mode because of innovations in other transport modes and must come up with an answer to new challenging developments in the road freight traffic segment, such as the implementation of autonomous driving modes.

Objectives of the IP and expected results

To tackle this broad spectrum of challenges, IP5 follows a whole-system approach whereby the different components interplay in an optimal way to ensure value creation for customers, the rail-operating community and society.

The innovations and enabling technologies stemming from the TDs in IP5 are regarded as milestones on a trajectory towards a long-term vision of a high-performing, 24/7-operating, automated/autonomous railway that optimises infrastructure capacity, is integrated with other transport modes through fluid and seamless terminal operations, and is sensitive to changing customer demands. When disruptions occur, customers are informed about alternatives and routes that meet their specific requirements and are rebooked, and rerouted in some cases, in a seamless way. The railway of the future fully exploits the potential of digitalisation to increase its attractiveness and viability. S2R will also be instrumental in the continuous development of rail freight's green credentials in door-to-door mobility solutions, which is a necessity, as the alternative modes are improving their environmental performance.

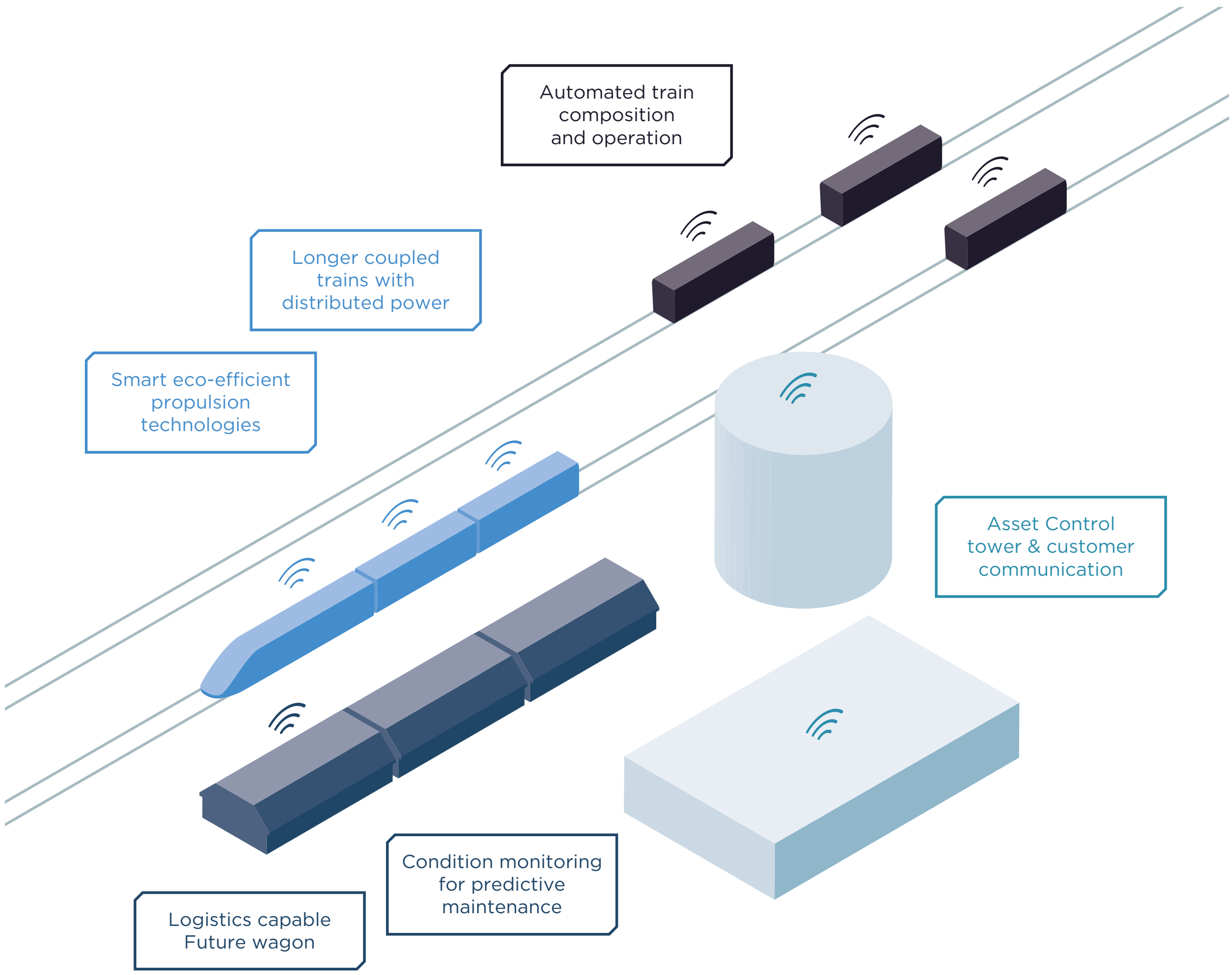


Figure 41 / ***Vision for IP5***

In particular, the huge potential offered by digitisation, building on TAF-TSI, is expected to boost rail freight productivity and punctuality, creating competitive cost structures and stimulating growth in Europe by providing more efficient, reliable and high-quality rail freight services.

The development of technologies that enable a higher degree of automation and autonomous operations is expected to raise productivity and reliability and reduce cost dramatically.

Automation in train composition and operation is expected to raise the quality of rail freight services, improve staff productivity and resource utilisation, and increase infrastructure capacity. Pan-European rail freight is a key enabler for automated driving systems.

Customers and LCC will benefit from predictive maintenance and smart, self-monitoring freight assets. The fusion of sensor data with pattern recognition methods will ensure cost-efficient asset management in both operations and maintenance.

Driver assistance, component optimisation and advanced propulsion technologies will significantly reduce energy consumption and emissions, strengthening competitiveness while lowering the carbon footprint.

Increased flexibility through virtual train coupling and the resulting increase in freight train lengths will help to respond to the challenge of road freight productivity and enable sustainable growth in freight traffic along core European corridors.

All work developed in each TD has to take into account the present and coming (2020) TAF-TSI standards for each relevant objective/topic and the TAF-TSI Strategic European Deployment Plan. Furthermore, the current processes in regard to TAF-TSI must be followed by each TD in relation to relevant issues.

The following table summarises the main objectives of IP5 and provides an overview of some of the concrete deliverables that can be expected to result from the activities undertaken in the IP.

Table 88 / ***Objectives and challenges of IP5***

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Capacity increase	Wagons with optimum payload, maintainability, lower noise and less track attrition. Flexible, faster train compositions and decompositions, and shunting. Environmentally friendly traction and first-/last-mile capabilities	Wagon electrification Upgraded braking Efficient propulsion Sensors, monitoring analysis Efficient terminal handling ICT systems Operating performance facilitating blending In-train communication Automated and virtual coupling
	Better control of the wagons, the train and its current performance	Distributed braking enabling better performance Modern wagon design Communication in-train and to the outside
Operational reliability increase	Modern and reliable technologies and components	Fail-resistant design with sensors and technology providing continuous monitoring, information and analysis Developed propulsion
	Smart operation and online information systems	Combination of border-crossing path allocation and slot planning and dispatching Real-time data processing Improvement of interoperability and safety Creation of incentives for product innovation and service quality networks Terminal handling and procedures
	Few unexpected occupancies	Monitoring of disturbances and events
	Proactively corrective actions enabled	Intelligent data analysis

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) DELIVERABLE
Railway system LCC reduction	Faster return on investment (ROI) for vehicles	New vehicle with high productivity and high yearly mileage
		Less downtime for vehicles
		Less need for spare parts and vehicles
		Lower operational costs
	Reduction in the number of vehicles needed for a given capacity	Vehicles with increased productivity and availability, more productive and with less downtime
	Reduction in the cost of vehicle maintenance	Modern and reliable system architectures and component technologies
		Better and more standardised online monitoring of current condition
	Reduced wear and tear on the infrastructure	Track-friendly vehicles with better running properties
		Smoother running
	Reduction of damage to the infrastructure	Sensors noting abnormal circumstances
	Reduction in the energy consumption	As explained below
Energy efficiency	Lighter wagons	Modern modular wagon design
		Distributed braking allowing reduced tare weight
		Monitoring of the running properties
	Reduction in energy losses	Better and more adapted braking
Noise reduction	Modern wagon design	Less noise from wagons
	Noise-reduction-oriented design of brakes	New braking systems
	Smoother operation	

IP5 has broken down the steering process into logical steps in order to guarantee a sensible and binding connection between the overall goals established in the vision for IP5 and the concrete project work at task and sub-task levels.

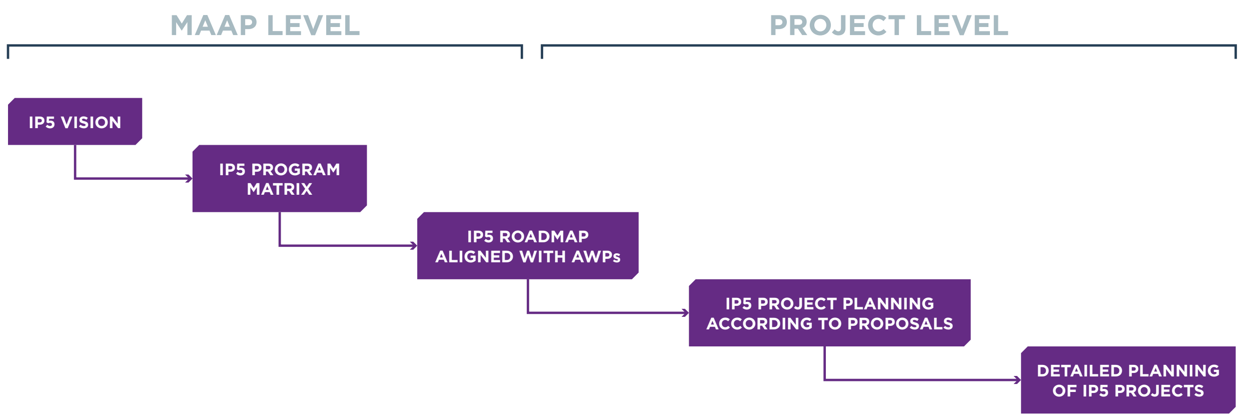


*Figure 42 / **IP5 steering hierarchy***

The IP5 programme matrix is the link between the top-level aims of the IP5 vision and the roadmap. The programme matrix differentiates the activities between the three asset classes 'freight locomotive', 'wagon' and 'infrastructure' to illustrate that on the one hand freight rail works as a system of integrated assets that work in concert but that on the other hand each part of the system can and must contribute to the overall goal individually.

The IP5 roadmap links the individual tenders and consortia of IP5 and is therefore the necessary intertemporal connection of all activities of IP5 over the total term of S2R. With the roadmap, IP5 ensures that the interdependencies between project results and follow-up activities are taken into account and visible to everyone.

In two further steps, IP5 smoothly transitions from the overall planning to concrete, coordinated project work on all individual tasks and deliverables within the consortia that carry out the research and development work.

Table 89 / ***IP5 programme matrix***

INPUT TO THE VISION	FREIGHT WAGON	FREIGHT LOCOMOTIVE	INFRASTRUCTURE (INCLUDING IT INFRASTRUCTURE)
Input to 'automated train composition and operation', including yard/ terminal	• Wagon condition monitoring Wagon load monitoring Wagon identity Automated coupling Train integrity control Optimised train dynamics	• Radio remote control of a locomotive Automated couplers of a locomotive Functional integration of driver advisory systems/ ATO on board Obstacle detection Interface to traffic management for ATO/ connected driver advisory systems	• Integration concept to connect yards and terminals in the network Train with wireless backbone for communication services on board, including train integrity OBU of train sending information to yards/ terminals Analysis of how to use wayside monitoring for reading of wagon IDs, monitoring derailments, etc. Automated wagon detection and recognition in terminals, including IDs and load schemes Damage control in terminals
Input to 'longer trains with distributed power'	• Technical concept automated coupling + potentially prototype Brake control	• Radio communication with no 'shadows' i.e. no communication coverage Control of the slave locomotive Optimised train dynamics including coupling/loading concepts Intelligent end-of-train (EoT) device	• Train with wireless backbone for communication services on board, including EoT

INPUT TO THE VISION	FREIGHT WAGON	FREIGHT LOCOMOTIVE	INFRASTRUCTURE (INCLUDING IT INFRASTRUCTURE)
Input to 'smart eco-efficient propulsion technologies'	• Low-friction running gear Wagon design optimised for aerodynamics	• Use cases for auxiliary diesel Assessment of advanced power technologies, mainline and shunting, named demonstrators ATO/C-DAS Low-noise running Low wear and tear, track friendly Battery-relevant life cycle, lower LCC Modular design	• Network management system connected to TMS maximising energy efficiency for entire network
Input to 'asset control tower and customer communication'	• Wagon condition monitoring Wagon load monitoring Wagon identification	• GPS localisation Condition monitoring, storage and forwarding of information	• Definition of overall IT infrastructure OBU of train sending information to yards/ terminals Information flow from assets to asset control tower Clarification of frequency of information sent from assets Clarification of information forwarded to the operator Demonstration of interoperability between IT production applications from different suppliers
Input to 'condition monitoring for predictive maintenance', including depots	• Wagon condition monitoring Wagon identification Condition-based maintenance method, processes, roll-out of new maintenance regime	• Sensors and OBU for condition monitoring Reduction of life-cycle cost through future locomotive design	• Backbone for wireless communication on the train Definition of overall IT infrastructure Common understanding of the processes for condition-based maintenance Applications for live data analysis Condition-based maintenance regime

INPUT TO THE VISION	FREIGHT WAGON	FREIGHT LOCOMOTIVE	INFRASTRUCTURE (INCLUDING IT INFRASTRUCTURE)
Input to 'logistics-capable future freight wagon'	• Light weight for higher payload Low-noise running gear Low wear and tear, track friendly Able to communicate automatically Shorter life cycle, lower LCC Modular design Market-relevant top speed Operational concept for new markets Automatic coupling	• Ways for gathering data from the wagons on the locomotive Interfaces between locomotive and freight train (mechanical, electrical, data)	• Wireless backbone for wagon monitoring Clarification of data interface between wagon and locomotives Railcar communicates with terminal

The programme breakdown in the matrix provides an overview of what IP5 does in order to contribute to achieving the vision, within the S2R lifetime. It serves to identify interfaces between the locomotive, the wagon and the infrastructure that need to be taken care of in the collaboration across all projects. It also serves to identify potential 'white spots that should be covered in follow-up-calls or in complimentary actions.

Table 90 / ***Overview of planned demonstrators***

FREIGHT WAGON	FREIGHT LOCOMOTIVE	INFRASTRUCTURE (INCLUDING IT INFRASTRUCTURE)
• Running gear Core market wagon 2020 Extended market wagon 2020, including OBUs for wagon monitoring and cargo monitoring sending communication to landside	• Distributed power technology Radial steering of bogie Last-mile application with homologated lithium ion battery Hybrid powertrain prototype for real operation Hybridisation of a legacy shunter with powerful traction battery Automated freight train/ connected driver assistance	• Design and operational testing of intelligent video gate terminal Real-time yard management tested in connection with timetable planning Condition-based and predictive maintenance dashboard tested for locomotives Demonstration of communication use case, e.g. wagon to locomotive to landside (terminal/yard) to data management system

Past and ongoing European and national research projects

IP5 will be supported to a great extent by many of the projects funded by the EU research programmes in the last few years. S2R will be an efficient tool to bring the results of these projects closer to the market, thus maximising the real benefits from the investment that European society has made in railway research in recent years.

The members plan to use input from other EU projects that have been developed in the field of freight, such as Marathon, Spectrum, Tiger, E-Freight and D-Rail. Furthermore, they will seek links to the Capacity4Rail project and to the project Smart Rail.

Set-up and structure of IP5

The IP is structured in five TDs with the ambition to deliver demonstrations at TRL 6–7. The main red thread is more intelligent equipment and automated processes and operations, with digitisation as an enabler.

The five TDs are organised around the three following work streams:

- optimisation of operational processes for infrastructure, operations and assets;
- automation of rail freight system;
- new markets.

Each TD is composed of different focus areas. The focus area is the framework and level of detail, where the project work is described and the activities of all involved parties are bundled. Figure 43 gives an overview of the TD structure, highlighting the changes compared with the previous version.

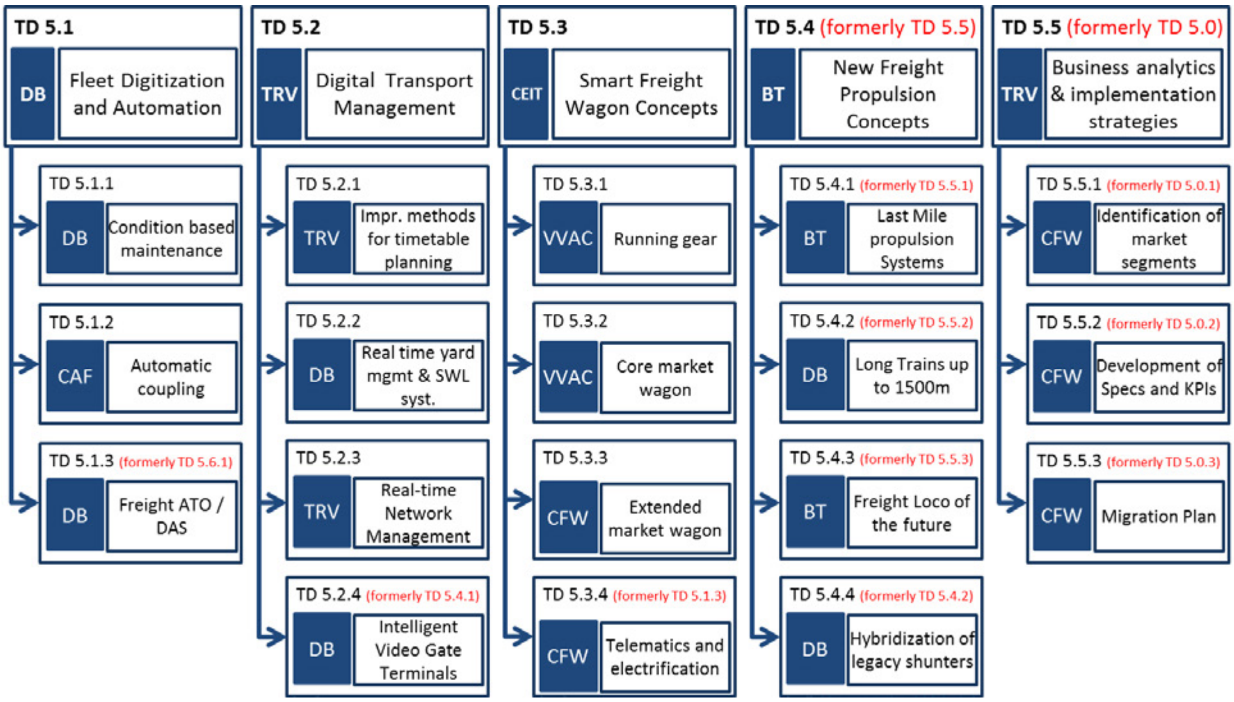


*Figure 43 / **TD structure***

Links to other IPs

There are increasing synergies in IP5 within its TDs, as well as with regard to other areas of the S2R programme and other relevant R&I projects.

			TD5.1	TD5.2	TD5.3	TD5.4	TD5.5
Input from S2R IP1	**TD1.1**	*Traction Systems*				x	
	TD1.3	*Carbody Shell*				x	
	TD1.4	*Running Gear*			x	x	
	TD2.2	*Railway Network Capacity Increase (ATO up to GoA4 – UTO)*	x	x		x	
	TD2.3	*Moving Block*	x	x			
	TD2.4	*Fail-safe Train Positioning (including satellite technology)*	x	x			
	TD2.5	*On-board Train Integrity*	x	x		x	
	TD2.8	*Virtually Coupled Train Sets*	x	x			
	TD2.9	*Traffic Management Evolution*	x	x		x	
Input from S2R IP3	**TD3.1**	*Enhanced Switch and Crossing System*			x		
	TD3.2	*Next Generation Switch and Crossing System*			x		
	TD3.3	*Optimised Track System*			x		
	TD3.4	*Next Generation Track System*			x		
	TD3.6	*Dynamic Railway Information Management System (DRIMS)*			x		
	TD3.7	*Railway Integrated Measuring and Monitoring System (RIMMS)*			x		
Input from S2R IP4	**TD4.1**	*Interoperability Framework*		x			
Input from S2R CCA	**WA4.2**	*Integrated Mobility Management*	x	x		x	
	WA6.1	*Long-term Needs and Socioeconomic Research*					x
	WA6.2	*KPI Method Development and Integrated Assessment*					x
	WA6.3	*Safety, Standardisation, Smart Maintenance, Smart Materials and Virtual Certification*	x		x		
	WA6.4	*Smart Mobility*	x	x		x	
	WA6.5	*Energy and Sustainability*	x	x	x	x	

			TD5.1	TD5.2	TD5.3	TD5.4	TD5.5
Input from fore-runner projects	**LH**	*Smart-Rail*					x
		Capacity4Rail	x	x			x
		On-Time	x	x			
		Spectrum	x		x		
	FP7	*Marathon*	x		x	x	
		FEBIS	x				
		FFZ	x				
		Fastrcargo			x		
		Newopera			x		
		Retrack			x		
		Velwagon			x		
		Sustrail			x		
		E-Freight			x		
	FP7	*Bestfact*				x	
	FP7	*Tiger*				x	
	FP7	*CleanER-D*				x	
	FP7	*Refresco*				x	

In addition, the existing interactions with other IPs and within relevant TDs of IP5 take into account the work on the S2R functional system architecture and conceptual data model performed in IPx.

5.1. TD5.1 Fleet Digitisation and Automation

5.1.1. Concept

In order to meet the ambitious objectives set out in the Transport White Paper in terms of developing rail freight, both quality and cost competitiveness need to be considerably improved. European railway undertakings and infrastructure managers are increasingly facing challenges that require a new focus and a complete paradigm shift in operations in order to achieve the objectives of an automated railway system.

To achieve the goal of a digital railway that boosts the quality of international freight relations and the cost efficiency of rail freight, IP5 introduces the idea of a digital SERA. IP5 sees a stepwise approach to these goals, going from the enablers on the technological level and intelligent assets onwards to the process level. In the final step, these processes will lead to the digital SERA.

The digitalised and automated railway system (TD5.1) builds upon all technical innovations in scope of TD5.2, Digital Transport Management, TD5.3, Smart Freight Wagon Concepts, and TD5.4, New Freight Propulsion Concepts, which focus firstly on freight infrastructure, secondly on freight wagons and thirdly on freight locomotives. In a systemic view of rail transport, TD5.1 focuses on topics that concern more than one of the three dimensions.

As key technologies to enable a digital and automated rail freight system, TD5.1 includes the four core topics condition-Based maintenance, automatic coupling (DAC), freight automatic train operation (ATO) and connected driver advisory systems (C-DAS). Further systemic topics, e.g. condition-based fleet steering and automatic train preparation, are subordinate topics included in these innovation fields.

TD5.1 will accelerate the development of 'digital railways' towards an overall integrated and high-performing system with the following activities.

- Laying the essential building blocks for the digital railway system by paving the way to a **Europe-wide standard for automatic coupling in the freight sector**. This will serve as a catalyst for all freight train-related digitalisation activities, including condition-based maintenance and ATO.

- Fostering condition monitoring and including assets across Europe in **condition-based maintenance activities with the goal of creating a smart European fleet**.

- Minimising energy consumption by **connecting advanced driver advisory systems (C-DAS) on legacy infrastructure to traffic management systems** of the IMs, harmonised across Europe and upward compatible to future ATO architecture.

- Beyond C-DAS, **taking direct control of throttle and brake** via an intelligent ATO module, for ETCS-based advanced grades of automation (GoAs), which maximise energy efficiency in safe, predictive mainline operation.

The technical objective of this TD is to develop demonstrators of rail freight digitisation and automation, including showcases of condition-based maintenance and ATO. The aim is to actively pursue the objectives of freight digitalisation as a basis for automation, realised progressively until 2035 in order to increase rail's competitiveness with road freight, achieve operational efficiency gains and optimise resource utilisation.

5.1.2. Technical objectives

TD5.1 has the objective of fostering and accelerating the development towards condition-based maintenance, which is enabled by digitised assets connected by automatic couplers and with an asset control tower for rail freight. The internet of things (IoT) architecture supporting condition-based maintenance is in turn an enabler of further condition-based operations and eventually of rail freight automation at the highest grade (GoA4), which represents the final target state of the IP5 vision according to the MAAP.

The following are the main technical objectives of this TD.

1. Automatic coupling and decoupling including power, air and data connectivity will serve the electrification of long and heavy trains for condition monitoring of wagon and goods, electro-pneumatic braking and train integrity testing, which will increase train and yard productivity by up to 30 % as well as reduce labour costs in the train composition process.

2. An end-to-end solution for condition-based maintenance will include processes, data handling, analytics, dashboards and a complete condition-based maintenance regime for a heterogeneous European legacy locomotive fleet to enable cost savings and incident reduction.

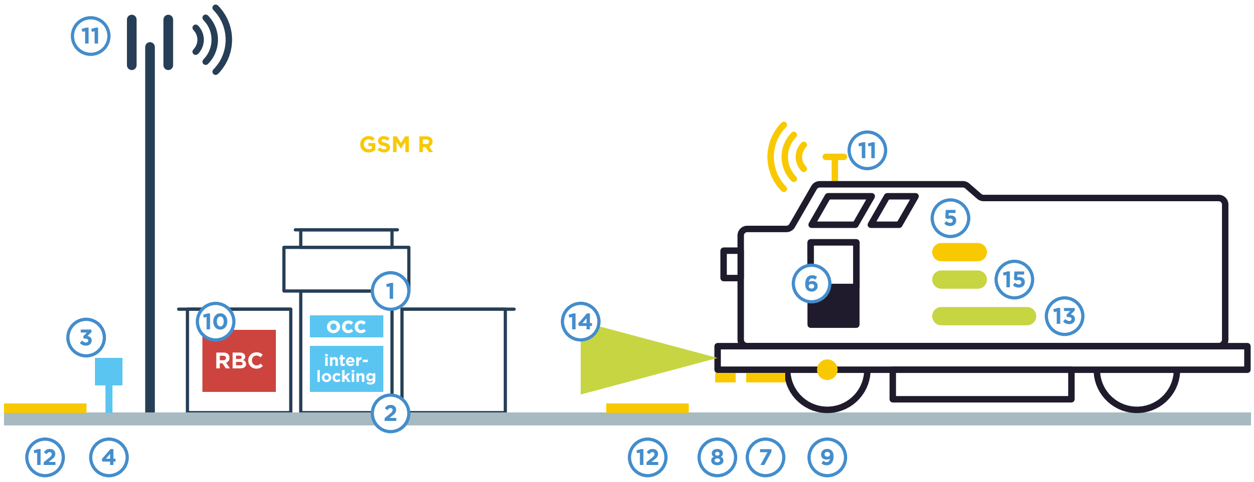
3. C-DAS as a first step, and fully automatic train operation built on it will improve current autopilots for mature, target-oriented application in rail freight, improving quality in terms of punctuality, reliability and flexibility on the one hand, while reducing the operating costs on the other.

5.1.3. Technical vision

The vision of S2R IP5 can be summarised in two words: digitalisation and automation. TD5.1 is a core contributor to this vision.

Automatic coupling for European rail freight business is urgently needed as an enabler for digitisation and automation and will pave the way for asset intelligence, condition-based operations, automatic train operation and train composition. Asset digitisation and condition monitoring are essential building blocks for ATO, allowing the vehicle to be self-monitoring to run in a fully automated mode under European train protection (ERTMS).

STATE OF THE ART	TD5.1 PROGRESS BEYOND STATE OF THE ART
Screw couplers with limitations on train dynamics and weight require a manual handling process in rail operation	Development of the technical requirements, business benefit analysis and migration plan for automatic couplers with air, power and data link
Maintenance strategy is preventative and corrective because of missing condition-monitoring data	End-to-end solution for predictive maintenance, including processes, data handling, analytics and dashboards for locomotives and wagons
Personalised expert knowledge and an ageing workforce/staff within the maintenance workshops	Replicable predictive maintenance processes, including new roles and responsibilities in the interaction with the asset, fleet and maintenance management areas
No usage of digitisation strategies (e.g. automated information sharing, configuration management)	Structured data handling, statistical and empirical analysis and development of neuronal, IT-based prognostics
Traditional time- or mileage-based maintenance	Development of a complete predictive maintenance regime for the core locomotive fleet
Few DAS with link to traffic management system implemented so far and limited to one operator or region	Definition and implementation of a European standard for DAS connected to the local traffic management systems, including the required interfaces and a demonstration
Manual train operation whereby a train driver controls starting, stopping and handling of incidents (GoA1)	ATO in which starting and stopping and handling of incidents are fully automated (GoA4)



Interlocking components *Ensure safe routes and train separation*	ETCS Level 2 components *Ensure safe speed limits*	Automated Driving components *Drive train and supervise system*
1. Operation control center 2. Interlocking 3. Track vacancy detection indication (TVDI) 4. Vacancy detection	5. European vital computer 6. DMI 7. Balise antenna 8. Radar 9. Odo Pulse generator 10. Radio block center 11. GSM-R 12. Eurobalises	13. Automated Train Operation module (ATO) 14. Obstacle detection (s. below) 15. CBM board computer

Figure 44 / ***ATO 'pilot line' demonstrator***

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged with other TDs and/or IPs, both from the point of view of technologies employed and from the point of view of interaction in performance and objectives, are:

- TD5.2, Digital Transport Management – interfaces for data communication between locomotive, wagons and data centres;
- TD5.3, Smart Freight Wagon Concepts – automatic coupling needs to be installed on the wagons and will enable telematics and electrification; condition monitoring on wagon bogies overlaps with condition-based maintenance activities;
- TD5.4, New Freight Propulsion Concepts – 'long trains up to 1 500 m' researches communication technologies for trains and locomotives that can be applicable for C-DAS and ATO;
- TD5.5, Business Analytics and Implementation Strategies – migration plans for the uptake of the researched technologies and KPIs for measurability of the impact;
- TD2.2, Railway Network Capacity Increase (ATO up to GoA4) – the freight pilot will implement prototypes developed in the scope of TD2.2;

- TD2.3, Moving Fluid Block – interaction with the train regulation and traffic management issues related to ATO;
- TD2.4, Fail-safe Train Positioning – an important prerequisite for safe ATO operations;
- TD2.5, On-board Train Integrity – constant monitoring of train integrity is a prerequisite for safe ATO operations;
- TD2.8, Virtually Coupled Train Sets – joint understanding of how train regulation and automatic driving can be performed dynamically inside a convoy of trains;
- TD2.9, Traffic Management Evolution – advanced traffic management and control systems (ERTMS/ETCS) for cross-border operations deliver necessary data input for C-DAS and ATO.

The interaction between the different TDs in IP5 is complex, with multilayer input–output relations between TD5.1 and its sister TDs.

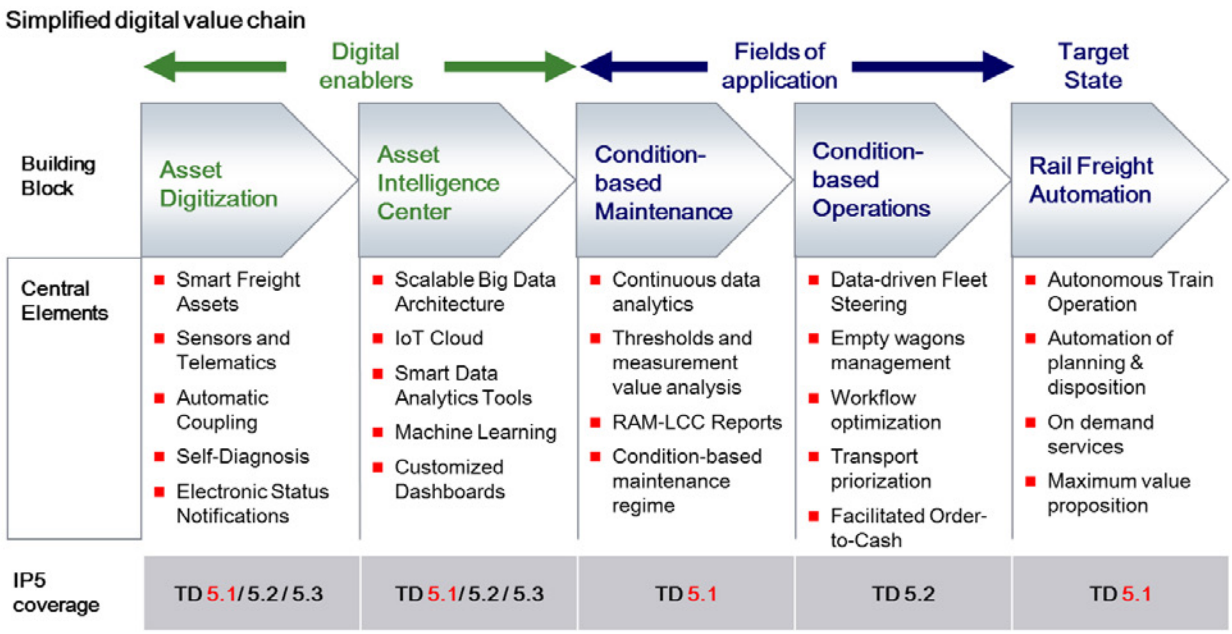


Figure 45 / ***Interaction between the TDs of IP5***

5.1.4. Impact and enabling innovation capabilities

TD5.1 has a major impact in the S2R system-level KPIs. The relative weights of the benefits provided by this work are estimated in the table below, which provides an overview of effects expected from the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Technological leadership supported by a combination of the development and final implementation of innovations and technical standards, setting up an effective advantage for European industry. Tangible benefits for the end user: • provision of real-time information, alert notifications on goods and/or train conditions / improve LCC (20 % reduction), and real-time health monitoring of goods and vehicles, wagon automation, control and monitoring of dangerous goods • improvement of dynamic train performances, on conventional trains and/or on trains supported by electronic technologies: / train set-up and uncoupling automation, longitudinal dynamics improvements (reduce damage to the railway infrastructure by 75 %) / optimisation of service intervals (condition-based maintenance) • technological leadership supported by the rail freight demonstration of ground-breaking technology for European industry • an autonomous freight test train running across Europe to showcase and validate the capacity for rail automation • EU industry including manufacturers, operators and infrastructure managers making rail freight automation a priority development
Compliance with EU objectives	• Promotion of modal shift: a big impact brought about by the implementation of these new technologies towards avoiding service disruptions and adding new innovation capabilities • Support to capacity increase: as mentioned above, this is allowed by flexible unit coupling and less service disruption due to lack of operational availability • Greening of transport through energy reduction by better integration between subsystems and communications outside the train, as well as optimised consists with flexible coupling
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRL 3–4. At the end of Shif2Rail it is expected that the successful concepts will be brought to TRL 6–7. For the recommended pilot showing GoA2 operations on the European mainline, the TRL level reached must be 7, in order to demonstrate the operational capacity for handling of the technology, verify the impact and come as close as possible to a marketable product in 2020

This TD will contribute to enabling nine innovation capabilities as follows.

INNOVATION CAPABILITY	TD5.1 FLEET DIGITALISATION AND AUTOMATION
1 – Automated train operation	Automated (passengers and freight) trains run closer together with increased flexibility, optimised energy consumption, increased punctuality and cost reduction: • BB5.1.2: Automatic coupling • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
3 – Logistics on demand	Automated yards, intermodal hubs, ports and cross-modal interchange locations connect the rail system into the multimodal logistic chain: • BB5.1.2: Automatic coupling • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)

INNOVATION CAPABILITY	TD5.1 FLEET DIGITALISATION AND AUTOMATION
4 – More value from data	Big data analytics enables a range of new and improved services to be developed. Secure IT services, protection of the rail system and business continuity in the event of an incident: • BB5.1.1: Condition-based maintenance (TRL 6/7) • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
5 – Optimum energy use	ATO improves energy efficiency: • BB5.1.2: Automatic coupling • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
6 – Service timed to the second	Automated recovery from disruption (a self-healing process) quickly restores normal service: • BB5.1.1: Condition-based maintenance (TRL 6/7) • BB5.1.2: Automatic coupling • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
7 – Low-cost railway	A whole-life operating cost approach balances the use of low-cost technical assets and good-value service: • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
8 – Guaranteed asset health and availability	The IoT enables real-time monitoring through connected sensors (ground/air/embedded). Shared real-time monitoring of asset health by a wide array of sensors connected together in an IoT environment feeds the predictive maintenance decision-making process. AI supports predictive maintenance decision-making to reduce manual interventions on infrastructure and rolling stock: • BB5.1.1: Condition-based maintenance (TRL 6/7) • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
9 – Intelligent trains	Autonomous trains can monitor and regulate themselves. Communication is possible between trains, between train and infrastructure, and between train and freight customers: • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)
10 – Stations and smart city mobility	Railways are a core part of smart city mobility management systems and city fulfilment and delivery services: • BB5.1.2: Automatic coupling • BB5.1.3: Freight ATO/C-DAS (TRL 6/7)

5.1.5. Demonstration activities and deployment

The following table summarises the contribution of TD5.1, Fleet Digitalisation and Automation, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Fleet digiti-sation and automa-tion’	Automatic coupling	Specification, architecture and interface definition	Freight	6	Development of the technical requirements, business benefit analysis and migration plan for automatic couplers with air, power and data link. Automatic coupling will enable integration of wagons in the condition-based maintenance framework, to enable, for example, longer trains (TD5.4) and train automation (TD5.1). Automatic coupling will include heavy load, electric and data connectivity and minimise manual workload through automatic coupling and remote-controlled decoupling
	Condition-based maintenance	Definition of maintenance procedures and migration process following standards EN 50126 and DIN 27201 part 1	Freight	6	Development of an end-to-end solution for predictive maintenance, including processes, data handling, analytics and dashboards, for locomotives and wagons. Beyond data handling, statistical and empirical analysis and development of neuronal prognostics, the core innovation of Predictive Maintenance (PM) takes place at the process level, including new roles and responsibilities in the interaction of the areas of asset, fleet and maintenance management

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Fleet digiti-sation and automa-tion’	Driver information for optimisation of speed profile in real time	Technology, functional requirements, interfaces	Freight	4	Concept development for bilateral communication layout. Development and demonstration of selected C-DAS functions. Evaluation of effects of selected C-DAS functions on capacity, punctuality and energy consumption. Specification of interfaces to external systems (e.g. interlocking, TMS, maintenance systems) and further innovations planned, e.g. free float optimisation C-DAS
	Freight ATO Maximum quality and minimum energy consumption, flexible disposition, reduction of factor cost	Technology, functional requirements, standardised plug and play interfaces and vendor-independent reference architecture	Freight	6	Automation module to be developed and validated. The intention is to achieve the most energy-efficient, timely, flexible and reliable transport plan realisation possible Develop a fully formal, interoperable, interchangeable, upgradeable and modular, vendor-independent logical architecture First demonstration of freight ATO (GoA2) use cases on ETCS Level 2 track in the open network, using ATO modules of IP2. Testing of interchangeability and functionality in the network (GoA2) to provide input into ERA TSI CCS. Corridor-based testing of the GoA4 specification in a freight simulation to obtain robust software and specification

The CCA have proposed ways to integrate the technical objectives of IP5 into a future ITD in Sweden, where innovative features of the remaining IP5 TDs will also be shown.

Planning and budget

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022
	Fleet Digitisation and Automation		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
TD5.1	5.1.1 High level specification definition, feasibility analysis and preliminary testing CBM and AC	n/a							
	5.1.2 Conceptual / architecture design CBM and AC	3							
	5.1.3 ATO over ETCS - GOA2 freight specification	3							
	5.1.4 Detailed design, implementation and unitary testing CBM and AC	4							
	5.1.5 GOA2 Pilot Line freight demonstration	6							
	5.1.6 Integration of components CBM and AC	5							
	5.1.7 C-DAS/ ATO interface assessment	3							
	5.1.8 ATO over ETCS - GOA4 freight simulation	3							
	5.1.9 Demonstration activities CBM and AC	6							

◆ milestone
○ quick win
ongoing activities
planned activities

Table 91 / ***TD5.1 milestones***

WHEN	WHAT
Q4 2019	ATO over ETCS – GOA2 freight specification
Q4 2019	GoA2 pilot line freight demonstration
Q4 2022	C-DAS/ATO interface assessment

The estimated total budget for TD5.1 is around EUR 21 million.

5.2. TD5.2 Digital Transport Management

5.2.1. Concept

Improved accessibility to rail freight and the provision of highly reliable and flexible solutions are of the highest importance for the competitiveness of the system, especially in market segments such as maritime and continental intermodal transport, where the truck is a very strong competitor. This TD will focus on improved service planning and operation, which also supports better utilisation of the available capacity.

Within the scope of digitisation for future rail freight, the TD serves to optimise the digital access and operations of local hubs (e.g. marshalling yards and sidings), which are essential but cost-intensive subsystems for rail freight business. The optimisation of hubs' operations should take into account the available new technologies.

The aim of this TD is to develop freight solutions that are highly reliable and flexible, and that enable the optimisation of overall transport time, in particular by increasing the average speed for rail freight operations and by reducing handling and set-up times at marshalling yards and in terminals, taking into account the new automation technology, but also by ensuring that rail freight is able to operate better in conjunction with passenger traffic in order to maximise the utilisation of the existing network. These solutions should build on best practice from the passenger sector and from other modes, in terms of information, planning and monitoring systems. The intention in the terminal is to work with a higher degree of automation. Reliability, service characteristics and cost competitiveness of freight traffic can make significant progress with the optimisation of terminal design and operations, e.g. through improved passage of information and better data exchange between involved parties along the intermodal transport chain. The focus will be on train inbound and outbound detection, documentation and transfer of wagons and on intermodal loading unit (ILU) data.

Other important issues include better performance in *total* dwell time/lead time for freight transport and a higher grade of accessibility/connectivity, which are key factors.

5.2.2. Technical objectives

The following table shows the main technical objectives of this TD.

S2R OBJECTIVES	OBJECTIVE IN DIGITAL TRANSPORT MANAGEMENT
Improved reliability	Enhanced service quality due to improved timetable planning, real-time monitoring, increased possibility of automating processes and customer information through tracking and tracing, routing, combining systems of different operators and transport modes, booking procedures and visibility of available services, creating quality improvements of 15 %. Dwell times and handling times in intermodal terminals are reduced, and reliable throughput is maximised, enhancing intermodal capacity

S2R OBJECTIVES	OBJECTIVE IN DIGITAL TRANSPORT MANAGEMENT
Enhanced capacity	Improved system utilisation thanks to better train capacity management, shared usage of marshalling yards and improved knowledge about the maintenance status of wagons, giving capacity increase of 15 %. Capacity increase of up to 20 % on bottleneck lines using faster freight trains during daytime traffic
Customer experience	Integration of rail freight into supply chain management, meaning a great benefit for, for example, automotive or chemical customers who rely on just-in-time delivery. Improved customer experience due to 100 % reliable delivery of consignments at estimated time of arrival (ETA)
Lower investment costs	20 % improved capacity utilisation of infrastructure, rolling stock and personnel resources in hubs
Reduced operating costs	10 % reduced operating costs due to efficiently optimised single-stream disposition decisions. Increased cost efficiency due to improved coordination of the actors in the multimodal chain and improved slot planning and management creating savings or reducing costs by 10 %. Refit of terminals with video technology avoids costly manual data handling for incoming and outgoing wagons and ILUs
Enhanced interoperability	Standard interfaces and operating instruments connecting the whole chain from nodes to different countries through Europe
Simplified business processes	Automated processes for trains based on real-time data, reducing lead time by 25 % between RU and IM

Specific achievements to be delivered by this TD

1. Improved methods for annual and ad hoc timetable planning.
2. Methods for analysing timetable efficiency and robustness in advance and in follow up process.
3. Decision support and automation in timetable-planning process (including the management of dangerous goods trains and their interaction with sensitive targets along the route).
4. Improved methods for handling large disturbances on the line and in yards and terminals in real time.
5. Slot planning/management (cross-border/cross-network).
6. ETA calculation for operation.
7. Real-time monitoring of resources' availability on yards, nodes and network.
8. A real-time yard management system.
9. Standardised data formats/new interfaces in coordination with current TAF-TSI standards.
10. Increasing speed of freight trains during daytime traffic to increase line capacity.
11. Systems for shared usage of marshalling yards between different service providers.
12. Optimised operational processes and utilisation of the capacity of intermodal terminals with intelligent video gate systems as used elsewhere in logistics, in order to automatically detect the wagon number and ILUs handled, as well as visible damage. In addition, a terminal design that allows efficient dwell times and handling is a prerequisite.

5.2.3. Technical vision

The future goal of the TD is to incorporate hubs, yards and connecting sidings into capacity-driven order management through optimisation of all relevant resources, taking into account new automated handling systems. Provision of real-time data will enable intelligent information design and integration into supply chain management. A transparent mathematically based standard system solution will facilitate partly automated, quick and resource-optimised decision-making in real time, including disruption and incident management, in order to achieve delivery at ETA. Operational information will be shown on handheld devices and displays in locomotives so that everyone in the yard will have access to information on live resource availability.

Table 92 / ***Future digital transport management***

STATE OF THE ART	NEW GENERATION OF DIGITAL TRANSPORT MANAGEMENT
Big marshalling yards with many functions are hard to run cost-efficiently and the lead time is too long	A real-time yard management system can optimise resource allocation and connect with external systems to improve network planning
Intermodal terminals are not making use of the potential of digitisation. They are not equipped with visual or sensing technology for detection of wagons and ILUs, and signs of damage	Intermodal terminals will be equipped with video gates for automated detection of incoming and outgoing wagons and ILUs, and signs of damage to clarify claims situations
Terminal operators and railway undertakings exchange data on wagon and ILUs in varying formats, leading to unnecessary manual work	The process of data management in intermodal transhipment will be standardised, based on automated data exchange and transaction. It will establish standard communication between terminals based on TAF-TSI messages
To improve real-time network management, there is potential for automation to better handle deviations in timetables and disturbances in operational traffic	A real-time network management system will improve decision support and digital automation, to improve interaction between yards/terminals and network, and between infrastructure manager and railway undertakings
On bottleneck railway lines, freight trains have to stop very often to let passenger trains overtake.	Faster freight trains can travel longer distances without stopping, and can help to increase line capacity and defend and increase market share
The flexibility in ad hoc planning is low	An improved ad hoc timetable-planning system meets the freight market's ups and downs
The IT systems of the network operator and the operators of terminals and yards are often not connected	The planning of timetables and train paths is done from the beginning to the destination including terminals and yards and the processes inside them

The main interactions envisaged, both from the point of view of technologies employed and from that of interaction in performance and objectives, includes coordination with other TDs of IP5, namely TD5.1, TD5.3 and TD5.4, and with IP2, in particular TD2.9 (for ad hoc timetable planning, methods of handling major disturbances, ETA and slot issues/definition of methods, concepts and requirements in IP5 and development in TD2.9, such as optimised speed profiles for ATO/driving style assistants), TD2.2 and TD2.4, as well as coordination with CCA WA4, Smart Processes.

5.2.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Standardisation and open systems that can be used everywhere in Europe open up a bigger market than before. Video gates will Increase the degree of automation, operational capacity, and reliability of intermodal transport and terminal operation
Compliance with EU objectives	Support to capacity increase: better planning tools in real time increase the capacity on the lines. Reducing the lead time in yards and optimising loads on trains will make transport greener. Promotion of modal shift will lead to a big impact from the implementation of cost-cutting and performance-enhancing technologies towards a more competitive rail freight offering
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRL 1 and 2 (principles observed and the possibility of using them formulated). At the end of Shif2Rail it is expected that the successful concepts will be brought to TRL 6 or 7

This TD will contribute to enabling six innovation capabilities as follows.

INNOVATION CAPABILITY	TD5.2 DIGITAL TRANSPORT MANAGEMENT
1 – Automated train operation	Rail operations are partly or fully automated. New operational approaches are employed: • BB5.2.1: Improved methods for timetable planning • BB5.2.2: Real-time yard management and SWL system • BB5.2.3: Real-time network management • BB5.2.4: Intelligent video gate terminals
3 – Logistics on demand	Better planning, tracking and shipment information capabilities combine to offer customers flexibility and capacity. Planning and scheduling are synchronised to customer demand in real time. Shipments are moved effectively, efficiently, safely and securely throughout the 'physical internet' logistic chain: • BB5.2.1: Improved methods for timetable planning • BB5.2.2: Real-time yard management and SWL system • BB5.2.3: Real-time network management • BB5.2.4: Intelligent video gate terminals
4 – More value from data	Rail manages a growing volume of data to provide reliable services through optimised operational processes. Secure, robust, scalable and resilient open architecture and protocols allow full interoperability: • BB5.2.2: Real-time yard management and SWL system • BB5.2.3: Real-time network management • BB5.2.4: Intelligent video gate terminals

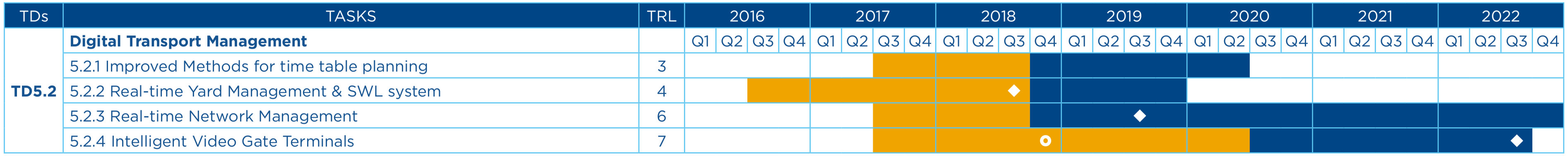
INNOVATION CAPABILITY	TD5.2 DIGITAL TRANSPORT MANAGEMENT
5 – Optimum energy use	Railways maintain their position as the most environmentally friendly mode of transport by decreasing energy consumption. This is achieved together with lowered operating costs through the use of an intelligent energy management system: • BB5.2.1: Improved methods for timetable planning • BB5.2.2: Real-time yard management and SWL system • BB5.2.3: Real-time network management • BB5.2.4: Intelligent video gate terminals
6 – Service timed to the second	Situational awareness, whereby each train's location is known at all times and in real time, supports service operation timed to the second: • BB5.2.1: Improved methods for timetable planning • BB5.2.3: Real-time network management
10 – Stations and smart city mobility	Railways are a core part of smart city fulfilment and delivery services. Railways are connected to smart city mobility platforms for a seamless end-to-end journey within and beyond the city: • BB5.2.2: Real-time yard management and SWL system • BB5.2.3: Real-time network management • BB5.2.4: Intelligent video gate terminals

5.2.5. Demonstration activities and deployment

The following table summarises the contribution of TD5.2, Digital Transport Management, to the different ITDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVES	SPECIFICATION ACTIVITIES	DEMONSTRATOR (TRL)	FOCUS OF ACTIVITY
Digital Transport Management	Improved methods for timetable planning	Ready-to-use basic systems	5	Module-based standards for deregulated markets with several actors. Connectivity requirements. Tools based on real-time information
	Intelligent video gate terminals (TD5.4.1)	Specification of terminal design transhipment processes in terminals equipped with intelligent video gates and information management	7	Based on a typical terminal along a European corridor, a solution for reduction of dwell time and improved handling of wagons and intermodal loading units using intelligent video gate technology
	Real-time yard management and single-wagon load systems	Ready-to-use basic systems ending with a pilot	7	Integration subsystems with an overall control system tested in a pilot
	Real-time network management	Ready-to-use basic systems	5	Integration subsystems with an overall control system
	Increasing speed of freight trains during daytime traffic to increase line capacity	Simulation of scenarios on freight corridors	5	Focus on simulation with timetabling systems and evaluation

Planning and budget



◆ milestone

o quick win

contracted activities

planned activities

Table 93 / ***TD5.2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
InnoTrans 2018 Berlin	Intelligent video gate	The project aims to investigate and develop an optimisation system for utilisation in intermodal terminals. Demo video gate technologies will be installed in a railway line where a wayside monitoring system is already operational by using a selected camera from the FR8HUB project together with possibly other acquisition sensors (e.g. radio frequency identification)

Table 94 / ***TD5.2 milestones***

WHEN	WHAT
Q3 2018	End of real time yard management project; the findings will be used in the network management and intelligent video gate projects
Q3 2019	Network management has now identified the communication requirements between the yards and terminals
Q3 2022	End of network management and intelligent video gate projects

The estimated total budget for the TD is around EUR 9.5 million.

5.3. TD5.3 Smart Freight Wagon Concepts

5.3.1. Concept

Highly productive freight trains will dramatically contribute to the modal shift from road to rail transport. In order to obtain a significant shift of freight transportation from road to rail in Europe – and reduce greenhouse gases – rail transport has to be cheaper, faster and better. Therefore, it is necessary to have high–quality paths that enable a high level of punctuality and reliability for rolling stock with proactive maintenance.

A new efficient wagon design with better performance for different categories of freight will be achieved, leading to a step change within S2R. A better payload per metre of train is one of the key efficiency factors, as is getting a greater volume per metre of train, particularly for low-density freight. High-performance freight wagons lead to massive improvements in the rail network's capacity, as they allow freight traffic to follow passenger traffic flows throughout the network. It also means that rail freight transport can be distributed to all parts of Europe, from locations in central Europe, within 24 hours. Faster transport in the rail sector also means a lower transport cost for the freight. The high-speed freight wagons will be designed for a maximum speed of 120–160 km/h while resulting in less wheel and track damage and wear. The freight wagons are highly productive and have a modular concept with combination possibilities to create different standard solutions for individual transport needs and allow rail freight automation thanks to integration of electrification, telematics and automatic coupling concepts. Because of low-noise solutions, 24/7 freight operation will be possible, and energy consumption will be reduced significantly thanks to the lowest aerodynamic resistance.

Thus, the aim of this TD is to produce technical demonstrations of the next generation of freight bogie and freight wagon in order to prove its competitiveness and to show that a rail freight option is equal to the freight market demands of the year 2020.

Based on market needs and business cases for rail freight, a common approach will be used to develop competitive freight wagon concepts. A new low-noise, track-friendly, high-speed freight running gear with modular interfaces to different wagon designs will serve as the basis for the development and demonstration of the *Freight Wagon 2020* for core and extended markets.

The *Freight Wagon 2020 body for core markets* will defend, regain and increase the market share in traditional rail freight transport markets. In this context, state-of-the-art technologies in wagon design will be improved significantly (e.g. reduction of weight by using high-strength steels in bogie and carbody design, improved passive suspensions and wheelset steering technologies for higher speeds and track friendliness, capability of advanced diagnosis and monitoring functionalities for increased customer experience and reliability).

The *Freight Wagon 2020 body for extended markets* aims to increase existing and expand future new market share for cargo transport by application of new technologies beyond the state of the art (e.g. reducing weight by using low-cost composite materials in the body and chassis design; aerodynamic and acoustic fairing for lower energy consumption and less noise; system integration to supply intelligence on board, e.g. for reefer transports). It will consist of a common chassis with different top units addressing container, groupage and combined intermodal transport needs separately. A successful opening of market segments will be identified in TD5.5.

Previous EU-funded projects such as On-Time, Spectrum, Smartrail and Capacity4Rail have already analysed and identified strategic areas that will enable an increase in the transportation market share. The strategic areas for rail freight transportation are a combination of new functionalities with a considerable improvement in performance. These strategic areas are listed below:

- increased punctuality;
- real-time monitoring and tracking of cargo (especially important for dangerous, perishable and temperature-sensitive goods);
- better transportation conditions.

To achieve improvements in these strategic areas, telematics for the wagons have to be developed towards the Smart Freight Wagon Concept. Moreover, the introduction of sensors for the wagon-monitoring system, a better understanding of the wearing of components and big data analysis techniques are enabling better scheduling of maintenance works (OPTIRAIL 2015). This is expected to bring reductions in the order of the 10 % of the maintenance costs. Therefore, within TD5.3 the development of three focus areas which are illustrated in the next figure:

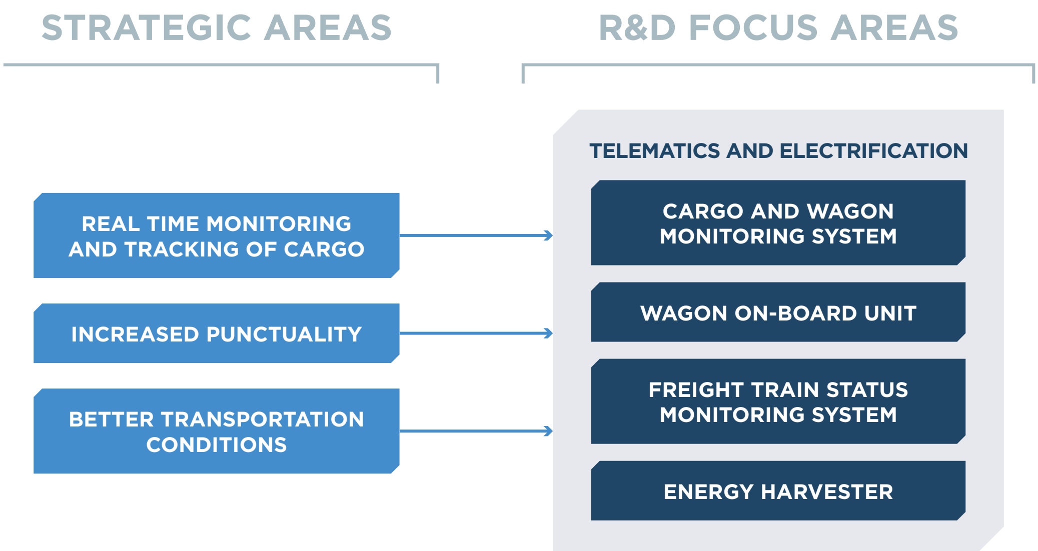


Figure 46 / ***Focused market areas for telematics and electrification***

Technological output to be delivered by this TD

- Low-noise, lightweight, high-speed and track-friendly freight running gear.
- Freight Wagon 2020 for core market share increase and extended markets.
- Telematics applications and electrification built on TAF-TSI standards, to provide new and innovative functionalities on real-time monitoring and tracking of cargo for logistic purposes and provide information to TMS about the convoy (EoT), real-time condition monitoring (wagon and goods), automatic train set-up functionalities and information to the driver.

5.3.2. Technical objectives

Existing major technical limitations, blocking points

A significant proportion of the issues addressed in IP5 is due to the limitations in wagon technology, and these limitations lead to uncompetitive offerings to the logistics market and a frozen business structure in the rail freight business. The potential provided by state-of-the-art locomotive technology (interoperability and efficiency) cannot fully be exploited as long as the following limiting factors on freight wagons remain.

- Unsatisfying train dynamics, due to standard couplers, poor manually controlled braking systems (UIC standard) and lower speeds than passenger traffic, prevent the exploitation of the remaining capacity of the network in daily hours and introduce high damage to the infrastructure.
- Payload–deadweight ratios are poor, especially in the emerging market segment of containerised single goods transport.

- Energy efficiency is low because of poor aerodynamics, and noise levels are high because of legacy technology in suspension and braking.

- The lack of electrification of freight wagons limits market access, as attractive market segments such as temperature-controlled transports (reefer market) cannot be served and digital integration in the leading logistic process is not possible (electronic freight orders and tracking – especially for dangerous goods) (integration of TD5.1 results).

The next generation of freight wagons will only complement the TSI standards for freight wagons with speeds of 120–160 km/h. All design will comply with TSI telematics applications for freight service, rolling stock freight wagons, operational and traffic management, infrastructure, energy, control command, signalling and noise. With the modular design of bogie and wagons, it is possible to cover most transport needs.

The vision for the wagon design TD proposed in S2R is based on the expected evolution of fundamental technologies within the following focus areas:

- track-friendly, low-weight, high-speed running gear (in order to be as flexible as possible for Wagon Design 2020, but also for other wagon types) – Running Gear ;

- Wagon Design 2020, modifications for core markets – Core Market Wagon 2020 ;

- Wagon Design 2020, for increased share and new market segments – Extended Market Wagon 2020.

5.3.3. Technical vision

Table 95 / ***Ambitions and advance beyond state of the art for TD5.3 wagon design***

STATE OF THE ART	TD5.3 PROGRESS BEYOND STATE OF THE ART
Modular lightweight wagon design still underexploited	Comprehensive lightweight design, including structural optimisation, functional lightweight and smart material selection and substitution (including fibre-reinforced plastics), will result in energy savings and higher capacity (payloads)
High sound pressure level	Multidisciplinary optimised very quiet wagons (according to TSI limits) comparable to passenger train limit (70 dB(A))
Expensive series of on-track noise tests required to achieve standard limits	Reliable noise emission prediction significantly reduces on-track testing
Wagon design not aerodynamically optimised	Validated advanced aerodynamic drag reduction concepts
Running gear not optimised regarding higher speeds, curving resistance, noise, wheel–rail interface and track degradation	Wheel- and track-friendly running gear with improved wheel–rail guiding for higher speeds
Application of reactive maintenance strategies	Condition-based maintenance based on wagon-monitoring systems
Wagons designed to comply with minimum level of relevant standards	Optimised wagon design by applying multidisciplinary methods (e.g. noise, aerodynamics, wheel–rail interface, LCC)

STATE OF THE ART	TD5.3 PROGRESS BEYOND STATE OF THE ART
Wagon on-board unit	Modular, mechanically robust, integrated antennae for wireless communications, connection to local power loads, energy management system, wagon monitoring system etc. A network gateway will provide access to wireless sensor network services from external systems. Specific communication services will be implemented and deployed over the train wireless backbone infrastructure in order to fulfil data exchange requirements across train composition. In addition, it will offer positioning services
Wagon monitoring system (WMS)	Smart cost-efficient sensor HW and SW for wagon component monitoring. New algorithms for vehicle status monitoring based on sensor fusion and vehicle–track interaction assessment will be developed in order to detect abnormal circumstances
Cargo monitoring system	Smart cost-efficient sensor HW and SW for cargo monitoring
Freight train status monitoring system	Information to the driver about the wagon's and cargo's status. Display of real-time information about convoy composition, integrity (EoT), efficient driving, maximum braking profiles and noise-sensitive driving
Energy management system	Ultra-efficient, robust, autonomous power generator providing basic cost-efficient freight wagon electrification attached to a bogie's axle box bearing. In combination with an on-board unit and energy-management-optimised battery system, different functionalities such as end-of-train device and wireless communication to wagons, loco and ground systems can be developed and integrated

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- TD5.5, Business Analytics and Implementation Strategies – migration plans for the uptake of the researched technologies and KPIs for measurability of the impact;
- TD5.1, Fleet Digitisation and Automation – condition-based maintenance of wagon components including driver advisory systems, based on the components condition and health, wagon electrification and telematics;
- TD5.2, Digital Transport Management – interfaces for data communication between locomotives, wagons and data centres;
- TD5.4, New Freight Propulsion Concepts;
- TD1.4, Running Gear;
- IP3, Infrastructure (TD3.1–3.4, criteria and models for the assessment of track friendliness; TD3.6–3.7, measuring, monitoring and maintenance).

5.3.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Technological leadership through intelligent freight assets: • Improved customer service and quality: / modular interoperable lightweight wagon design / intelligent wagon concept with real-time condition- and health-monitoring functions / smart wagon integration into asset management systems • Reduced total costs of ownership: / predictive and condition-based maintenance / wheel-/track-friendly design / automation of manual services on a wagon (e.g. enabling an automatic brake test) • Maximised interoperability through standardisation within S2R • Improved approval process, reduced design verification and testing effort: / development of virtual models enhancing the product development process / development of verification and testing concepts / models and concepts supporting virtual certification to speed up market uptake • Providing real-time information, alert notifications on goods and/or train conditions: / improved LCC (20 % reduction), and real-time health monitoring of goods and vehicle, wagon automation, control and monitoring of dangerous goods • Enabling trains to interact and exchange information with ground systems: / new unconventional train configuration validation before service tests (time reduction 10%–50%) • Improved reliability, since better ETA estimation • Improved dynamic train performances, on conventional trains and/or on trains supported by electronic technologies: / train set-up and uncoupling automation, longitudinal dynamics improvements (reduce damage to the railway infrastructure by 75 %) / optimisation of service intervals (condition-based maintenance) • Reduction in energy consumption through efficient driving profile based on real-time traffic information and current convoy characteristics (10 % reduction)

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Compliance with EU objectives	• Promotion of modal shift: / wagon design for integration into multimodal goods/wagons transhipment concepts supporting modal shift / big impact created by the implementation of these new technologies by demonstrating the economic benefits of new improved logistics making rail freight more attractive • Maximised capacity: / modular lightweight freight wagon design with increased payload and platform wagon frame / wheel- and track-friendly running gear for higher speed and low noise, with interfaces to vehicle and goods status monitoring and localisation based on new value-added service features, such as electric power supply/connection and automation due to automatic coupling / by EoT-train integrity functionality • ROI increase through minimisation of cost of operational and maintenance costs: / aerodynamically optimised lightweight freight wagon design for increased energy efficiency / wagon component monitoring functionalities for predictive maintenance strategies based on widely accepted economic assessment methods / noise reduction and wheel- and track friendly running gears for lowest wear and tear / larger volume/higher payload to improve utilisation of the wagon, resulting in relative reduction in required number of vehicles of given capacity • Enhanced interoperability: / increased standardisation of wagon frames and running gear for different segments together with vehicle and goods status and localisation • Simplified business processes (speeding up market entry): / virtual development and certification, multidisciplinary optimisation • Greening of transport through energy reduction and lower noise, achievable by providing information through the freight train status monitoring system about the driving and braking profiles adapted for specific characteristics of the freight convoy
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are at TRL 3–4. At the end of S2R it is expected that the successful concepts will be brought to TRL 6–7

This TD will contribute to enabling seven innovation capabilities as follows.

INNOVATION CAPABILITY	TD5.3 SMART FREIGHT WAGON CONCEPTS
3 – Logistics on demand	Flexible, interchangeable, multipurpose and smart freight transport units increase handling flexibility and unit utilisation. Shipments are moved effectively, efficiently, safely and securely throughout the physical internet logistics chain: • BB5.3.1: Running gear • BB5.3.2: Core market wagon • BB5.3.3: Extended market wagon • BB5.3.4: Telematics and electrification
4 – More value from data	Secure, robust, scalable and resilient open architecture and protocols allow full interoperability: • BB5.3.2: Core market wagon • BB5.3.3: Extended market wagon • BB5.3.4: Telematics and electrification
6 – Service timed to the second	Automated vehicle identification and monitoring is the basis of precise service operation. Smart traffic management ensures every train is in the right place and travelling at the right speed: • BB5.3.2: Core market wagon • BB5.3.3: Extended market wagon • BB5.3.4: Telematics and electrification
7 – Low-cost railway	Optimisation of the wagon and its elements with regard to manufacturing and operation (light weight, aerodynamics, more load capability, etc.) will contribute to reducing the cost of freight railway services: • BB5.3.1: Running gear • BB5.3.2: Core market wagon • BB5.3.3: Extended market wagon
8 – Guaranteed asset health and availability	The IoT enables real-time monitoring through connected sensors (ground/air/embedded): • BB5.3.4: Telematics and electrification
9 – Intelligent trains	Communication is possible between trains, between train and infrastructure, and between train and freight customers: • BB5.3.2: Core market wagon • BB5.3.3: Extended market wagon • BB5.3.4: Telematics and electrification
10 – Stations and smart city mobility	The IoT enables real-time monitoring of the assets through connected sensors (ground/air/embedded) and therefore contributes to station operation and smart city mobility: • BB5.3.4: Telematics and electrification

5.3.5. Demonstration activities and deployment

The overall S2R goals will be addressed by the six focus areas (i.e. demonstrators) summarised in Table 96.

Table 96 / ***Contribution of TD5.3 wagon design to the different ITDs***

TD	FOCUS AREAS	DEMONSTRATOR		DEMONSTRATOR
		MARKET	TRL	
Smart Freight Wagon Concepts	Running gear	Freight	5–7	A track-friendly, low-weight, low-noise high-speed **running gear** capable of running under standard wagon bodies and the 2020 freight wagons, to be demonstrated **in hardware in relevant environment** in a freight train
Smart Freight Wagon Concepts	Core Market Wagon 2020	Freight	5–6	Modular, logistics-capable and cost-efficient, low-weight, high-payload and aerodynamically optimised **freight wagons for core and extended markets**, to be demonstrated together **in hardware in relevant environment** (including electrification, diagnosis and monitoring, telematics and communication and automatic coupling) in a freight train
Smart Freight Wagon Concepts	Extended Market Wagon 2020	Freight	5–6	
Smart Freight Wagon Concepts	Automatic coupling, and telematics and electrification	Freight	6	Automatic coupling, electrification, wagon on-board unit and on-board unit integrated with the new wagon design
Smart Freight Wagon Concepts	Telematics and electrification	Freight	6	Integration of the information provided by the convoy with real-time network management
Smart Freight Wagon Concepts	Telematics and electrification	Freight	6	Integration of the information provided by the convoy within the terminal operations offered by the intelligent gate terminals

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Smart Freight Wagon Concepts		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TD5.3	5.3.0 Scanning of innovations	1				ongoing	ongoing	ongoing	ongoing	ongoing																				
	5.3.1 Wagon design	4				ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	planned ◆																
	5.3.2 Running gear	4				ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	planned	planned ◆															
	5.3.3 Definition of components and running gear and wagon manufacturing	4											planned	planned	planned	planned	planned	planned	planned	planned ⚬										
	5.3.4 Complete freight wagon demonstrator implementation	5-6															planned	planned	planned	planned	planned	planned	planned	planned	planned ◆					
	5.3.5 High level specification definition, feasibility analysis and preliminary testing of telematics	1				ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	planned																
	5.3.6 Conceptual / architecture design of telematics	3												planned	planned	planned	planned ◆													
	5.3.7 Detailed design, implementation and unitary testing of telematics	5														planned	planned	planned	planned	planned ⚬										
	5.3.8 Integration of components of telematics	5																planned	planned	planned	planned	planned	planned	planned ◆						
	5.3.9 Demonstration activities of telematics	6																			planned	planned	planned	planned	planned	planned	planned	planned	planned	planned	planned	planned ◆

◆ milestone
⚬ quick win
ongoing activities
planned activities

Table 97 / ***TD5.3 quick wins***

WHEN	WHAT
Q2 2020	Running gear and wagon manufacturing
Q2 2020	Telematics components manufactured

Table 98 / ***TD5.3 milestones***

WHEN	WHAT
Q4 2018	Wagon design completed
Q1 2019	Running gear design completed
Q3 2021	Wagon demonstrator completed
Q3 2019	Telematics architecture completed
Q2 2021	Telematics components integrated
Q4 2022	Telematics demonstrator completed

The estimated total budget for the TD is around EUR 17.5 million.

5.4. TD5.4 New Freight Propulsion Concepts

5.4.1. Concept

The major objectives of the Transport White Paper, such as shifting 30 % of road freight over 300 km to rail by 2030 or doubling transport by rail freight compared with 2005, are still very challenging.

The target of this TD is to provide more attractive rail freight services to the final customer, with competitive rail solutions maximising flexibility and efficiency while reducing the operating and maintenance costs. The focus of this TD is on improving the overall performance of today's locomotives by adding and integrating additional functionalities and technologies. Future locomotives will:

- provide extreme flexibility for operation on non-electrified and electrified lines, allowing private and public operators to offer broader rail freight services based on demand without the need to change the locomotive or allowing new operational concepts;
- feature remote control for distributed power, thus allowing an increase in train length to 1 500 m and consequently improving the cost efficiency of rail transport;
- have reduced LCC;
- recover braking energy as much as possible, store it onboard and reuse it whenever required, for traction purposes, for power peak shaving, and to supply auxiliaries and other systems;
- provide more traction force;
- increase operational efficiency by automating various activities such as train start-up, train preparation, start of mission, stabling and parking, and general shunting.

Some of the results achieved in this TD will be of value and interest for passenger locomotives too, thus supporting the overall goal of modal shift.

5.4.2. Technical objectives

TD5.4 has the objective of accelerating the development of the features and systems mentioned above. In more detail, the technical objective is the development of the following.

1. Powerful and/or flexible dual power (hybrid) traction chains for future freight locomotives (mainline and shunter). Removing diesel propulsion systems results in a reduction in fuel consumption of up to 30 % for hybridised legacy vehicles, and up to 15 % for others.

2. Innovative last-mile propulsion systems based on powerful lithium ion batteries or other clean energy sources, reducing fuel consumption to zero.

3. Radio remote-controlled distributed power systems, allowing a doubling of capacity (100 %).

4. Efficient subsystems, able to recover braking energy and store it on board, e.g. with lithium ion batteries or other energy storage systems, able to implement peak power-shaving features and able to turn off selectively certain loads. Up to 5 % higher energy efficiency.

5. Automation of features such as the start of mission (automated loco start-up, train data entry, brake test, etc.), train stabling, train parking, shunting – all for the ultimate automated logistic chain. Up to 15 % higher energy efficiency during mission, reduction in LCC of up to 30 % (less personal costs).

6. Propulsion concepts with increased traction performance, up to 5 %.

5.4.3. Technical vision

The ambition and vision of this TD are ultimately to implement a locomotive equipped with the features outlined above, which will consequently actively support the shift to rail.

Table 99 / ***Ambitions and advance beyond state of the art for TD5.4***

STATE OF THE ART	AMBITIONS AND EXPECTED ADVANCE BEYOND STATE OF THE ART
Four-axle multi-system or diesel locos; no combination on the market capable of pulling heavy trains over longer distances at adequate speed	Development of advanced propulsion concepts for novel logistic production concepts, based on dual-power multisystem traction chains (e.g. electric and diesel or with powerful energy storage systems), high pulling capability (traction performance) combined with low LCC
Last-mile propulsion systems based on diesel engines or small lead–acid batteries	Development of powerful last-mile propulsion system, in hybrid constellation or full electric with lithium ion batteries only, giving possibility of running on last mile with high power during a relative short time, e.g. over 1 MW for 15–30 minutes. This includes an optimised cooling and heating system, the development of a powerful mission management system, the authorisation of such a system and, last but not least, the demonstration

STATE OF THE ART	AMBITIONS AND EXPECTED ADVANCE BEYOND STATE OF THE ART
Train lengths usually limited to 750 m; in some special cases up to 850 m. No radio remote-controlled distributed power implemented so far in Europe	Definition and implementation of standardised radio remote control for distributed power allowing trains up to 1 500 m with up to four locomotives, including authorisation of the solution
Energy efficiency of locos	Definition and implementation of technologies that drastically increase energy efficiency of locos, including smaller energy storage systems, peak power-shaving concepts, intelligent consumer control, sleeping modes, etc.
Locomotives must be started up manually by the train driver, train data must be entered manually, shunting and stabling requires train driver, etc.	Definition and implementation of concepts, systems and features for the automation of locomotive start-up activities, including start of mission, stabling and parking

The main interactions envisaged with other TDs and/or IPs, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- IP2, Advanced Traffic Management and Control Systems (ERTMS/ETCS) for cross-border operations;
- IP2, ATO, together with IP5, TD5.1, integration of relevant subsystems in the locomotive;
- TD5.5, Business Analytics and Implementation Strategies – migration plans for the uptake of the researched technologies and KPIs for measurability of the impact;
- TD5.1, Fleet Digitisation and Automation;
- TD5.2, Digital Transport Management – interfaces for data communication between locomotives, wagons and data centres;
- TD5.3, Smart Freight Wagon Concepts – automatic coupling to be installed on the wagons and enable telematics and electrification; condition monitoring on wagon bogies overlapping with condition-based maintenance activities;
- TD5.4, New Freight Propulsion Concepts – 'long trains up to 1 500 m' researches communication technologies for trains and locomotives that can apply to C-DAS and ATO.

5.4.4. Impact and enabling innovation capabilities

TD5.4 has a major impact on the S2R system-level KPIs, as it focuses on the traction system of the freight ecosystem. The relative weights of the benefits provided by this work are estimated in the table below, which provides an overview of effects expected from the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Technological leadership supported by a combination of the development and final implementation of innovations and technical standards, setting an effective advantage for the European industry. Tangible benefits for the end user: • increasing the flexibility of rail freight system for operation under the TEN-T corridors, the main EU lines and the non-electrified feeder lines, providing cost savings by using the most efficient traction mode depending on the infrastructure • allowing the free circulation of freight trains for cross-border transport • operation of longer trains and reduction in operating costs • LCC reduction through energy savings, new low-maintenance concepts and the design of new low-wear components
Compliance with EU objectives	Promotion of modal shift from road to rail expected with the improvement of rail freight competitiveness. Support to capacity increase, which is expected by lengthening the trains to 1 500 m. Greening of transport through the implementation and demonstration of environmentally friendly solutions and optimisation of energy consumption, hence contributing to the EU target for CO_2 reduction too
Degree of maturity of the envisaged solutions	A big step in the degree of maturity of the technologies to be applied in freight rail transport. At the end of S2R it is expected that the successful concepts will be brought to TRL 7
Authorisation as key to success	Successful integration and authorisation of the locomotive including the last-mile traction battery, with enormous impact on future battery-related developments. In fact, a variety of battery-based implementations is envisaged, consisting of different sizes of battery systems, battery systems with different chemistries and different characteristics, and even battery systems with modules dispersed along whole trains

This TD will contribute to enabling six innovation capabilities as follows.

INNOVATION CAPABILITY	TD5.4 NEW FREIGHT PROPULSION CONCEPTS
1 – Automated train operation	Providing features for the automation of processes not directly related to ATO during driving (e.g. autonomous train stabling, train preparation, etc.): • BB5.1.3: Freight ATO/C-DAS
3 – Logistics on demand	Flexible, interchangeable, multipurpose and smart freight transport units increase handling flexibility and unit utilisation. Freight trains able to integrate within high-intensity passenger operations. Shipments moved effectively, efficiently, safely and securely throughout the physical internet logistics chain. Last-mile and dual-mode propulsion concepts support logistics on demand through operational independence: • BB5.4.1: Last-mile propulsion systems • BB5.4.2: Long trains up to 1 500 m • BB5.4.3: Freight loco of the future • BB 5.4.4 Hybridisation of legacy shunters

INNOVATION CAPABILITY	TD5.4 NEW FREIGHT PROPULSION CONCEPTS
5 – Optimum energy use	Alternative propulsion concepts introduced. Hybrid-power trains to allow running over non-electrified track sections. Integration of various energy storage systems, implementation of peak power-shaving concepts, implementation of various sleep mode concepts: • BB5.4.1: Last-mile propulsion systems • BB5.4.3: Freight loco of the future • BB5.4.4: Hybridisation of legacy shunters
7 – Low-cost railway	A low-cost, affordable rail system supporting the rural economy. Integration of low-maintenance systems and devices, including wheel- and track-friendly running gear solutions: • BB5.4.1: Last-mile propulsion systems • BB5.4.4: Hybridisation of legacy shunters
9 – Intelligent trains	Trains featuring advanced mechatronics, reducing dependence on wheel conicity and permitting simplified running gear design. Automated train and loco preparation, stabling and parking: • BB5.4.2: Long trains up to 1 500 m • BB5.4.3: Freight loco of the future • BB5.1.3: Freight ATO/C-DAS
11 – Environmental and social sustainability	Reduced energy consumption: • BB5.4.1: Last-mile propulsion systems • BB5.4.2: Long trains up to 1 500 m • BB5.4.3: Freight loco of the future • BB5.4.4: Hybridisation of legacy shunters

5.4.5. Demonstration activities and deployment

The overall S2R goals will be addressed by the four focus areas summarised in the following table.

RESEARCH AREA	FOCUS AREA	SPECIFICATION ACTIVITIES	DEMONSTRATOR TRL	FOCUS OF ACTIVITY
New Freight Propulsion Concepts	Hybrid/advanced propulsion	Concepts, specifications and development	4, for some subsystems up to 7	Generic: specification of new production concepts; definition of power requirements including last mile; specification, design and development of bogie; energy efficiency; remote control via radio without driver for freight loco of the future. Study of applicability of new technologies to retrofitted locomotives. Subsystem specification and validation with functional mock-ups and laboratory prototypes. Study and implementation of new features for energy efficiency, including new concepts, such as peak power shaving. Study and implementation of new features for automated activities for start-up phase, train preparation, train stabling and parking
	Last-mile propulsion systems	Architecture, specifications (HW, SW, test, etc.), documentation for construction and commissioning	7	Lithium ion batteries, recovery, authorisation, mission management system maintenance, system optimisation, definition of last mile, assessment of batteries. For both new locos and retrofitting. Demonstrator loco in operation (TRL 7)

RESEARCH AREA	FOCUS AREA	SPECIFICATION ACTIVITIES	DEMONSTRATOR TRL	FOCUS OF ACTIVITY
New Freight Propulsion Concepts	Long trains up to 1 500 m	Development of authorisation documentation	6/7	Refinement of requirements and use cases for regular usage of distributed power in freight trains. Coordination of simulation of train dynamics and safety assessment. Demonstration of distributed power technology in trains of 740 m and up to 1 500 m length. Marathon project is baseline; focus is now getting authorisation of a train with no driver on the second loco Phase 1: development of a European longer train concept including the coordination of an EU-recognised certification method for operating longer trains and identification of the operational and infrastructural constraints Phase 2: realisation of TDs by developing and testing a distributed power solution by radio remote control. Phase 3: European authorisation and roll-out preparation including the development of a European roadmap for the implementation of longer trains
	Hybridisation of legacy shunters	Hybridisation of legacy shunting locomotives for environmentally friendly second life	7	Reduction in implementation time and enhancement of cost competitiveness for environmentally friendly innovation. Improvements in the ecological footprint and LCC of diesel shunters. Increase in flexibility and freight operational efficiency

Planning and budget

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022
	New Freight Propulsion Concepts		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
TD5.4	5.4.1 Last Mile Propulsion System	7							
	5.4.2 Long Trains	7							
	5.4.3 Freight Loco of the Future	7							
	5.4.4 Hybridization of legacy	6							

- ◆ milestone
- ○ quick win
- ongoing activities
- planned activities

Table 100 / ***TD5.4 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
May 2019	Building block for full electric last-mile propulsion tested in lab	The project aims to develop the building blocks for more efficient and environmentally friendly last-mile propulsion system, giving the operator maximum flexibility for all use cases
May 2019	First demonstrator of distributed power technology developed in IP5 using GSM-R with a 540 m heavy coal freight train with loco at the end of the train being remote controlled by leading one	This is the first step in introducing a remote control for distributed power for European operators. With the technology, the KPI of doubling capacity will be achievable by allowing an increase in the train length from today's 750 m to future 1 500 m. Increasing energy efficiency is also achieved, especially in train configurations such as the one described on the left. The loco at the end can brake dynamically much stronger, thus recuperating more energy.

Table 101 / ***TD5.4 milestones***

WHEN	WHAT
Q3 2019	End of project FFL4E
Q3 2020	End of project FR8HUB (hybrid propulsion)
Q3 2021	End of project FR8RAIL II (DAS, freight automation, freight propulsion, long train)
Q3 2022	End of projects FR8RAIL III and FR8RAIL IV (advanced auxiliary propulsion, battery technology, automation)

The estimated total budget for the TD is around EUR 13.5 million.

5.5. TD5.5 Business Analytics and Implementation Strategies

5.5.1. Concept

The core objective of IP5 is to increase the competitiveness of European rail freight by:

- maintaining its market position in today's transport segments, making use of digitalisation;
- opening up new market segments so that in total an effective gain in overall market share becomes reality.

To achieve that objective, IP5 follows a dual-strategy concept. IP5 comprises several development tasks in the field of wagons, equipment and components, operational procedures, automation and algorithms, which support either one of those strategic directions or both. However, the mere support of technological advancement is not sufficient to ensure success. This is illustrated by the following examples.

- The development of new equipment, such as a wagon enabling higher payloads and transport speeds, may appear desirable at first sight, but the efforts are in vain if the improvements come at a cost that rail customers are not ready to pay.

- Substantial technological advances in some areas may only be achieved if the requirement for compatibility between new and existing equipment is abandoned. This implies the need for a well-founded plan for migration towards new technology, especially in areas with considerable investments and long life cycles.

In this regard, IP5 perceives rail freight transportation as an integral part of the transport and logistics supply chain (e.g. different business models depending on the value of the goods), which has to meet the requirements of the transport market today and in the future under progressive socioeconomic and environmental constraints.

5.5.2. Technical objectives

The following are the main technical objectives of TD5.5.

1. Overview of relevant segments of the transport and logistics market that are currently served by rail (fully or partly) and of segments that could be served with appropriate technical improvements and adequate business models (focus on wagon design and components).

2. vDefinition of features and quality/cost parameters (KPIs) required by customers and railways/logistics service providers, in close collaboration with cross-cutting activities. The goal is to improve the competitiveness of rail freight and to realise the potential of rail freight to a greater extent.

3. Development of migration plans for the introduction of new technologies, equipment and services to be developed in TD5.1–TD5.4, including compatibility issues. The focus will be on the Europe-wide roll-out of key technologies following S2R. This will include the demands of TAF-TSI standard data exchange.

4. Addressing short-term improvements (quick wins) for increased quality and cost competitiveness of the freight rail sector, also taking up results of the Smart Rail project.

5.5.3. Technical vision

STATE OF THE ART	BUSINESS ANALYTICS AND IMPLEMENTATION STRATEGIES
Spectrum project, 2012–2015	Consideration of a synthesis of advanced features and of more advanced technology to be developed in IP5
Smart-Rail project (Smart Supply Chain Oriented Rail Freight Services), from 2015	Extension of analysis to services enabled by new equipment to be developed in IP5 and not considered in the Smart-Rail project
Studies and recommendations for the development of single wagonload traffic, e.g. Study on Single Wagonload Traffic in Europe, PricewaterhouseCoopers/University of Rome La Sapienza, 2012–2014	Consideration of a higher degree of automation enabled by the technologies to be developed in IP5 (including last-mile delivery, and automation in sidings and marshalling areas)

TD5.5 serves as a support for the subsequent TDs in IP5 and does not include a TD in the strict sense. The task of TD5.5 is to serve the needs of TD5.1–TD5.4, regarding certain prerequisites for better performance. Furthermore, TD5.5 will contribute to a migration plan.

5.5.4. Impact and enabling innovation capabilities

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	Specification of market prerequisites for development of automated concepts and equipment in TD5.1–TD5.4 that will have advanced capabilities compared with the state of the art and thus strengthen the European rail industry
Compliance with EU objectives	Promotion of modal shift, capacity/energy improvements per payload through enhancing the performance of rail freight (indirectly by contribution to TD5.1–TD5.4); implementation of relevant EU law – TAF-TSI
Degree of maturity of the envisaged solutions	The analytic nature of TD5.5 and the connection to SmartRail etc. should be seen as a basis for reaching higher TRLs in TD5.1–TD5.4, to which they contribute. Beyond that, the migration plan will facilitate the dissemination to real operations

This TD will contribute to enabling four innovation capabilities as follows.

INNOVATION CAPABILITY	TD5.5 BUSINESS ANALYTICS AND IMPLEMENTATION STRATEGIES
3 – Logistics on demand	The migration plan, following the findings of the business analytics, will propose a stepwise change in rail freight, ensuring that the demand for transport is met by developed offers and a supply chain perspective is also considered: • BB5.5.1: Identification of market segments • BB5.5.3: Migration plan
4 – More value from data	The customer and the rail system communicate intelligently with each other. Big data analytics enables a range of new and improved services. Moreover, the definition of KPIs and KPI improvements should increase the attractiveness of rail freight: • BB5.5.1: Identification of market segments • BB5.5.2: Development of KPIs
7 – Low-cost railway	A low-cost, affordable rail freight system and services to support the rural economy. Efficiency in running assets with the help of information and intelligence leads to low cost as well as more automated solutions: • BB5.5.1: Identification of market segments
8 – Guaranteed asset health and availability	R&D based on effective collaboration ensures the rapid integration of technology into the railway, removes barriers to the adoption of new technologies and decreases time to market: • BB5.5.3: Migration plan

5.5.5. Demonstration activities and deployment

TD5.5 serves as a support for the subsequent TDs in IP5 and does not include a TD in the strict sense. The task of TD5.5 is to serve the needs of TD5.1–TD5.4, regarding certain prerequisites for better performance. Furthermore, TD5.5 will contribute to a migration plan.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
TD5.5	**Business Analytics and Implementation Strategies**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	5.5.1 Identification of market Segments	n/a																												
	5.5.2 Development of KPI's	n/a																												
	5.5.3 Migration Plan	3																												

lighthouse projects
contracted activities

The estimated total budget for the TD is around EUR 0.5 million.

6. Cross-cutting activities

Context and motivation

The performance of the railway system will only be improved if it is understood and managed as a whole system shared between many actors, with particular attention to the interfaces between the parts of the system.

To achieve this ambitious goal, S2R must introduce novel and innovative technologies applied to each of the components of the system. Introducing new technologies at the component level and in different TDs needs to be addressed not only at a vehicle/infrastructure level, but also at the complete railway system level, considering the different requirements, operational conditions and other aspects of the various application segments.

To implement this systems approach, the work conducted within the five IPs is supported by cross-cutting themes proposing specific activities that are of relevance to several of the TDs across S2R, and that take into account the interactions between IPs and the different subsystems that have been defined. These CCAs, organised around working areas, will also contribute to developing common methodologies across the JU.

Objectives and expected results of the CCA

The objective of the CCAs is to ensure that the R&I activities within the different IPs are closely aligned in terms of their objectives and requirements, as well as in terms of the methodologies to be used for evaluating and assessing the expected impacts. These activities include elements already taken into account in the different innovation programmes that require horizontal coordination, such as safety, standardisation, maintenance, traffic management, energy and noise management, and virtual certification. Furthermore, the CCAs will carry out the additional research needed to complement and leverage S2R's technical work.

The interactions between the different IPs will be of major importance, given that evolutions in technology in one part of the system, managed by a specific actor, can lead to changes in performance or even create barriers that are visible in another part of the system, managed by a different actor. In addition, cross-cutting activities will also include research on long-term economic and societal trends, such as customer needs, human capital and skills, which need to be taken into account by the different innovation programmes.

The following table summarises the main objectives of the CCAs and provides an overview of some of the deliverables that will result from the activities undertaken in the area.

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
Socioeconomics: gain an understanding of how rail can be a catalyst in transformational societal changes	Open up the railway system to a wider audience with an interest in mobility but uninterested in the modes	The value of S2R lies in its capacity to address the challenge to enable better accessibility and connectivity through the delivery of a high-capacity and cost-effective rail system seamlessly interconnected with other modes and embedded in local, regional and cross-border contexts

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
KPI and IA: show that the results of the JU are fulfilling the expected results of the key S2R targets and the other expected benefits, in advance, during the project run time and after the completion of the TDs' work	Provide prognosis for KPIs at the beginning of the JU's activities, constant monitoring of the TDs' progress and a comparison of the predicted outcomes against the demonstrated results	KPI development foresees huge added value for research in the rail sector and future projects. It embodies a systematic approach to the understanding of the complex interrelationships in railways, which will also be useful to forecast a project's costs and benefits. The deployment of the KPI tool for monitoring the IPs' and TDs' progress enables continuous reporting and evaluation of the TDs' progress and their influence on the S2R goals, and, if necessary, prioritisation of activities

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
Enhanced interoperability Safety, standardisation, smart maintenance, smart materials and virtual certification	Safety: develop a global approach of the safety of the railway system; quantify the safety improvements carried out in S2R TDs	Safety remains the first priority of the railway transport but the complexity and the constraints become very high. The management of safety becomes a key issue to be addressed here
	Standardisation: transfer S2R results and outcomes of innovation activities into standards or normative documents	This addresses the S2R target to remove the remaining administrative and technical barriers, in particular by establishing a common approach to safety and interoperability rules to reduce costs
	Smart maintenance: develop an overall maintenance concept taking into account all smart maintenance developments within S2R	Next to energy consumption, maintenance is the other driver of LCC. Lowering maintenance costs by using the new opportunities of knowledge about vehicle's conditions by digitisation will have strong impact on reliability, availability and LCC and thus on attractiveness and competitiveness of rail traffic
	Smart materials: explore the latest research on designing smart materials and possibilities for applying various techniques and innovations in materials science to railways	Smart materials help in removing the boundaries between structural and functional materials, which may result in a significant revolution in materials science development. It Is a challenge for the rail sector to be on top of this development
	Virtual certification: reduce authorisation costs, facilitate cross-acceptance procedure, reduce time and cost of (sub) system authorisation process	The proposal for mixed experimental/numerical processes for authorisation will result in less on-site testing, more lab or vehicle testing and more simulations Common methods and processes for authorisation will consider standardised lab tests, vehicle tests, on-track tests and simulation procedures. Introducing virtual testing will make the cross-acceptance process easier

OBJECTIVE	RESULT	PRACTICAL (CONCRETE) CHALLENGE
Operational reliability increase Railway system life-cycle cost reduction Smart planning	Smart mobility: provide the basis for an open micro-level simulation, integrating planning activities and status information from the various actors within the railway system (e.g. RUs with their fleet and staff planning processes, IMs whose assets are in a certain condition), to schedule planning and external parameters	This will enable railway stakeholders to make the best decisions for the overall system, for example concerning schedules and the availability of rolling stock and staff, based on up-to-date operational data, taking into account all essential information in order to ensure quality promised is delivered to customers
	Integrated mobility management: specify, develop and integrate all necessary elements into the traffic management system to integrate actual and forecast traffic asset and freight operations status information into a seamless operational process	The challenge addressed is to be smart and based on real-time seamless access to heterogeneous railway data sources (signalling data, maintenance plans, environmental conditions, fleet status, passengers' requests and needs, etc.)
Environmental sustainability Energy efficiency	Deliver a standardised methodology for estimation of energy consumption by simulation and a standardised methodology for measurement of energy consumption enabling the standardised specification of energy-efficient railway systems	This will reduce the operational costs through reduction of energy consumption
Environmental sustainability Noise and vibration control	Develop future methods for predicting overall noise and vibration performance on a system level including both rolling stock infrastructure and its environment Ensure that the N&V aspects are properly considered and integrated in all relevant technology demonstrators within the different innovation programmes of S2R	Reducing the annoyance and exposure to N&V related to the rail sector in Europe will enable an increase in traffic and enhance the attractiveness of rail as a means of transport
Operational reliability increase Human capital	Increase flexibility for both employers and blue-collar employees. Make use of the benefits of digitisation and automation for job profiles and skills	This will overcome the challenges imposed by demographic change and comprehensive and radical technological innovations

Past and ongoing European and national research projects

A number of projects funded by the EU in the last few years will give important input and starting reference points to the CCAs within S2R. S2R has here a potential to enhance the investment that European society has made in railway research in recent years.

Details of the projects are presented in the section devoted to each WA, but some of the ones most relevant to the activity proposed in S2R are listed here.

- Noise and vibration: this incorporates outcomes from the European research projects Acoutrain (Virtual certification of acoustic performance for freight and passenger trains) and RIVAS (Railway Induced Vibration Abatement Solutions) about ground-borne vibration mitigation on open tracks.

- Energy: RailEnergy (2006–2010) deals with energy reduction on electric and diesel mainline trains. Osiris (started in January 2012) has many similar targets to those of RailEnergy but focuses on urban railway systems.

- Safety: many European projects such as TrioTrain, Acoutrain, Euraxles and Secret deal with the safety level of the components of the railway system. Safety and authorisation are closely linked together in these projects. For example, the Opencross (Open platform for evolutionary authorisation of safety-critical systems) FP7 project aims to develop the first Europe-wide open safety authorisation platform.

- Standardisation: examples include Bridgit (Bridging the gap between research and standardisation), which aims to demonstrate that standardisation is a significant instrument for the dissemination of research results in due time, as well as the market uptake of innovations. In addition, the group STAIR (STAndardisation, Innovation and Research) was created to provide strategic advice to the CEN and CENELEC technical boards on the synchronisation of standardisation with innovation and research.

- KPIs: experience from the work on the technology evaluator of the JTIs Clean Sky 1 and Clean Sky 2 can be used, in terms of methods for the definition and calculation of KPIs.

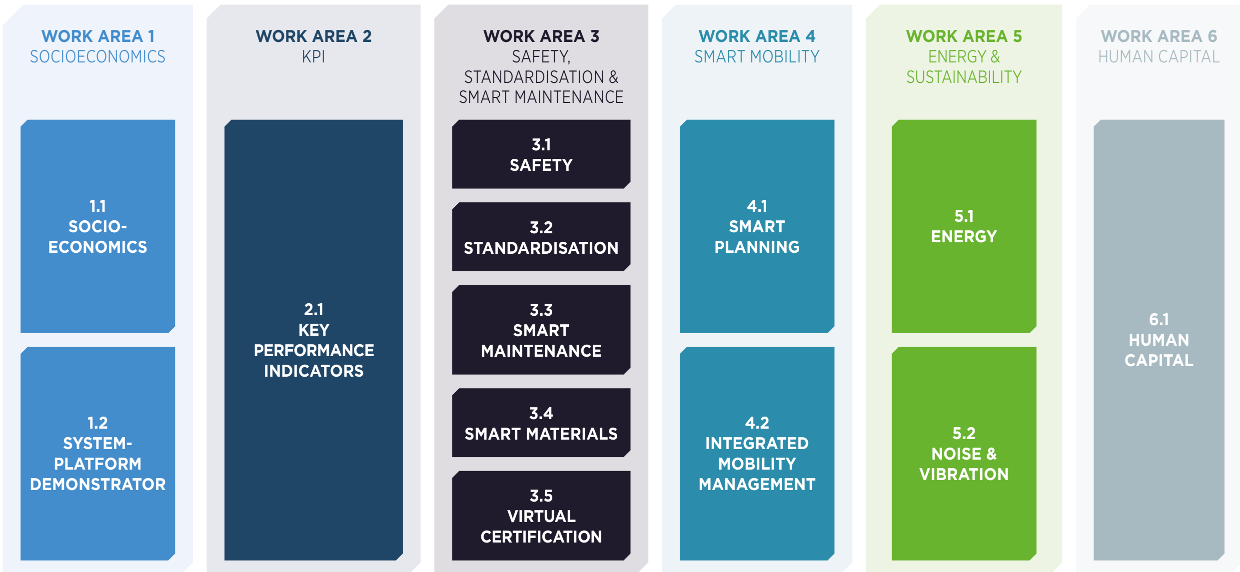
- Human capital: the EU FP7 projects Futurail and Skillrail have contributed to increasing knowledge of human capital in the rail sector.

Finally, the Roll2Rail and In2Rail lighthouse H2020 projects were orientated towards pre-starting some of the work lines of S2R. CCA areas included are integrated mobility management in In2Rail and energy and noise in Roll2Rail. Results of In2Rail and Roll2Rail have been incorporated into the corresponding CCA area and will constitute an essential element of the end result of the programme.

One or more members of S2R working within the CCA areas have participated in most of the finalised and ongoing EU projects, so the information flow and leverage from these will be automatically ensured.

Set-up and structure of the CCAs

The CCAs are structured into work areas and are shown and described in the figure and table below.

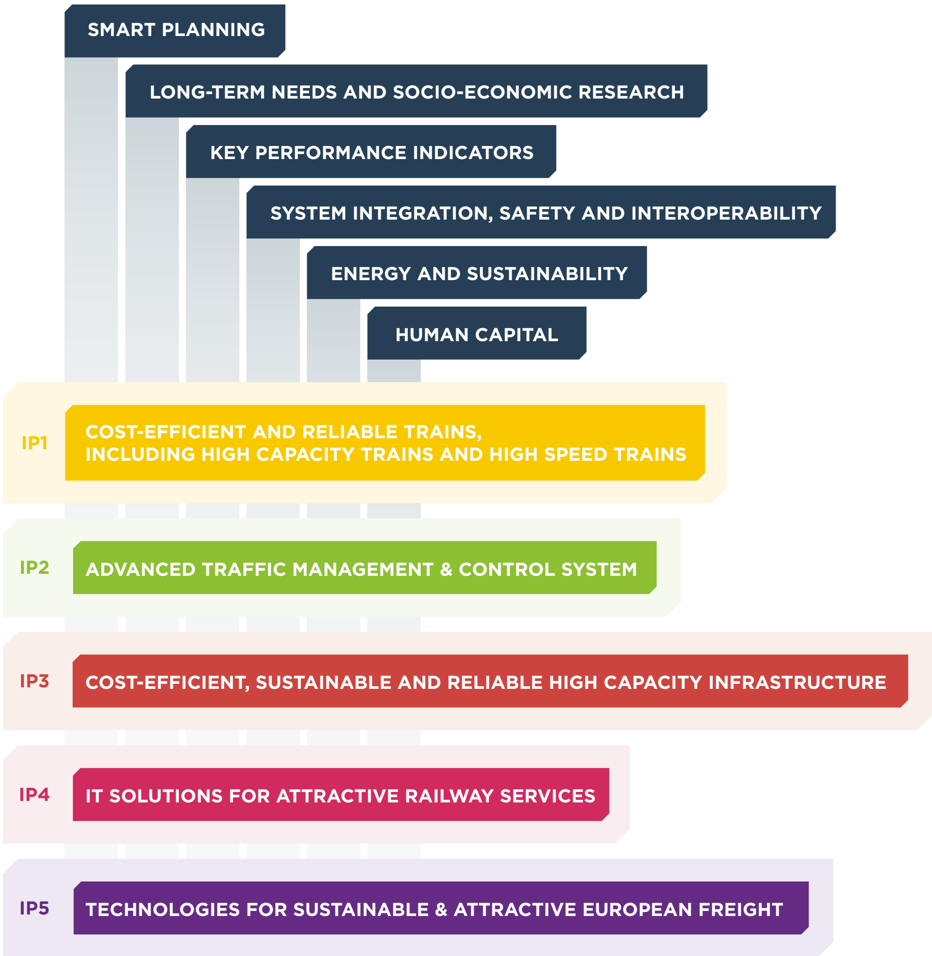


WORK AREA	AIM AND ACTIVITY RELATED TO MASTER PLAN
1.1 Socioeconomics	Create knowledge of success factors for a future railway system based on customer needs and the mobility behaviour of users, and better understanding of key trends, such as urbanisation, demographic changes, ageing of society, hyper-connectivity, etc.
1.2 SPDs	Define the four **SPDs**: freight, urban, regional and high-speed railway system demonstrators
2 KPIs	**KPI method development** and integrated assessment: devise methodology for assessing the achievement of the S2R objectives (improved services for users and customer quality, reduced system costs, simplified business process and enhanced interoperability) and the contribution of the IPs and TDs
3.1 Safety	Establish a **global approach to the safety** of the railway system. Manage the safety level of the existing railway system. Quantify the **safety improvements** carried out in **S2R TDs**
3.2 Standardisation	Coordinate and address **standardisation issues for all IPs** to ensure it is possible to meet overall S2R targets
3.3 Smart maintenance	**Lower maintenance costs** by using the new opportunities for **knowledge of vehicles' conditions by digitalisation**. This will have a strong impact on reliability, availability and LCC and thus on the attractiveness and competitiveness of rail traffic
3.4 Smart materials	This activity is relevant to more than one segment of the rail system. However, dedicated activities are carried out in dedicated IPs, such as IP1, which is looking into new materials for rolling stock components
3.5 Virtual certification	Develop methods and processes for design validation for the purpose of obtaining authorisation to put into service. Transfer tests from on-track train testing to bench testing and simulations
4.1 Smart planning	**Improve planning activities** of various stakeholders in the railway system by means of precise railway **simulation**. This concept will cover all phases of railway planning and include an outlook on operation
4.2 Integrated mobility management	Specify and Implement substructures needed for **automated message exchanges between passenger and freight operations and Traffic management system** via the integration layer
5.1 Energy	Achieve and assess the **overall energy reduction on all ITDs and SPDs** and demonstrate the **cost-effectiveness energy-saving** features Help and support all energy-saving-related work across the IPs and TDs Stimulate the emergence of pre-normative texts when needed to pave the way towards a shared European understanding of energy figures in railways Link energy and sustainability actions with existing initiatives outside S2R in order to align understanding and positions of railway and energy stakeholders
5.2 Noise	Develop future **methods for predicting overall noise and vibration performance on a system level, with a proper ranking** and characterisation of each contributing source so as to include different combinations of entire vehicles and infrastructure and optimise cost–benefit scenarios as well as exposure and comfort Ensure that the **N&V aspects are properly considered and integrated in all relevant technology demonstrators** within the different innovation programmes of S2R

WORK AREA	AIM AND ACTIVITY RELATED TO MASTER PLAN
6 Human capital	Achieve a number of benefits and **overcome the challenges imposed by an ageing workforce through:** • **increasing diversity** and flexibility for both employers and (blue collar) employees • a healthier workforce because of the use of automated and robotic systems to **reduce the physical strain on humans** • **lifelong development of new skills** and changes in job profiles

Approach within the CCAs

The CCAs are part of the S2R System Integration Working Group and, within it, they have a dedicated organisation, with a CCA Coordinator and Steering Committee.



Cooperation with all the relevant IPs and TDs in the respective areas will be ensured, as illustrated above. This means that during the start-up of the project the purpose is to identify all relevant components for each CCA work area included in S2R TDs and to set and follow up targets for each contributor to achieve an optimal result on overall system levels. In addition, the CCA part will develop methodologies to be able to properly address simulation of results in different TDs. Experts from CCAs can also provide their know-how in many TDs and IPs, especially to translate local performance indicators into the S2R macro-indicators.

In addition, the existing interactions with other IPs and within relevant WAs of CCA take into account the work on the S2R system functional architecture and conceptual data model performed in IPx.

6.1. WA1 Long-term needs and socioeconomic research and system platform demonstrator

6.1.1. Sub-WA1.1 Long-term needs and socioeconomic research

6.1.1.1. Concept

The work area will assess the railways from a wider socioeconomic perspective and bring about an understanding of how and to what extent rail can be a catalyst in transformational societal changes. The added value of the work area is that it opens up the railway system to a wider audience with an interest in mobility but not necessarily in the modes. The future scoping of societal values, technological and behavioural trends and the assessment of how the railways can interact, respond and also be a driver of change are important for investment in assets with such longevity as rail.

The rail system is part of the multimodal transport chain and it aims to support the development of an attractive, sustainable society that is prosperous and cohesive. Free movement of goods and people accounts for two of the 'four freedoms' of the internal market. The value of this work lies in its capacity to provide a path to enable better accessibility and connectivity through the delivery of a high-capacity and cost-effective rail system seamlessly interconnected with other modes and embedded in local, regional and cross-border contexts. It is important to better understand how rail services should be planned and managed to be a tool in societal development, and in what way safe, reliable, comfortable train services can be beneficial, e.g. for the enlargement of regions and the integration of major conurbations. The work area will analyse how society is influenced by the rail system in general but will also study in particular the areas and the expected improvements that the work developed within S2R will bring to the European context in terms of social and economic benefits.

WA1.1 will look at the rail system from a wider perspective, assessing rail as a functioning part of the socioeconomic aspect of the entire transport system.

6.1.1.2. Technical objectives

The overall purpose of WA1.1 is to put the rail system and its development in the larger context of society and of users' and stakeholders' views. Since it will be based on the latest and most relevant trends and developments, the impact will be its guidance for the future, and the possibility of making qualified and well-justified decisions.

More specifically, the objectives of WA1.1 are to evaluate the potential impact of the technical achievements in S2R in terms of competitiveness, modal split and societal effects, and also to examine how robust these impacts are, considering different future scenarios of the development of society as a whole. The cost efficiency of the implementation of S2R achievements needs to be evaluated in cost–benefit analysis. There is also a need to investigate the influence of different political policy measures on the implementation and impact of the S2R achievements. A further objective is to investigate the need for new business models.

6.1.1.3. Technical vision

Strengthening the role of rail in European transport

Today, figures from the rail sector show that in most countries around Europe there is a low level of railway usage in general (passenger and freight), with only limited changes and improvements during the last 20 years (increase of 5–8 % of railway usage for distances over 50 km). This WA will assess the obstacles to and benefits of rail transport and how to make the system fit the needs of future society to make it more accessible and attractive.

Sometimes railway systems are more successful than the existing physical possibilities allow (within Paris, London and Munich, and connections such as Copenhagen–Malmö, Paris–Marseilles and Frankfurt–Nuremberg), with the effect that lines are crowded and more or less uncomfortable. In these cases of crowded systems, capacity improvements are necessary, which is one of the main objectives of S2R. In all other cases, it requires a combination of different factors to fulfil passenger and freight needs in the future. Reduced costs and better reliability will be some of the key factors to improve the customer experience, but a lot of additional factors (such as appropriate governance structures) are relevant to customer behaviour. Knowledge of both key factors in governance of rail and customer behaviour should be enhanced to respond to the customer and mobility needs in Europe.

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged with the IPs and WAs listed below, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- CCA WA1.2, KPI method development and integrated assessment – define the four SPDs that will be used to demonstrate the effects of the S2R activities;
- CCA WA2, KPI integrated assessment – refine and extend the SPD definition with more technical details and populate it with values;
- all TDs of IP1, IP2 and IP3 – deliver input for the definition of the three different SPDs for passenger rail transport;
- all TDs of IP4 – deliver input for the improvement of the attractiveness of passenger rail systems based on IT services;
- all TDs of IP2, IP3 and IP5 – deliver input for the definition of the one SPD for rail freight transport.

6.1.1.4. Impact and enabling innovation capabilities

WA1.1 will deliver knowledge of key success factors for a successful railway system based on customer needs (and not on technical possibilities of the railway system) in a changing world. One major trend is digitisation. Digitalisation of society and the economy will affect the way people live, work, consume and move. A new industrial revolution that rewrites the manuals on how products are engineered, produced and marketed to end costumers could significantly alter supply chains, as well as human contacts, behaviour and interests. Macro-changes in the global economy will influence trade patterns and travels, and thus the goods being shipped and the mobility of passengers. Therefore, S2R through CCA WA1.1 needs to pave the way for enhancements of the European rail system by studying the societal and economic implications and preparing the necessary developments to cope with these macro-changes.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	A better understanding of the relationship between policies, technical potentials of rail, expected development of competing modes and customer demand is important for strategic decisions on how to develop the rail system in different market segments This knowledge improves the basis for investing in cost-effective solutions, i.e. maximising customer experience in relation to investment and operating costs
Compliance with EU objectives	A better understanding of the relationship between political policies, technical potentials of rail, expected development of competing modes and customer demand is important for strategic decisions on how to develop the rail system in different market segments. This knowledge improves the basis for investing in cost-effective solutions, i.e. maximising customer experience in relation to investment and operating costs. It supports the EU policies on a smarter, connective and more affordable transport system. It looks at rail's contribution to the multimodal transport chain and ensuring the provision of a better passenger services
Degree of maturity of the envisaged solutions	Existing methods for analysing the effect of different measures with the purpose of improving the transport system are scientifically based, generally accepted and widely used, especially on a national level. The experience of analysing systems on a European scale is more limited

This TD will contribute to enabling 12 innovation capabilities as follows.

INNOVATION CAPABILITY	WA1.1 LONG-TERM NEEDS AND SOCIOECONOMIC RESEARCH
1–12	The contribution of WA1 is to provide an increased understanding of how the achievements in the different innovation capabilities may contribute to the overall goal of increased attractiveness and competitiveness as well as to the modal shift to rail

6.1.1.5. Demonstration activities and deployment

The main overall outcomes of the WA are:

- to provide S2R with analysis methods and tools appropriate to exploring the future market for the railway and performing cost–benefit analysis of S2R achievements;
- to explore the potential of the S2R achievements in terms of market share and cost–benefit.

Planning (and budget)

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Long-term needs and socio-economic research		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA1.1	1.1.1 Societal needs analysis	-																												
	1.1.2 Influences to 2025, 2035, 2050 from Mega-Trends	-									◆																			
	1.1.3 Societal development by transportation	-									◆																			
	1.1.4 Key success factors for a successful railway system	-																							◆					
	1.1.5 Rail Transport Governance	-																												
	1.1.6 Shift2Rail Societal Effects	-																					◆							
	1.1.7 Rail as a design tool in societal development	-																												

◆ milestone
lighthouse projects
contracted activities
future activities

Table 102 / ***WA1.1 milestones***

WHEN	WHAT
Q2 2018	Future trends and scenarios
Q1 2021	Long-term changes and future needs
Q1 2022	Socioeconomic impact
Q2 2022	Key success factors
Q4 2022	Cost–benefit analysis

The estimated total budget for WA1.1 is around EUR 2 million.

6.1.2. Sub-WA1.2 System platform demonstrators

6.1.2.1. Concept

The objective of WA1.2 is to define the four SPDs that will be used to demonstrate the impacts of the S2R activities. The four SPDs to be defined will cover the markets of high-speed/mainline passenger rail, regional passenger rail, urban/suburban passenger rail and rail freight. For each SPD, important use cases will be defined to allow an analysis of the broad range of S2R activities. The aim of the four SPDs is not just to showcase the S2R results but also to provide a wider understanding of the impacts of S2R.

The WA1.1 results on societal needs, obstacles to improving customer attraction and requirements for defining the future desired dimensions will be analysed based on the SPDs. Therefore, the WA1.1 results together with TDs and ITDs also give the requirements imposed on the SPDs to analyse rail systems with the objective of identifying the most promising systems to ensure fast exploitation of the results of S2R. To this end, the KPI model of WA2 can be implemented, as effect relationships, in the macroscopic modelling and forecasting tools that make up the SPDs.

To achieve as far as possible quantifications of the KPIs, the four SPD defined in WA1.2 are to be used as system use cases for the KPI model in WA2.

The use cases are the basis for the societal usage of the demonstrations/ITDs.

6.1.2.2. Technical objectives

The following are the main technical objectives of this WA.

1. Define and refine the four SPDs for high-speed, regional, urban/suburban and freight to evaluate the impact of S2R on these examples.
2. Identify the appropriate conditions to perform the socioeconomic impact analysis in WA1.1.
3. Prepare the appropriate set-up to perform the integrated assessment of KPIs in WA2.
4. Ensure coherence between both refined sets of SPDs for WA1.1 and WA2.

6.1.2.3. Technical vision

The main aim is to provide the basic definition of the four SPDs to be used in the socioeconomic impact analysis in WA1.1 and the integrated assessment in WA2.

The technical vision for the SPD definition proposed in S2R is based on the following:

- defining overall SPDs to be used for all KPIs;
- time- and cost-efficient validation of the SPDs.

STATE OF THE ART	SPD DEFINITION
Use of specific or tailored scenarios to evaluate the impact or performance indicators of new technology	Integrated definition of SPD scenarios for all TDs to ensure a coherent evaluation of the impacts of all TDs
Application to a specific targeted optimal use case	Definition and refinement of four overall SPDs to be used for all TDs
Impact assessment mainly on operational improvements	Impact assessment on technology and the subsequent improvement of attractiveness

Interaction with other TDs (in the same IP and/or in other IPs)

The main interactions envisaged with the IPs and WAs listed below, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- CCA WA1.1, Socioeconomic impact analysis – the SPDs are used to evaluate the overall impact on society and economy;
- CCA WA2, KPI integrated assessment – the SPD definition will be refined and extended with more technical details and populated with values;
- CCA W5.1, Energy – reference scenarios and trains are defined there and taken by WA1.2 to be used in the SPD definition;
- all TDs of IP1, IP2 and IP3 – input for the definition of the three different SPDs for passenger rail transport;
- all TDs of IP4 – input for the improvement of the attractiveness of passenger rail systems based on IT services;
- all TDs of IP2, IP3 and IP5 – input for the definition of the one SPD for rail freight transport.

Figure 47 / ***Interaction with other TDs and IPs***

6.1.2.4. Impact and enabling innovation capabilities

The SPD definition will be used to show the impact of all TDs in the S2R system-level KPIs as well as the socioeconomic impact.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	Early evaluation of technological developments with respect to their impact on the four SPDs in cooperation with the KPI integrated assessment
Compliance with EU objectives	Supporting the definition of the different SPDs and of an integrated railway system with efficient mixed traffic
Degree of maturity of the envisaged solutions	No TRL for the SPD itself; the KPI model and the tool will be brought to TRL 5

This TD will contribute to enabling 12 innovation capabilities as follows.

INNOVATION CAPABILITY	WA1.2 SYSTEM PLATFORM DEMONSTRATORS
1–12	To evaluate the impact of this innovation capability, it needs to be applied to relevant SPDs. Relevant building blocks to set up the KPI integrated assessment of the affected SPDs: • BBA.1.2: Influences to 2022, 2030, 2040 from mega-trends, scenarios, disruptions; key factors • BBA.1.3: Societal development by transportation • BBA.1.4: Key success factors for a successful railway system; perceptions, mobility patterns • BBA1.6: S2R societal effects • BBA1.8: SPD use case and scenario specification, application, results, analysis and wider effects

6.1.2.5. Demonstration activities and deployment

The S2R SPDs will be used to simulate and test the effects of, and interactions between, the various innovative systems resulting from the S2R activities in the specific environments of each of the relevant market segments. With this as input, traffic and transport modelling and forecasting tools are selected to be used as a basis for the development of the SPDs. The SPDs will thereby include the specifics of each market, and its particular challenges and needs, allowing analysis of market opportunities.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	System Platform Demonstrators		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	1.2.1 SPD use case and scenario specification	-																												
WA1.2	1.2.2 SPD application	-																												
	1.21.3 SPD result analysis and wider effects	-																												
	1.2.4 Future SPDs	-																												

- ◆ milestone
- lighthouse projects
- contracted activities
- future activities

Table 103 / ***WA2 milestones***

WHEN	WHAT
Q1 2017	Scenarios as of today
Q3 2017	S2R scenarios issue 1 defined
Q1 2018	Baseline SPD application
Q3 2018	SPD use case specification
Q4 2020	SPD results
Q3 2022	Final SPD integrated assessment (SPD-IA)

The estimated total budget for system platform demonstrators is around EUR 0.6 million.

6.2. WA2 KPI method development and integrated assessment

6.2.1. Concept

A technology and impact evaluation is an essential element within S2R. The objective of Work Area 2 is to show how the expected results of the key S2R targets are achieved through the TDs' work. The overall S2R targets defined in the regulation will be assessed based on high-level KPIs defined in this work area. This requires an agreed model and baseline scenarios of KPIs at the beginning of the S2R programme, as well as constant monitoring of the TDs' progress, and a comparison of the predicted outcomes with the demonstrated results.

The achievement of the S2R targets will be supported by regularly assessing the degree of target achievement for each TD. Furthermore, by setting up an integrated KPI model that shows interrelations, parameters that are crucial for the achievement of the objectives can be identified and help decision-making on priorities for the JU.

By analysing how every single TD contributes to S2R objectives, by defining what impact the TDs plans to achieve on low-level KPIs and by regularly assessing the TDs' success in achieving their objectives, the success of the whole JU is supported. In particular, a KPI model that shows the relevant interrelations between all KPIs is to be set up. This includes contributions of individual technologies to the various KPIs as well as inherent goal conflicts. The model should cover all systems including infrastructure, rolling stock and train operation, as well as intermediate performance indicators and finally all KPIs from the Master Plan.

As far as possible, the application of this model in the framework of S2R, in particular in terms of the determination of quantitative results, will be supported by tools. At this point, existing tools and models are to be investigated and complemented with new developments.

The deployment of the KPI tool for monitoring the IPs' and TDs' progress enables continuous reporting and evaluation of the TDs' progress, their influence on the S2R goals and, if necessary, prioritisation of activities.

To achieve as far as possible quantifications of the KPIs, the four SPD defined in WA1.2 are to be used as system use cases for the model. The SPD definition has to be populated with further parameters to describe the scenarios as far as needed.

6.2.2. Technical objectives

The following are the main technical objectives of this WA.

1. Develop a model of the impact of the individual outcomes of all TDs and their interrelation in a KPI model.
2. Implement the KPI and the four SPDs from WA1.2 in a tool.
3. Identify and quantify the relevant input parameters for the model and the SPDs.
4. Determine the three Master Plan objectives/KPIs LCC, capacity and reliability.

6.2.3. Technical vision

The final target is to provide a tool incorporating the KPIs and their interrelations in one consistent model. The model is to be implemented in a tool and so give the possibility of continuously monitoring the effects of the different technologies developed in all TDs.

The technical vision for the KPI method development and integrated assessment proposed in S2R is based on the following:

- development of an integrated KPI model showing the effects of all technologies of the TDs and their interrelations;
- defining overall SPDs to be used for all KPIs;
- time- and cost-efficient validation of the model.

STATE OF THE ART	KPI METHOD DEVELOPMENT AND INTEGRATED ASSESSMENT
Local definition of the impact or performance indicators of new technology	Systemic view of all defined performance indicators and their interrelation
Application to a specific targeted optimal use case	Definition and refinement of four overall SPDs to be used for all TDs
Impact assessment mainly on operational improvements	Impact assessment on technology and the subsequent improvement of attractiveness

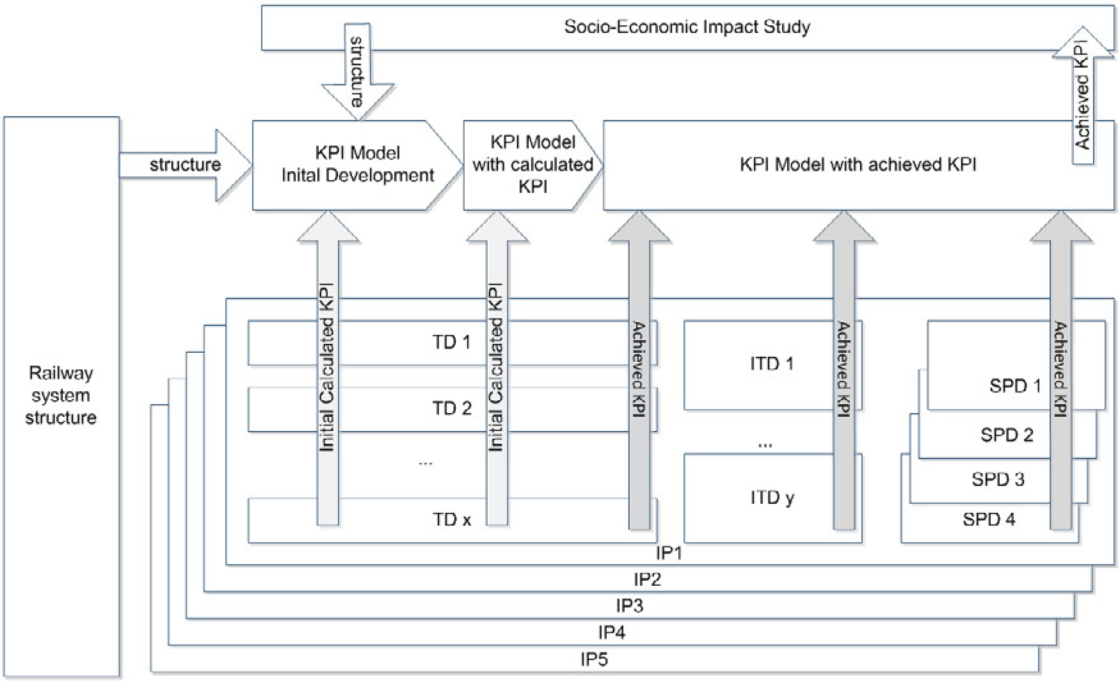


Figure 48 / ***Schematic representation of how the KPI model reflects the project structure***

Interaction with other TDs (in the same IP and/or in other IPs)

The KPI activity affects the entire S2R Programme and all IPs and TDs. The main interactions envisaged with the TDs and WAs, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- All TDs in IP1 to 5 – providing their impact with respect to the targets of S2R given in the Master Plan. Individual description and quantification are the objective of individual discussions between WA2 and the TD.
- CCA WA1.2, System platform demonstrators – the SPDs were defined at a higher level in WA1 and then given to WA2 for refinement and population with values.
- CCA WA5.1, Energy – reference scenarios and trains are defined there and given to WA2 to be used in the SPD definition.

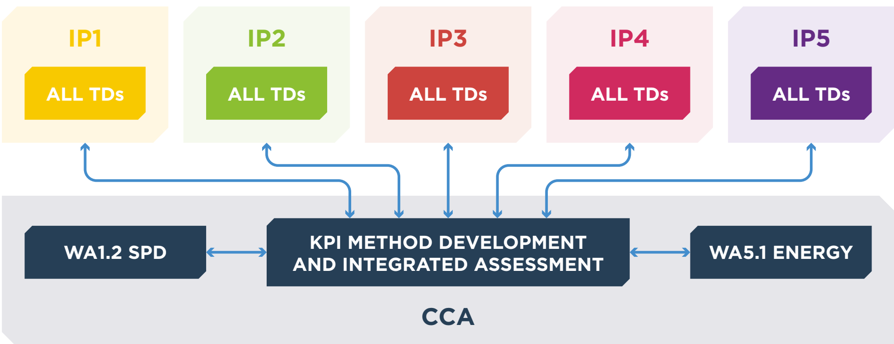


Figure 49 / ***Interaction with other TDs and IPs***

6.2.4. Impact and enabling innovation capabilities

The KPI model will show the impact of all TDs on the S2R system-level KPIs. The relative weights of the benefits provided by this work are estimated (over a total of 100 %) by the TDs.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	Early evaluation of technological developments with respect to their impact on KPIs
Compliance with EU objectives	Early evaluation of technological developments with respect to their impact on KPIs
Degree of maturity of the envisaged solutions	The KPI model and the tool will be brought to TRL 5

This TD will contribute to enabling 12 innovation capabilities as follows.

INNOVATION CAPABILITY	WA2 KPI METHOD DEVELOPMENT AND INTEGRATED ASSESSMENT
1–12 capabilities	These innovation capabilities need to be evaluated for optimal introduction with respect to LCC, effect on capacity and reliability. Relevant Building Blocks to set up the KPI integrated assessment of the affected SPDs: • BBA2.1: Reference scenario • BBA.2.2: Subsystem structure • BBA.2.3: Sublevel KPIs • BBA.2.4: Tool specification and development • BBA.2.5: Validation of the KPI model

6.2.5. Demonstration activities and deployment

The objective of WA2 is to show how the expected results of the key S2R targets are achieved through the TDs' work.

KPIs have to be aligned with the overall S2R targets: improved services for users and customer quality, reduced system costs, simplified business process and enhanced interoperability can be reflected. They have to be characterised in terms of their units, their lower level performance indicators and their relation to KPIs of capacity, reliability and LCC. Each TD's contribution has to be defined to feed into the target achievement. In addition, a system structure for the railway system including infrastructure, rolling stock, railway operation and customer services is to be modelled in alignment with the innovation programmes.

The result of a combination of these three approaches is an integrated KPI model that shows qualitatively the interdependencies of the KPIs horizontally with each other as well as vertically between low-level functional-technical parameters and high-level socioeconomic objectives.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA2	**KPI method development and integrated assessment**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	2.0.1 Reference Scenario	-																												
	2.0.2 Subsystem Structure	-																												
	2.0.3 Sublevel KPIs	-																												
	2.0.4 Tool specification and development	-																												
	2.0.5 Validation	-																												
	2.0.6 Monitoring	-																												

- ◆ milestone
- ○ quick win
- lighthouse projects
- contracted activities
- future activities

Table 104 / ***WA2 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q1 2018	KPI tool set up and filled with initial values	First validation of the tool and the initial values for the KPIs

Table 105 / ***WA2 milestones***

WHEN	WHAT
Q1 2018	Qualitative KPI tree initial issue defined
Q3 2018	Initial quantitative KPI model defined
Q3 2022	Final SPD-IA

The estimated total budget for KPI method development and integrated assessment is around EUR 1.9 million.

6.3. WA3 Safety, standardisation, smart maintenance, smart materials and virtual certification

6.3.1. Sub-WA3.1 Safety

6.3.1.1. Concept

The overall objective of WA3.1 is to develop a global approach to the safety of the railway system. The end result of this work is to provide mainly the infrastructure managers and operators, and in general decision-makers, with an integrated management system for the safety of their railway system.

The term 'safety (risk) management' includes the process followed, the means used and measures taken in order to achieve a specific goal related to the safety of the railway system.

Safety management encompasses the following issues:

- identification, assessment and ranking of risks;
- inclusion of all scientific tools, methodologies, relevant legislation and regulations, human and financial resources, equipment and technologies (TDs) – financial resources include money allocated by the infrastructure manager for the implementation of means/measures to improve safety but also for equipment operation and maintenance;
- constructional and operational characteristics of the constituent and/or component for the measures to be taken.

6.3.1.2. Technical objectives

The following are the main technical objectives of this WA.

1 On one hand the global approach developed could be used to select the most efficient everyday tasks to guarantee a given level of safety.

2. One the other hand this global approach will be also able to evaluate the impact of the new equipment integrated into the existing railway system (and in particular the innovations introduced in the different TDs).

6.3.1.3. Technical vision

WA3.1 proposes a global approach to safety in the railway system. This approach is based on a global risk assessment model, and will provide key results to achieve the following objectives:

- manage the safety level of the existing railway system;
- quantify the safety improvements carried out in S2R TDs.

The safety level that a railway system provides to its users can be defined with the aid of the two following approaches.

1. Definition according to the risk level, which suggests a qualitative assessment of safety. The classification of the risk is uniquely accrued by the combination of the frequency and the severity of the consequences of an event (European Standard EN50126). The improvement in the safety level can then be reached either by reducing the probability of having an accident, or by reducing the consequences of the accidents or by a combination of both. The aim is to assist towards the qualitative improvement in the initial risk level.

2. Definition according to incident indicators, which suggests a quantitative assessment of safety. The safety that a railway system provides is evaluated by the incidents that occurred during a specific time period. Indicators are then used to take further decisions, the aim being that the measures addressing incidents should assist towards the reduction of the selected accident's quantification indicator.

STATE OF THE ART	SAFETY MANAGEMENT WITHIN S2R
The automotive and especially aerospace domains have long experience in risk assessment methods compared with the rail sector	A complete state-of-the-art survey of risk assessment will cover all the methods used in the rail domain but also methods in use in the automotive sector, aerospace, etc. The most appropriate methods will be selected from a very large panel of existing methods and industrial applications
Risk assessment can lead to theoretical results that cannot be used for day to-day safety management	Methods will be selected from a large panel coming from industrial applications and will be applied in specific application cases that affect the day-to-day safety of the railway system
Risk management is not always based on risk assessment and can lead to inappropriate decisions	Risk management based on risk assessment is the key focus. In a large and complex system, field workers and managers have difficulty managing safety every day. Risk analysis is a useful tool to support decision-makers

Interaction with other TDs (in the same IP and/or in other IPs)

Potential impacts on railway operation (I2M smart planning in CCA) but also on IP3, Infrastructure Maintenance. No formal links with other IPs.

6.3.1.4. Impact and enabling innovation capabilities

The table below shows the effects generated at a larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM WA3.1
Support the competitiveness of the EU industry	• Safety is a key issue for the European railways. All industrial partners, operators and infrastructure managers are involved, from conception to the operational phase. A safe management system is also a competitive skill that can be exported
Compliance with EU objectives	• Enhances the safety and interoperability of the railway system
Degree of maturity of the envisaged solutions	• The work on safety will start at a low TRL, as it will select and promote new risk assessment methods. These methods can be already used in other sectors, such as automotive and aerospace, or developed by academics. They will be transferred to railway operators and industries • The day-to-day management of safety based on risk assessment can also enable innovation on the management of some subsystems. This innovation will be illustrated in application cases, moving the project from TRL 3 to TRL 5

This WA will contribute to enabling two innovation capabilities as follows.

INNOVATION CAPABILITY	WA3.1 SAFETY
1 – Automated train operation	• The global approach to safety developed in WA3.1 will contribute to assessing the new safety rules developed for ATO. In particular, the impact of the reduction of train headways and the impact of automation on human factors will be addressed
8 – Guaranteed asset health and availability	• Methods developed in WA3.1 will be used to quantify the safety improvements induced by new maintenance and operation procedures. For instance, the reduction in traditional inspection regimes means there is a much-reduced human presence on the network, reducing the associated personal safety risk • Monitoring systems for obstacle and critical event detection will be developed to be used in maintenance and operation decision-making tools

6.3.1.5. Demonstration activities and deployment

The following table summarises the contribution of WA3.1 Safety to the different SPDs of S2R.

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFIC ACTIVITIES	SYSTEM PLATFORM DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Safety	Risk assessment and decision-making process	Implementation of monitoring systems for obstacle detection specifically on safety-critical sectors of infrastructure, such as level crossings, bridges and tunnels	High-speed passenger rail, regional passenger rail, urban/suburban passenger rail, rail freight	2	Demonstrate the implementation of monitoring systems into a decision-making tool for the optimisation of maintenance planning and identifying short- and long-term risks. Develop emergency management in case of critical events

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Safety		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA3.1	3.1.1 State of the art of risk assessment methods	2																												
	3.1.2 Requirements to conduct a risk assessment study	2																												
	3.1.3 Requirements to apply the risk assessment method	2																												
	3.1.4 Development of a safety monitoring system	2																												

◆ milestone
lighthouse projects
contracted activities
future activities

Table 106 / **WA3.1 milestones**

WHEN	WHAT
Q1 2017	State of the art of risk assessment methods
Q1 2018	Requirements to conduct a risk assessment study
Q3 2018	Requirements to apply a risk assessment method

The estimated budget for the sub-WA is around EUR 0.85 million.

6.3.2. Sub-WA3.2 Standardisation

6.3.2.1. Concept

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

Bridging the gap between research and standardisation in an integrated approach within S2R appears an essential lever to foster access to market and implementation of the innovative project outcomes.

6.3.2.2. Technical objectives

The main objective of WA3.2 is to foster the transfer of S2R results and outcomes of innovation activities into standards or regulatory documents when needed and beneficial, as well as to coordinate the approach across the S2R research activities by developing optimised pre-standardisation aligned processes with the relevant standardisation bodies. The following technical objectives are envisaged in WA3.2:

- to carry out a strategic analysis of the S2R research activities in terms of standardisation potential;
- to manage the process of transforming the S2R results in terms of standardisation and regulation, whenever it is relevant;
- to propose innovative standardisation processes and tools to speed up market uptake of the R&I results from the S2R activities;
- to propose a standardisation deployment plan based on the analysis of the S2R R&I and provide a prioritisation process based on a state-of-the-art analysis of the different ongoing and planned standardisation processes at EU and international levels;
- to monitor the European standardisation processes for the S2R activities;
- to map for closing TSI open points and define relevant roadmap in coordination with ERA.

6.3.2.3. Technical vision

The benefits of integrating standardisation into the R&I process are numerous ([5]) and have been explored in past research projects (e.g. Bridgit, Interest):

- it ensures compatibility of the results with what is already on the market or in practice;
- it makes the results available to a wide range of stakeholders, offering opportunities to discuss and promote project outcomes with the entire community;
- it ensures that the project results will be used well beyond the duration of the project;
- it helps in complying with regulatory requirements;
- by incorporating the findings and integrating the latest knowledge into standards, and as a technology transfer channel, it provides foundations for further developments and research;
- it is a powerful tool for bringing research and new technologies to the market;
- it promotes innovation to policymakers and, particularly in emerging technologies, it increases the credibility of innovation, therefore attracting further investment.

Once achieved, the WA3.2 results will provide the following added value:

- enhanced synergies and coordination between European and worldwide official standardisation bodies, professional standards organisations, standardisation initiatives and S2R;
- innovative and time-efficient mechanisms and processes to foster future standardisation of European research results, taking part in the continuous improvement of recent links between research and standardisation;
- improved standard framework conditions for the implementation of new and emerging markets and technologies;
- production of new and/or improved sets of innovative technology standards

The following table shows the most important advances to be achieved with reference to current knowledge and practice in the different fields considered in the proposal.

Table 107 / ***WA3.2 Vision to achieve progress***

STATE OF THE ART	STANDARDISATION ADVANCE BEYOND STATE OF THE ART
Standardisation sometimes a lengthy and expensive process	Definition of improved innovative processes to harmonise and speed up standard development and deployment from collaborative research results
Diverse levels of awareness and integration of researchers into standardisation activities and processes	Harmonised templates and guidelines to help researchers draft standards from their results in a harmonised and efficient way

([5]) Blind, K., *The impact of standardization and standards on innovation*, Manchester Institute of Innovation Research, Manchester, February 2013. The European Committee for Standardization and the European Committee for Electrotechnical Standardization (CEN-CENELEC), *How to link standardization with EU research projects: advice for CEN and CENELEC members*, CEN-CENELEC, Brussels, 2013.

STATE OF THE ART	STANDARDISATION ADVANCE BEYOND STATE OF THE ART
Need for standard mapping at EU level	• Contribution to European standard mapping • Contribution to the definition of future EU research objectives

WA3.2 interacts with CCA by exchanging information and data between all TDs and CCA WAs contributing to standardisation.

6.3.2.4. Impact and enabling innovation capabilities

This standard-focused harmonisation process across IPs will bring better conditions for the generation of **interoperable products and processes**, giving access to a broader base of mass production suppliers of standard technology, which will be cost-effective and lead to a sustainable and efficient rail system that is attractive to end users while maintaining a very high level of safety performance.

A harmonised set of specifications on standardised interfaces and operational rules will contribute to optimisation of production with increased economies of scale and the delivery of components that are more easily interchangeable and deployable throughout Europe.

WA3.2 monitors and addresses through its activities **the TSI open points**, in continuous cooperation with the European Union Agency for Railways.

The S2R activities will in general affect technical standardisation and regulation in the following ways:

- contributing to closing existing TSI open points;
- contributing to improve existing standards and TSIs;
- creating new standards or regulations based on the outcome of disruptive technology innovation.

*Table 108 / **WA3.2 links to Master Plan objectives***

MASTER PLAN OBJECTIVES		ADDRESSED BY
Improved services and customer quality	Improved reliability	• Incorporating the standardisation perspective from the beginning of the activities • Simplifying and improving the standardisation process itself • Setting new and/or improved standards in relation to Master Plan objectives • Identifying harmonised products, components and processes to be standardised
	Enhances capacity	
	Customer experience	
Reduced system costs	Lower investment costs	
	Reduced operating costs	
	Externalities	
Enhanced interoperability	Respect for and adaptation of TSIs	
	Removal of open points	
Simplified business processes	Improved standardisation	
	Simplified authorisation	

This WA will contribute to enabling seven **innovation capability**.

<table>
<tr><th>INNOVATION CAPABILITY</th><th>WORK AREA 3.2 STANDARDISATION</th></tr>
<tr><td>1 – Automated train operation</td><td rowspan="6">Enhance the close cooperation within the sector on standardisation to accelerate market deployment. Reduce the duration and cost of validation of new subsystems through efficient standardisation activities.
• By fostering the deployment of harmonised solutions, standardisation provides the conditions for improved technical compatibility of products and interoperability of processes. It acts as a potential amplifier of the benefits and efficiency of innovations in the technical areas to which it is applied
• Therefore, standardisation is likely to have a positive effect on all S2R innovation capabilities, provided the corresponding innovative outputs are proposed and pushed towards the standardisation process
• Expected benefits of standardisation regarding the Master Plan objectives are to be assessed on a case-by-case basis</td></tr>
<tr><td>3 – Logistics on demand</td></tr>
<tr><td>4 – More value from data</td></tr>
<tr><td>5 – Optimum energy use</td></tr>
<tr><td>6 – Service operation timed to the second</td></tr>
<tr><td>7 – Low-cost railway</td></tr>
<tr><td>9 – Intelligent trains</td><td>Harmonisation of data formats, data transfer protocols and telecommunication technologies, in a harmonised railway system architecture, already appears as one of the key enablers for efficient deployment of future railway capabilities</td></tr>
</table>

6.3.2.5. Demonstration activities and deployment

Working in close cooperation through the Rail Standardisation Coordination Platform for Europe with the standardisation bodies and with the Sector Forum Rail (formerly Joint Programming Committee Rail), WA 3.2 will play a pivotal role between the research and standardisation communities, allowing the identification and selection of best standardisation targets and joint determination of the standardisation trajectories.

It will ensure availability of information from standardisation bodies that is directly relevant to the research project. It will improve mutual understanding, so that research results have reasonable chances of being adopted in the appropriate standardisation context.

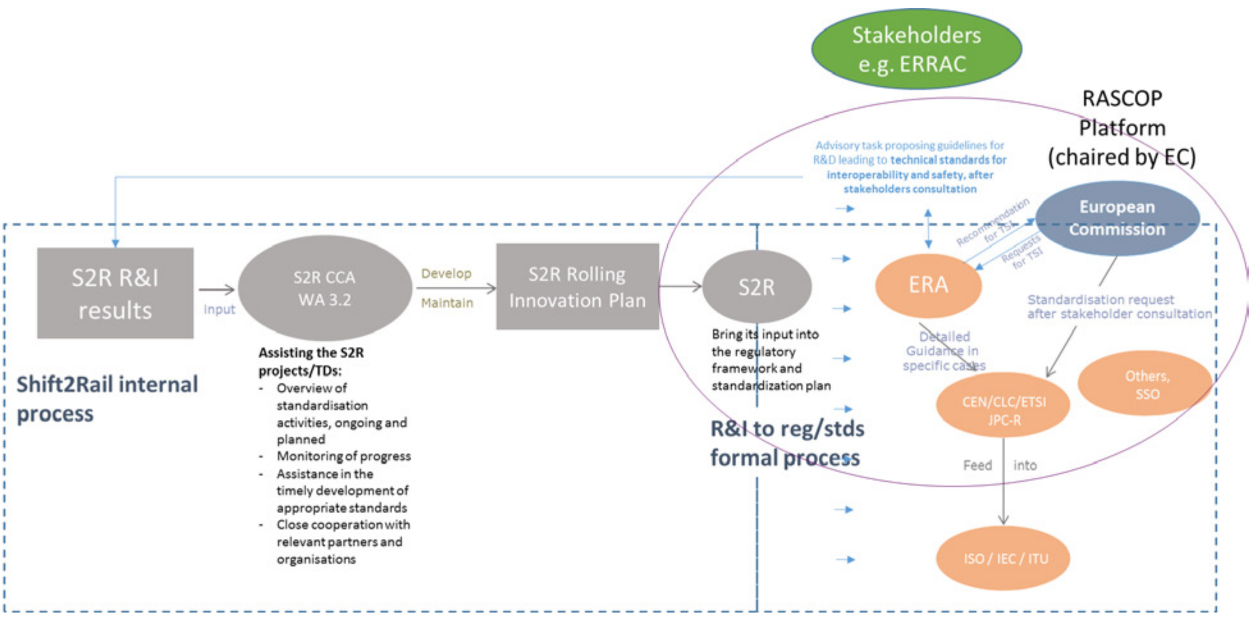


*Figure 50 / **WA3.2 connections to standardisation and regulation ecosystem***

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Standardisation		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA3.2	3.2.1 Strategic analysis of the Shift2Rail activities in terms of standardisation and regulation	-																												
	3.2.2 Definition of the S2R organisation managing standardisation and regulation (TSI) matters	-																												
	3.2.3 Benchmark of existing organisation and processes towards innovative standardisation	-																												
	3.2.4 Establishment of the Shift2Rail internal standardisation	-																												
	3.2.5 Transfer of the Shift2Rail inputs to standards	-																												
	3.2.6 Management of Shift2Rail results and regulation (TSIs and open points)	-																												

◆ milestone
lighthouse projects
contracted activities
future activities

Table 109 / **TD1.2 milestones**

WHEN	WHAT
Q3 2018	Standardisation roadmap v.1
Q3 2019	Standardisation roadmap revision
Q3 2020	Standardisation roadmap revision
Q3 2020	Standardisation process improvements
Q3 2020	Report on standardisation status

The estimated total budget for the standardisation sub-WA is EUR 0.2 million.

6.3.3. Sub-WA3.3 Smart maintenance

6.3.3.1. Concept

The current maintenance system is characterised by a combination of:

- scheduled preventative maintenance with service activities at defined intervals;
- unscheduled/corrective maintenance with repair/replacement of parts that have failed.

The introduction of digitisation presents significant opportunities for changing the maintenance philosophy to condition-based maintenance with reduced asset failures during operation.

Diagnostics systems have been used in rail vehicles for many years. Modern vehicles are equipped with on-board diagnostics systems that continuously generate operational data. Such technical solutions already improve the ability to monitor and diagnose vehicle components. However, at present, event data, log files and process data are not yet being analysed with the aim of establishing the condition of the subsystem.

The future lies in developing a condition-based maintenance system, not only for vehicles but also for stationary components of the railway system. Diagnostics in the individual subsystems will utilise process parameters from existing sensors that are required for control purposes.

The implementation of condition-based maintenance requires the use of new information and communication technology concepts (implemented in other TDs) for:

- collection of diagnostic data within the vehicle and within stationary components;
- transferring the data to a central stationary IT server;
- development of diagnostic software for condition-based maintenance for the maintenance shops.

Modern vehicles and stationary components are already equipped with diagnosis systems that can be used and are capable of gathering huge volumes of various data.

However, so far, these monitoring systems have been implemented independently, and this has had an influence on the way operators have made use of their potential: separately and without any system point of view. Yet the data from one subsystem often contain huge amounts of relevant information regarding other parts of the railway system; for example:

- rolling stock monitoring data contains information about infrastructure components' state of degradation;
- infrastructure monitoring data contains information about rolling stock's state of degradation (wheel defects, axle loadings, etc.).

6.3.3.2. Technical objectives

WA 3.3 has the following objectives.

1. Paradigm shift to condition-based maintenance.
2. Less downtime and increased availability of railway assets due to better prediction of component failures.
3. Reduced maintenance costs due to better planning and coordination of maintenance activities.
4. Pre-standardisation for diagnostic data of vehicle and infrastructure components.
5. Pushing the supervision of infrastructure by means of measuring devices within the vehicle and measuring devices on the infrastructure to monitor rolling stock.

6.3.3.3. Technical vision

The technical vision for smart maintenance is:

- all wayside and vehicle-based sensors and assets of the railway system send diagnostic data in a standardised format to common data servers;
- the data can be used by different stakeholders with assigned access rights;
- the data are used for failure prediction and the implementation of condition-based maintenance for all railway assets;
- hence the reliability of the railway assets as well as punctuality is increased.

Interaction with other TDs (in the same IP and/or in other IPs)

Within WA3.3 a common condition-based maintenance concept will be developed covering four strategic condition-based maintenance areas, as illustrated. Each area requires collaboration with work conducted in other TDs.

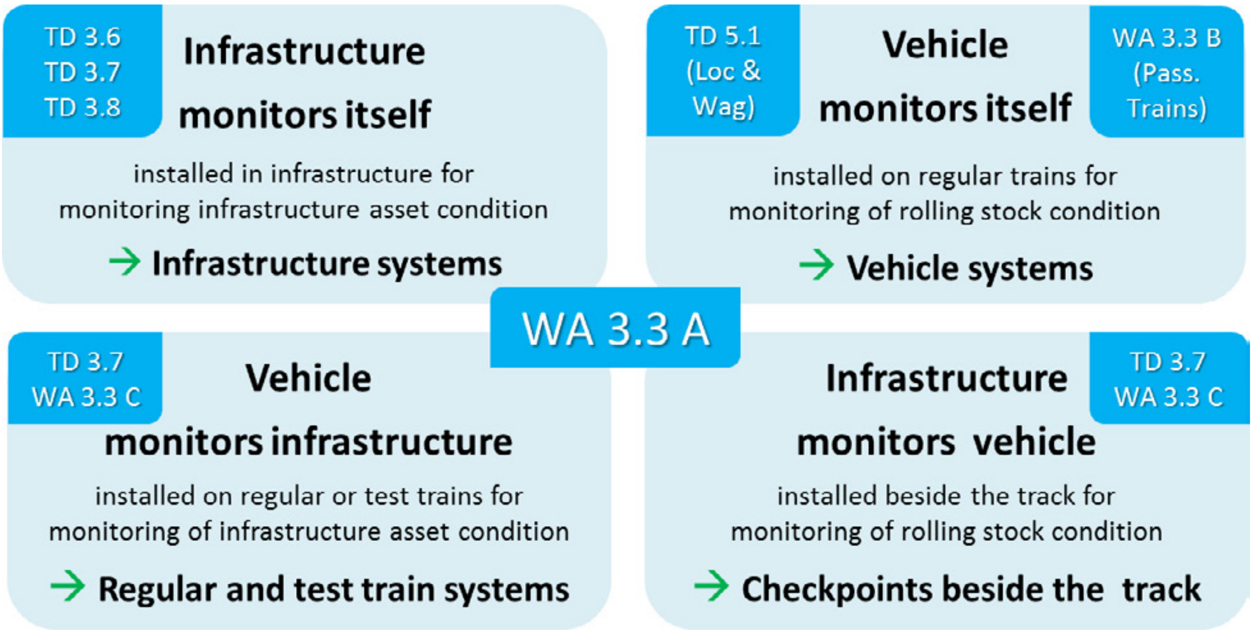


Figure 51 / ***Application fields of smart maintenance for railway undertakings and infrastructure managers***

The implementation of smart maintenance requires close cooperation with other S2R TDs:

- TD1.1–1.7, condition-based maintenance concept for vehicle components;
- TD1.2, transfer of diagnostic data on vehicle components;
- TD3.6–3.8, railway information, monitoring and asset management;
- TD5.3–5.4, condition-based maintenance for freight wagons and locomotives.

6.3.3.4. Impact and enabling innovation capabilities

Smart maintenance addresses the following S2R objectives of the Master Plan.

MASTER PLAN OBJECTIVES	ADDRESSED BY
Improved services and customer quality	Increased asset reliability and punctuality
Reduced system costs	Reduction in maintenance costs

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	Improvement of asset maintenance to provide low LCC as well as better reliability and quality. The use of data plays a key role in optimising condition-based as well as preventative maintenance
Compliance with EU objectives	Enhancement of the competitiveness of the rail sector by means of lowering the maintenance costs and improving the availability and reliability of railway assets
Degree of maturity of the envisaged solutions	The result will show a generic picture of the benefits to be gained as well as the obstacles to be surmounted for the implementation of condition-based maintenance in the whole railway system. The result will emphasise the key role of data – access, availability, understanding, etc. – for the whole process of implementation of condition-based maintenance, independent from any specific rail asset

Furthermore, smart maintenance will contribute to enabling five innovation capabilities as follows.

INNOVATION CAPABILITY	TD3.3 SMART MAINTENANCE
1 – Automated train operation	Condition-based maintenance improves the availability and the reliability of all kinds of railway assets. Therefore, it improves the basis for all levels of automated train operation
4 – More value from data	Diagnostic data about railway components are used to predict component failures The improved knowledge about the real behaviour of the components and their actual maintenance requirements can also provide valuable input for the design and engineering of new components and assets
8 – Guaranteed asset health and availability	Condition-based maintenance increases the availability of railway components
9 – Intelligent trains	Diagnostic data about train assets are used for condition-based maintenance and for failure prediction
12 – Rapid and reliable R&D delivery	Standardised data transfer protocols, formats and structures for rolling stock and infrastructure are developed

6.3.3.5. Demonstration activities and deployment

The benefit of condition-based maintenance for some vehicle components of selected vehicle classes will be demonstrated up to TRL 3.

The development of a smart maintenance concept considering the whole railway system can show the benefit of the holistic approach to maintenance. It helps to find new opportunities as well as common solutions to common challenges independent from any specific rail asset.

Essential for the implementation of any kind of data-based maintenance, such as condition-based or, in the next step, predictive maintenance, is the successful management of all kinds of relevant data. To facilitate data management, standardisation in some key data-related areas, especially harmonised data structures and data formats, would be very helpful.

Planning and budget

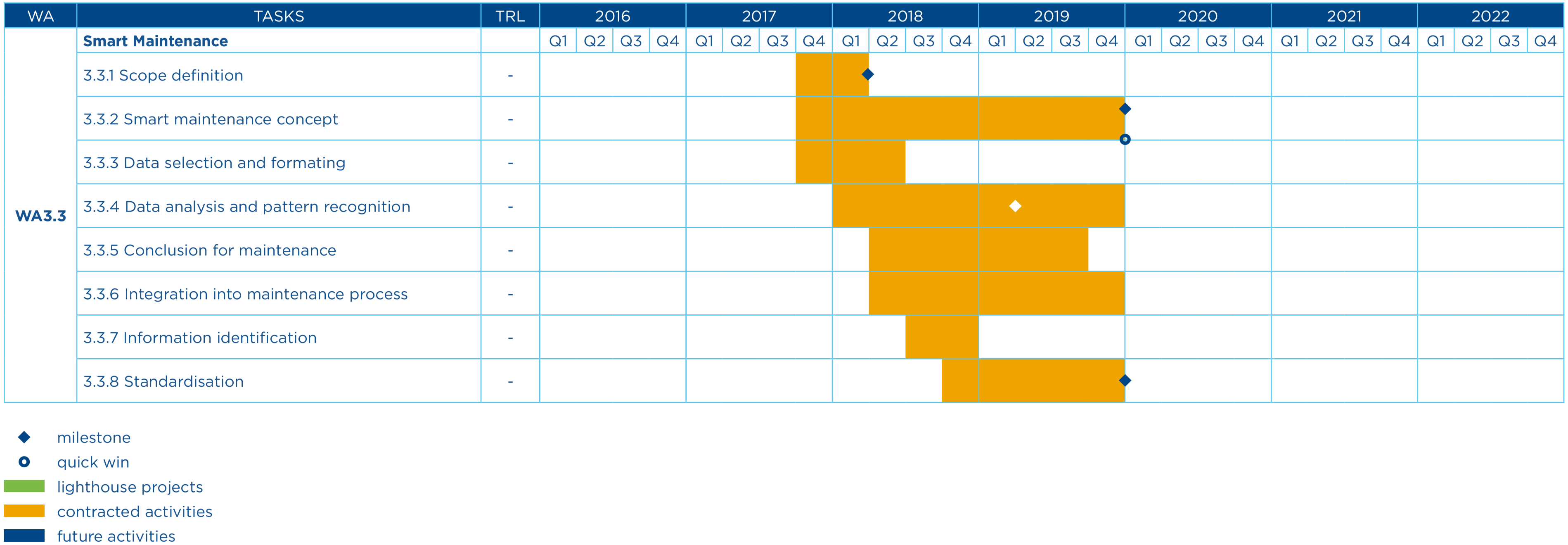


Table 110 / ***WA3.3 quick wins***

WHEN	WHAT	CONTRIBUTION TO MAAP
Q1 2020	Smart maintenance concept	Showing the benefits of as well as the obstacles to the implementation of condition-based maintenance in the whole railway system

Table 111 / ***WA3.3 milestones***

WHEN	WHAT
Q1 2018	Condition-based maintenance data structures defined
Q2 2019	Condition-based maintenance data analysis for specific rail vehicles
Q1 2020	Development of a common smart maintenance concept
Q1 2020	Standardised data transfer protocols, formats and structures for rolling stock and infrastructure

The estimated total budget for WA3.3 is around EUR 1.52 million.

6.3.4. Sub-WA3.4 Smart materials

6.3.4.1. Concept

Modern mass transportation needs to be fast, efficient, comfortable and safe. Speed, energy efficiency and passenger comfort and safety have a lot to do with the design concept, smart components and materials employed.

- A light train can accelerate, move and brake faster. It consumes less energy. In addition, more durable and easy to clean materials translate into lower maintenance costs over the whole life span of a train. Passenger comfort can be also improved by new materials leading to better designed interiors.

- The next generation of components for infrastructure should take advantage of the availability of new materials to ensure significant improvement at LCC and RAMS level, while considering environmental impact.

All these aspects can be optimised by using state-of-the-art composite materials and solutions.

In the railway industry, the use of smart materials has a threefold goal:

- relief (energy savings, reduction in axle load, integration of equipment and/or increased payload);

- lower costs of acquisition, operation and recycling of rolling stock;

- acquisition of new skills.

The activities related to this work area are carried out in the dedicated innovation programmes. Below is an indicative list of research activities highlighting some of the innovations on new materials that will be materialised in the S2R programme:

- TD1.3, Carbody Shell – incorporation of non-metallic parts into the carbody structure for a lighter solution;

- TD1.4, Running Gear – lightweight and LCC-optimised materials validated and certified for the running gear environment;

- TD1.6, Doors and Access System – new composite and metallic doors to improve interior noise reduction;

- TD3.2, Next Generation Switches and Crossings – advanced materials and enhanced elastomeric components for achieving lower overall life costs;

- TD3.4, Next Generation Track – new materials (reuse, recycle materials) in the design of rail supports, fastenings and pads, and analysis of the influence on N&V reduction.

6.3.5. Sub-WA3.5 Virtual certification

6.3.5.1. Concept

Today, the authorisation process for putting new rolling stock or subsystems into service is largely based on full-scale field and line tests, which is not only expensive but also time- and capacity-consuming. For example, the line assessment of the dynamic behaviour of a train can last several months and costs about EUR 1 million. Furthermore, the whole process is repeated for several countries and the same costs and test duration are therefore duplicated, which is hardly compatible with an opening up of the market to competition aiming for a more competitive offer in Europe. There is hence a clear need for a reduction in the duration and cost of the process for an appropriate authorisation to put into service. The fourth railway package will support simplifying the process by having a single authorisation for placing new rolling stock into the market if more than one Member State is concerned. In that respect, it is a great challenge to propose methods that support the single European harmonised process for vehicle authorisation defined by ERA. This can be achieved by introducing new methods and tools making it possible to embrace the various European operational conditions without multiplying the physical tests, making the process easier and less expensive.

One of the major issues is sometimes encountered when performing validation tests. As an example, the train dynamics line tests as defined in European standard EN14363 require some test conditions that are difficult to meet (e.g. ranges or statistical distributions according to track curvatures, cant deficiencies, etc.). Those tests on specific dedicated routes affect the train path's capacity and commercial traffic, and lead to additional costs for the stakeholder. Moreover, even if all the mandatory conditions are fulfilled, line tests do not capture all the possible operating conditions. For all these reasons, there is a need to simplify the procedures and to improve the representativeness of the test conditions.

Technically, the way to make a breakthrough in performance is to introduce numerical simulation progressively in a mixed virtual/experimental validation process for authorisation, resulting in fewer field tests.

Some recent work, led within European projects, has helped to make progress in this area, but simulation is barely used for validation. That is partly because of the remaining technical open points, but also for many non-technical reasons (organisations, cultural habits, availability of necessary data, multiplicity of stakeholders in the process and fragmentation of responsibilities, not being allowed by TSIs and standards, etc.). Nevertheless, the switch to virtual validation processes seems ineluctable and can be seen as a great opportunity for the sector.

A European research programme is seen to be the most appropriate framework for performing collaborative work, gathering complementary expertise from industrialists, operators, infrastructure managers and academia. It will facilitate convergence on shared processes and maximise the chance of their translation into standards.

6.3.5.2. Technical objectives

A mixed physical and virtual process for authorisation raises many technical issues, needing the contribution of experts who are specialised in specific domains (braking, traction, car body shell, TCMS, running gear, signalling, etc.). For that reason, the technical developments are carried out within the associated IPs and TDs. However, there is still a need for:

- appropriate coordination among IPs and relevant TDs to define and share generic approaches and methods when possible;

- a common interface with standardisation/regulation bodies (ERA, CEN, CENELEC, etc.).

The main technical objectives of WA3.5 are the following:

- an overview of the state of the art, a gap analysis and barrier identification for a mixed physical and virtual validation process for authorisation in the different railway technical domains;

- an overview of the TDs' progress within the S2R programme and the organisation of meetings with leaders of the technical tasks related to virtual validation and authorisation, task participants, IPs leaders and other railway experts;

- proposal of generic methods and procedures for a mixed physical and virtual testing validation process for authorisation;

- defining a dissemination plan targeting the relevant standardisation bodies.

The goal is to maximise the chance to reach applicable complementary methods, and above all, comprehensive practical industrial processes for validation of rolling stock subsystems and systems based on a mixed experimental and virtual approach, by finding synergies between TDs and coordinating the dissemination activities. The task will aim to steer the project outcomes in standards and guidelines.

6.3.5.3. Technical vision

WA3.5 will give numerical simulations and laboratory tests more significance in the authorisation process than they have in the state of the art. Although simulations will not totally replace field tests, a mixed virtual and experimental authorisation process will make a breakthrough in performance as shown in Figure 52.

Irrespective of the type of system to be validated, some generic questions are raised. How can simulations be validated? By whom? When and in what configurations can simulations replace field tests? How should the different stages (laboratory tests, simulations, field tests) be organised? And so on.

Some standards already allow the use of simulations in the validation process for authorisation, but practical applications remain limited. It is hence necessary to clarify all these open questions to generate high-quality methods, which have potential for broad acceptance by approval bodies.

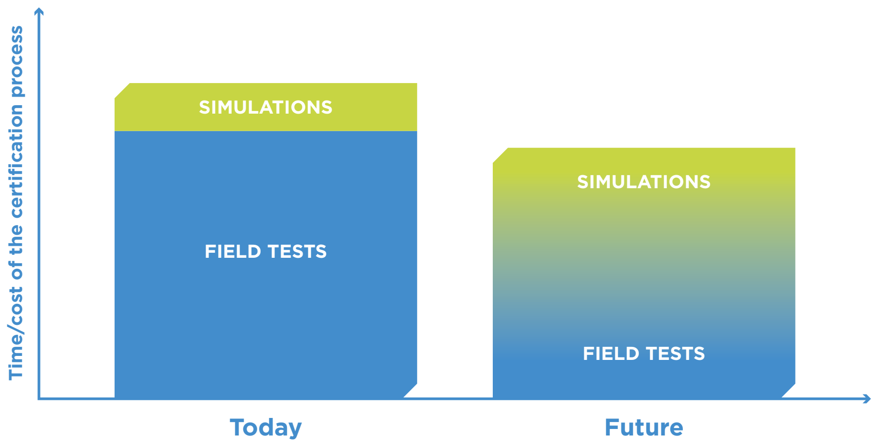


Figure 52 / ***Technical vision for virtual certification***

STATE OF THE ART	NEW GENERATION OF CERTIFICATION
The authorisation process for putting new rolling stock on the market is largely based on line tests, which are long, expensive and capacity-consuming. Moreover, it can only be performed at the end of the design process, which does not help to reduce the time to market	Generic mixed experimental and virtual methods and practical processes for the certification of components, subsystems and systems will be proposed
Some individual standards (e.g. EN14363) allow the use of simulation as one possible verification path	These individual approaches should be widely extended to other technical domains

Interaction with other TDs (in the same IP and/or in other IPs)

The task aims to coordinate all the virtual validation/certification tasks that are defined in the TDs. The interactions with the associated TDs are therefore strong. The identified TDs and tasks are:

- TD1.1, Traction:
  - Task 1.1.5, requirements, specifications and developments for virtual validation and certification (up to TRL 4/5);
- TD1.2, TCMS:
  - Task 1.2.4, virtual placing on the market;
- TD1.3, Carbody Shell;
- TD1.4, Running Gear:
  - Task 1.4.7, virtual certification of train dynamics;
- TD1.5, Braking System:
  - Task 1.5.6, certification process;
- TD2.6, Zero On-site Testing – control command in lab demonstrators.

6.3.5.4. Impact and enabling innovation capabilities

The most significant quantitative benefits to be obtained are:

- LCC – reduction in capital costs: reduction in the traction system, TCMS, train dynamics, braking system, running gear, signalling validation and authorisation costs by around 20–30 % through simplification, harmonisation of rules and shifting from on-site tests to simulation and/or bench tests;
- time to market: reduction in the duration of the authorisation process to put into service around 30 % (even more for cross-acceptance) through simplification, harmonisation of rules and shifting from on-site tests to simulation and/or bench tests;
- reduction in demands on access to lines for test trains, enabling more paths for freight or passenger operations;
- facilitation of cross-acceptance, and hence interoperability, by enabling all products to be assessed with identical tools and parameters;
- facilitated introduction of innovations, since the process will be less expensive, clearer and able to test more virtual situations;
- enhanced products by improving simulation tools for validation of designs.

The degree of maturity of the envisaged solutions will depend on the domain, but the final results could reach TRL 3 or 5.

The table below provides an overview of the effects generated at larger scale by the application of the TD results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE TD
Support the competitiveness of the EU industry	• Harmonising and simplifying traction/braking/TCMS/train dynamics/running gear/ signalling authorisation processes with the aim of putting new vehicles on the market faster, decreasing cost and duration by introduction of virtual tools • Proof of tangible benefits for the end user: LCC reduction
Compliance with EU objectives	• Promotion of modal shift: a big impact made by the implementation of these new technologies on avoiding service disruptions and adding new innovation capabilities • Support to capacity increase: as mentioned above, this is allowed by flexible unit coupling and fewer service disruptions due to lack of operational availability • Greening of transport through energy reduction: achievable by better integration between subsystems and communications out of the train, as well as optimised consists with flexible coupling
Degree of maturity of the envisaged solutions	• Depending on the domain, final results reaching TRL 3, in some specific cases TRL 5 • Potential recommendations for standards revisions

This TD will contribute to enabling five innovation capabilities as follows.

INNOVATION CAPABILITY	VIRTUAL CERTIFICATION ENABLERS
1 – Automated train operation	It will reduce the duration and cost of validation of new subsystems (automated trains and signalling systems), and help to test new configurations
4 – More value from data	One of the key points for success of a virtual approach is the quality and representativeness of input data. Collecting more data will make it possible to define more realistic specifications and mission profiles, and therefore will improve the whole process for design, validation and authorisation for putting new trains in service
7 – Low-cost railway	By reducing the cost of the certification of rolling stock subsystems (TCMS, traction, running gear, braking, carbody shell) and signalling systems, using physical and virtual methods will help to reduce the railway LCC
11 – Environmental and social sustainability	By reducing the LCC, mixed physical and virtual authorisation will help to promote rail transport
12 – Rapid and reliable R&D delivery	With the simplification and the reduction of duration and cost of the certification process, the manufacturers will introduce more seamlessly innovations in their products. The acceleration of the design validation process will also facilitate the renewal of technologies in the rail sector

6.3.5.5. Demonstration activities and deployment

WA3.5 will give an overview of the progress in virtual approaches made by the different technical domains, share generic methods and define a practical industrial mixed test/simulation process to reduce time for authorisation for putting new rolling stock on the market.

WA3.5 will form a preferential point of contact between the S2R projects and the approval stakeholders and will coordinate dissemination to the standardisation authorities, promoting the derived generic methods and processes.

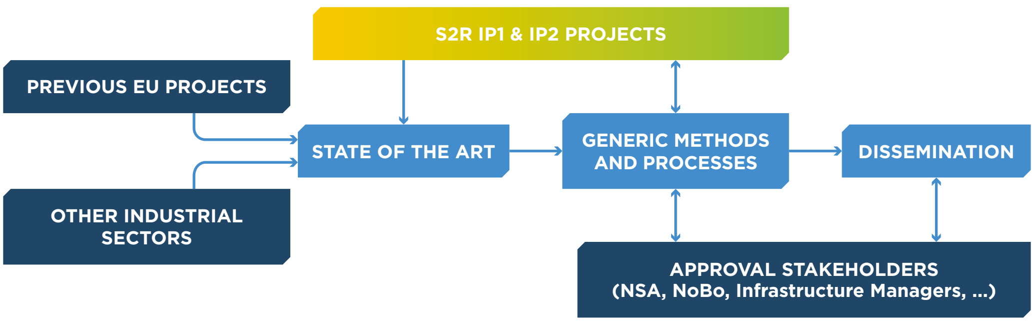


Figure 53 / ***Interactions with stakeholders and deployment***

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA3.5	**Virtual Certification**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	3.5.1 State of the art, gap analysis and barriers identification	3																												
	3.5.2 Overview of the generic methods and process	3																												

◆ milestone
lighthouse projects
contracted activities
future activities

Table 112 / ***WA3.5 milestones***

WHEN	WHAT
Q4 2018	Start of S2R WA3.5 activities
Q4 2019	Plan for engagement with relevant stakeholders
Q4 2020	Description of generic methods and processes for mixed test/simulation certification

The estimated total budget for Virtual Certification is around EUR 0.2 million.

6.4. WA4 Smart mobility

The overall objective of WA4, smart mobility, is to improve railway planning and operation by means of precise railway simulation (WA4.1) and by specification and implementations of message exchange between freight operations and traffic management systems (WA4.2).

6.4.1. Sub-WA4.1 Smart planning

6.4.1.1. Concept

Working Area 4.1, smart planning, will provide the basis for a macroscopic simulation, integrating planning activities and status information from the various actors within the railway system, e.g. RUs with their fleet- and staff-planning processes, IMs whose assets are in a certain condition, schedule planning and external parameters (such as weather conditions).

The aim of smart planning is to enable railway stakeholders to make the best decisions for the overall system, for example concerning schedules and the availability of rolling stock and staff, based on up-to-date operational data, taking into account all essential information in order to ensure that the quality promised is delivered to customers. The task also enables optimum allocation of funds by using knowledge of all relevant system parameters and their interaction to promote the best possible use of existing capacities. With limited resources, these data will provide a basis for operating the railway system far more cost-efficiently in the long term.

6.4.1.2. Technical objectives

The goal of the smart planning subproject is to make the effects of planning decisions on large, complex railway networks measurable and predictable, to help decision-makers in railway stakeholders select the best options. A holistic approach that takes into account many different aspects of railway planning, including timetable construction, resource planning and dispatching, will make it possible to achieve greater punctuality, minimise disruptions and optimally use available resources.

WA4.1 addresses railway operational planning, which is crucial for a cost-efficient, reliable and robust railway system all across Europe. The comprehensive approach includes all key aspects of the railway system identified in previous research and operational analysis, and substantially enhances its value in both the long and the short term.

The main objective is to map the different railway-planning activities and develop a basic model. This is meant to lay the foundations for an enhanced integrated macroscopic railway simulation system including the first development steps concerning the impact of disturbances on railway operation.

6.4.1.3. Technical vision

The end results of WA4, will lead to improved reliability and customer experience, which in turn will lead to reduced system costs and simplified business processes.

Precise railway network simulation will enable RUs and IMs to identify operational bottlenecks and harmonise long-, medium-, and short-term planning activities. It will support all actors to generate recommendations for decisions that enhance efficient and punctual operation. Furthermore, it can provide support for strategic investment decisions and serve as a tool to determine the effectiveness of measures, thus allowing the optimum allocation of resources and enhancing the sustainability of the railway system.

The approach to this project will ensure the scalability of the task, thereby adding value to the entire European railway community.

Interaction with other TDs (in the same IP and/or in other IPs)

Clear links with WA4.2 and TD2.9 are defined. Once the data structure and the format of the integration layer are clearly defined, the smart planning simulation model can be adapted to them and run simulations with these data.

6.4.1.4. Impact and enabling innovation capabilities

The WA will bring a significant technological advance in the field of precise railway network simulation and railway operational planning. The use of state-of-the-art IT and smart data analysis will make it possible to incorporate substantial detail in the simulation and to extend the scope from small areas to larger regions, and later entire cross-border networks, without losing the precision in predictive capacity. Operational data and output of planning activities from all actors across the railway system can be included in this flexible and open analytical framework.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA4.1
Improved services and customer quality	• Integrated approach to railway planning will increase punctuality
Reduced system costs	• Stability of the system is increased and resource allocation is improved
Simplified business processes	• Use of smart data and new IT capabilities will improve operational planning

Smart planning is a key instrument to resolve urgent operational issues in the network, but it will also help pave the way towards a more integrated approach to railway planning and operation that involves a multitude of stakeholders in the system. This WA addresses the challenges of service quality, cost and innovation, all evoked in the S2R Master Plan. In addition it will assist railway operators in improving their decision-making and processes and so safeguard the railway system's sustainability and competitiveness. It promotes open data exchange and communication.

The integrated approach and the focus of the analysis for model validation will help establish a SERA and it can be augmented by means of a thorough operational analysis of parts of the TEN-T corridors and their cross-border connection points.

This WA will contribute to enabling four innovation capabilities as follows.

INNOVATION CAPABILITY	WA4.1 SMART PLANNING
1 – Automated train operation	Enable railway stakeholders to make the best decisions for the overall system in view of efficient and on-time operation
3 – Logistics on demand	Enable railway undertakings to make reliable plans in accordance with customer requests, taking the actual timetable and operational quality into account
6 – Service operation timed to the second	Achieve higher punctuality, minimise disruptions and use available resources optimally, which results in higher quality delivered to customers
10 – Stations and smart city mobility	Give reliable and precise predictions of railway delays due to disturbances relevant to the whole transport chain, especially when travellers take/switch to other modes when travelling to/leaving the train station

6.4.1.5. Demonstration activities and deployment

A model prototype has been developed, and the test simulations will be carried out on the entire German railway network with a runtime of approximately 1 minute for 1 day of operation. Applicability of the model to other networks will be extensively assessed.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Smart Planning		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA4.1	4.1.1 Project design and integration	-																												
	4.1.2 Railway planning activities and basic model	3																												
	4.1.3 Model refinement and strategic planning	3																												

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future activities

Table 113 / ***WA4.1 Milestones***

WHEN	WHAT
Q3 2017	Development of a basic model prototype for proof of operability of the simulation approach
Q2 2018	Enhancement of the prototype by the influence of disruptions
Q3 2019	Summary of methods for dealing with incomplete data
Q3 2020	Interplay between microscopic and macroscopic simulation

6.4.2. Sub-WA4.2 Integrated mobility management

6.4.2.1. Concept

Integrated mobility management must be smart and based on real-time seamless access to heterogeneous railway data sources with a view to enabling all rail stakeholders to measure their performance and optimise their operations and planning, and ultimately the service they offer to the end users (travellers and freight customers). It will also provide a seamless exchange of information between fixed and mobile services in different transport modes, and achieve a standardisation of interfaces, processes and data structures on such a level as to ensure compatibility independent from suppliers' subsystems and modules.

I2M provides this step change towards seamless fully automated process integration of railway-related services and other modes of transport. This integrated process will support intelligent, automated and flexible rail traffic operations but also an integrated approach to the optimisation of railway architecture and operational systems at network, route and individual train levels. These will reconcile business and operational requirements with real-time field and asset condition monitoring and intelligent traffic planning.

For freight and passenger operations it is essential to receive high-precision and real-time forecasts of traffic status and demand to manage resources such as availability of platforms and terminals, locomotives or coaches, operators, drivers and others in an efficient way. Maintenance services depend strongly on the dynamic planning of free slots to carry out maintenance activities, and updated nowcast and forecast periods of availability of the assets for maintenance are key.

The overall objective of WA4.2 is to specify, develop and integrate all necessary elements into the traffic management system to integrate actual and forecast traffic asset and freight operations status information into a seamless operation process. The works under WA4.2 aim to specify and develop the functionalities needed to deliver, as a first step, an integrated and automated real-time rail operations process applying nowcast and forecast data about traffic, asset and freight operations status.

6.4.2.2. Technical objectives

- Increase in operational reliability in freight: integrated status data exchange between traffic management, asset management and freight management systems will allow better forecasting of traffic and reduce delays.

- Increase in operational performance for passenger services: through the integration of traffic management with available and accessible business information, operators will be able to improve decision-making.

- Increase in the efficiency of rail freight operations: new advanced business service software modules will allow a high-precision ETA forecast for freight train services and improve the efficiency and the organisation of freight-handling processes.

- Increase in the efficiency of passenger-focused operations: advanced business services will also allow new data combinations to take place. This will achieve greater business intelligence and assist operators, infrastructure managers, drivers and staff in the field in understanding their assets better.

6.4.2.3. Technical vision

Sub-WA4.2, Integrated Mobility Management, aims to demonstrate and enable the automated data exchange between all rail business services and rolling stock (both passenger and freight) into one communication platform, known as an integration layer.

This will enable:

- advanced traffic regulation decision-making processes to increase reliability of train services, both freight and passenger,

- high-efficiency maintenance strategies for the various assets integral to running trains,

- improved information on traffic status for internal and external clients to support decision-making and assist in the modal shift of passengers and freight from road to rail.

I2M will also promote seamless reporting of status information about all services, systems, subsystems, rolling stock and resources involved, applying a standardised data representation format such as the conceptual data model.

A subscribe-and-publish messaging methodology will replace point-to-point communication principles. An example of this is an enhanced freight information system (FIS) that offers online updates on the current position and status of critical freight to monitor the consignment, ensuring that emergency activities such as the activation of cooling systems can take place remotely.

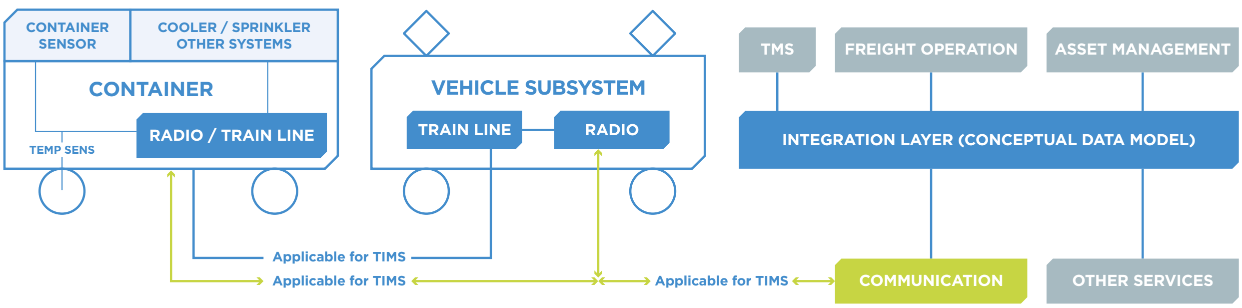

Figure 54 / ***Integrated data exchange, in a freight scenario***

Interaction with other TDs (in the same IP and/or in other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and from that of interaction in performance and objectives, are:

- TD2.1, Adaptable Communications – providing concept to utilise the different technologies for a new T2T interface for freight on-board monitoring and management technologies,

- TD2.9, Traffic Management Evolution – providing specification for integration layer and canonical data model,

- TD3.6, DRIMS – providing the data elements to be represented in the CDM for Infrastructure assets,
- IP5 – providing input on freight operation management processes.

6.4.2.4. Impact and enabling innovation capabilities

The following table details the benefits generated at a larger scale by the application of the WA4.2 results.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	• **Global technological leadership supported by a combination of innovation and technical standards, setting up an effective advantage for the European industry** WA4.2 I2M will contribute to the following TSIs and official or de facto standards: / S2R conceptual data model to create railway-specific universally applicable data exchange format / TAF-/TAP-TSI aiming to define the data exchange between IMs and RUs • Increase in operational reliability (fewer service disruptions) through more robust traffic management processes integrating dynamic forecast asset status in the decision process and improved efficiency of maintenance operations due to better scheduling following more precise traffic forecast information • Reduced cost as fewer disruptions of the train services enable better utilisation of available resources and energy consumption • Increased capacity due to better tools (applications) enabling higher utilisation of line capacity without destabilising the robustness of the timetable
Compliance with EU objectives	• **Achieve a SERA:** a standardised approach to integrated data exchange, as the one developed within WA4.2 will reduce the technical obstacles to a proper interconnection of technical solutions • **Enhanced interoperability:** the usage of a standardised data format will guarantee that information can be accessible to all stakeholders; algorithms, based on a canonical data model, should be able to be easily used by different organisations involved in traffic management process
Degree of maturity of the envisaged solutions	At the end of S2R it is expected some of the successful WA4.2 concepts will reach TRL 6/7

WA4.2 addresses the following innovation capabilities.

INNOVATION CAPABILITY	WA4.2 ENABLERS
1 – Automated train operation	Services, processes and building blocks of original work from WA4.2 improve the flow of traffic, enabling automated train operation for freight and heavy haul trains, and allow automated or remotely controlled monitoring or management of critical freight (food, dangerous goods, etc.): BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.6: Plug-ins to enable integration of services Integration of building blocks from TD2.9
2 – Mobility as a service	Building blocks of WA4.2 provide all subscribed clients or services with real-time updated status information about traffic and all related information, improving mobility: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services
3 – Logistics and demands	Building blocks of WA4.2 enable freight operations to improve the performance and efficiency of their logistics and reduce operational cost: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.6: Plug-ins to enable integration of services
4 – More value from data	Building blocks of WA4.2 will enable, through the standardised data model, the utilisation of legacy data representations to support new system functionality without any adaptation: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services

INNOVATION CAPABILITY	WA4.2 ENABLERS
5 – Optimum energy use	New functional service application modules of WA4.2 optimise the flow of traffic in terms of reducing delays, and optimise braking and accelerating manoeuvres of trains, to contribute to a more efficient use of energy: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.6: Plug-ins to enable integration of services
6 – Service operation timed to the second	Services, processes and building blocks of WA4.2 optimise the flow of freight and passenger traffic: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services
7 – Low-cost railway	New applications of WA4.2 improve the flow of freight traffic and hence reduce operational cost, and seek to identify new value streams from data combination: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services
8 – Guaranteed asset health and availability	Broadcasting asset status, as well as nowcast and forecast information, via an integrated communication network to all subscribed clients/services will lead to an increase in efficiency of the service and maintenance operations: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services

INNOVATION CAPABILITY	WA4.2 ENABLERS
9 – Intelligent trains	Innovative applications allow critical freight to be monitored during transport and, if needed, emergency activities can be started automatically or remotely using on-board tools and communication: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.6: Plug-ins to enable integration of services
10 – Station and smart city mobility	Seamless availability of traffic status forecasts through an integrated communication network will provide support to and boost smart city concept: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services
11 – Environmental and social sustainability	Optimising the flow of traffic following the introduction of new applications for the TMS will reduce energy consumption and N&V: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services
12 – Rapid and reliable R&D delivery	Development of innovative applications following well-proven processes, working closely with customers, will secure fast deployment in the rail sector: BBA4.2.1: Technical assessment and integration BBA4.2.2: Upgrade of integration layer BBA4.2.3: TMS application supporting highly efficient freight operations BBA4.2.4: Advanced rules and business logic supporting highly efficient freight operations BBA4.2.5: Advanced rules and business logic supporting high-efficiency passenger operations BBA4.2.6: Plug-ins to enable integration of services

6.4.2.5. Demonstration activities and deployment

RESEARCH AREA	SPECIFIC TECHNICAL OBJECTIVE	SPECIFICATION ACTIVITIES	DEMONSTRATOR		FOCUS OF ACTIVITY
			MARKET	TRL	
Integrated mobility	Data exchange between the various rail services	Extension of the SRS for integration layer, specification of conceptual data model	Mainline (freight)	3/4	Specification and prototypes Enhancement of the CDM
	Business applications for traffic management (freight traffic) and freight operation services	SRS for applications in scope of TD2.9	Mainline (freight)	3/4	Specification and development of new applications
	Interfaces for TMS database, asset management database and freight operation systems	Interface for TMS database, asset management database and freight operation services	Mainline	6/7	Specification and development of Interfaces

The partners of WA4.2 that have proposed prototypes for constituents of the system or business application are developing guidelines to secure interoperability of the prototypes and to specify, together with the partners of the open call, the specific details of the demonstrator platform.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Integrated Mobility Management (I2M)		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA4.2	4.2.1 Technical assessment and integration	NA																												
	4.2.2 Upgrade of integration layer	3/4																			◆				◆					
	4.2.3 TMS application supporting high efficient freight	4/5															◆								◆					
	4.2.4 Advanced rules and business logic supporting freight	3/4																							◆					
	4.2.5 Advanced rules and business logic supporting passenger	3/4																					◆				◆			
	4.2.6 Demonstrator	6/7																						◆				◆		

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lighthouse projects
contracted activities
future activities

*Table 114 / **WA4.2 milestones***

WHEN	WHAT
Q3 2019	Description of basic use cases for advanced freight operation
Q1 2020	Concept of demonstrator
Q3 2020	System requirement specification for freight-related topics integrated in integration layer
Q1 2021	Delivery of test platform for integration layer (critical dependency) System requirement specification of the interfaces
Q3 2021	Prototypes available Description of business rules and logic to support highly efficient freight operations
Q3 2022	Prototypes validated

The estimated total budget for WA4.2 is EUR 8.42 million.

6.5. WA5 Energy and sustainability

6.5.1. Sub-WA5.1 Energy

6.5.1.1. Concept

Energy is one of the key concerns in the ambitious goal to increase the competitiveness of railway transport, to boost the competitiveness of the European manufacturing rail sector and to limit environmental impact.

Energy efficiency simultaneously enables improvement of rail's excellent environmental balance by cutting down CO_2 emissions and improvement of the economic business model of the rail transport sector by reducing the cost of energy, making train travel more affordable and thus promoting modal shift to rail.

The overall goal is to promote energy saving as well as reduction of CO_2 emissions in the whole railway systems including operations, infrastructure, rolling stock, subsystems (such as traction and running gear) and components.

6.5.1.2. Technical objectives

The overall objective of WA5.1 is to reduce operational costs through a reduction in energy consumption.

The end result of WA5.1 has the added value of a standardised methodology for estimation of energy consumption by simulation and measurement, enabling the standardised specification of energy-efficient railway systems.

The objectives of the Energy and Sustainability WA are:

- to define the energy baseline for the four SPDs;
- to achieve and assess the overall energy reduction on all TDs and SPDs as an input to the KPI monitoring carried out within WA2;

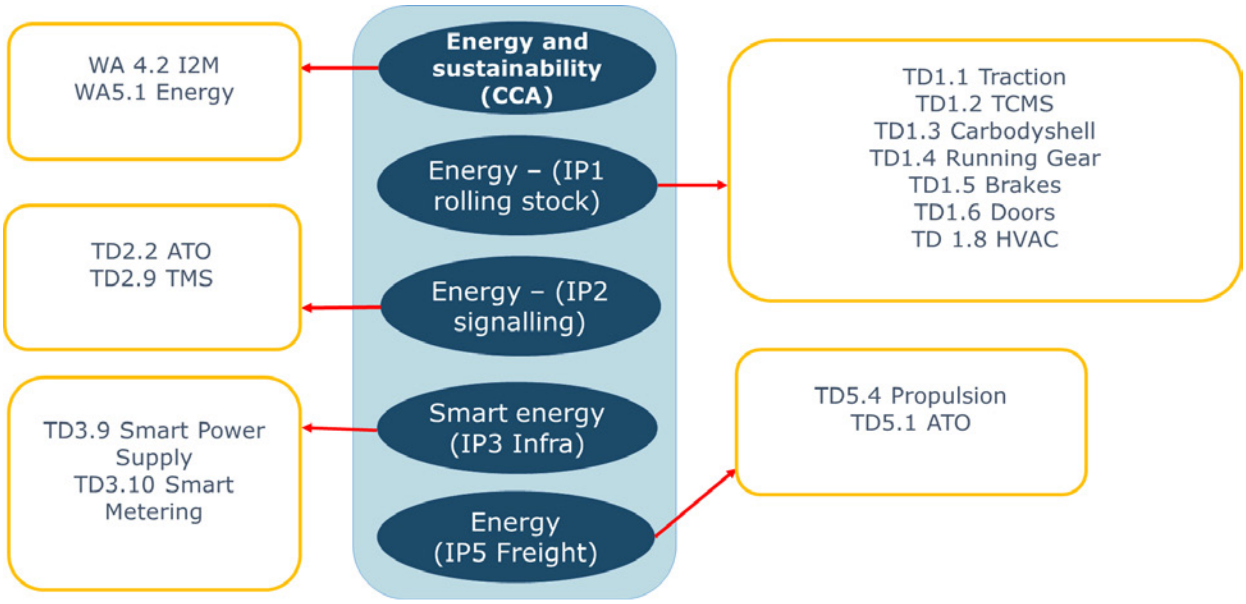
- to help and support all energy-saving-related work across the IPs and TDs;
- to stimulate the emergence of pre-normative texts when needed to pave the way towards a European shared understanding of energy figures in railways;
- to develop the future railway system with respect to energy;
- to propose the eco-labelling approach for rail.

6.5.1.3. Technical vision

This work area will develop an energy baseline that covers the speed profiles for the reference lines for each SPD and all energy-relevant data about the reference vehicles. Furthermore, a simulation tool for energy calculation will be specified, developed and tested. Last but not least, the future railway system concerning energy will be described, when all energy-relevant TDs are realised.

The assessment of the energy improvement due to S2R innovations will be carried out. It is based on the collected improved energy KPIs of the TDs. The estimation of the energy improvement is carried out in order to deliver preliminary results, to have an overview of how much each TD contributes to the overall S2R targets. The result of the energy assessment will be delivered as an input to WA2, in which the overall KPI-assessment is carried out.

Interaction with other TDs



6.5.1.4. Impact and enabling innovation capabilities

In order to propose progress allowing a new solution to be deployed on the markets, the framework conditions, existing regulations and standards will be evaluated.

This TD will contribute to enabling eight innovation capabilities as follows.

INNOVATION CAPABILITY	WA 5.1 ENERGY
1 – Automated train operation	Estimation of the energy improvement due to optimised driving by means of automatic train operation
4 – More value from data	Definition of all energy-relevant parameters of the traction chain as an input for the energy estimation by simulation
5 – Optimum energy use	Estimation of the energy improvement of all S2R TDs concerning energy
6 – Service operation timed to the second	Estimation of possible energy improvement due to S2R TDs for improved service operation
7 – Low-cost railway	Reduction of energy consumption, reducing the LCC
9 – Intelligent trains	Estimation of possible energy improvement due to S2R TDs for intelligent trains
11 – Environmental and social sustainability	Reduction of energy usage reduces the CO_2 impact
12 – Rapid and reliable R&D delivery	Standardisation of energy quantification enabling optimal development and market entry (business cases) of energy-efficient technology

6.5.1.5. Demonstration activities and deployment

Contribution to energy standards such as prEN 50591 is undertaken. It was selected as the key reference for evaluating energy consumption related to eco-labelling. In parallel, the most relevant energy-related KPIs are selected, pointing to mass and efficiency.

An eco-label for the rail sector is assessed. In addition, an energy cost sensitivity analysis and EU policies analysis will be included.

Technology of the future railway system will consider the implementation of all S2R innovations related to energy, and further relevant technology developments outside S2R will be analysed. Based on this list of potential energy-saving technologies, research activities are suggested that can contribute to further improving the energy efficiency of the railway system, which will contribute to reducing CO_2.

Energy calculation methodology and an energy simulation tool will be developed within the programme that considers the four S2R SPDs.

Energy improvement coming from the S2R technologies is assessed, which feeds into the KPI activity.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA5.1	**Energy and Sustainability**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	5.1.1 Interface with other S2R groups	-										◆																		
	5.1.2 Energy calculation methodology	-					◆	◆					◆																	
	5.1.3 Assessment of energy improvement	-														◆														

◆ milestone
lighthouse projects
contracted activities
future activities

*Table 115 / **TD1.2 milestones***

WHEN	WHAT
Q2 2018	Establish interfaces with the relevant S2R experts
Q1 2017	Requirement specification for energy simulation tool
Q2 2017	Complete simulation methodology and tool
Q3 2018	Energy KPI definition

The estimated budget for sub-WA is around EUR 2.5 million.

6.5.2. Sub-WA5.2 Noise and vibration

6.5.2.1. Concept

Noise and vibration represent one of the biggest environmental challenges for the railway. The end result of this work area is to support a reduction in exposure to noise and vibration related to the rail sector in Europe. The population in the vicinity of railways no longer accepts the increasing N&V annoyance, while on the other hand a shift to rail traffic is important for environmental reasons.

To facilitate effective noise and vibration management, it is crucial to apply an overall whole-system approach. To achieve this, it is essential to have commonly agreed and validated simulation tools to correctly quantify and rank the N&V sources before deciding on costly measures for their mitigation. A proper ranking for relevant combinations of rolling stock, infrastructure and running conditions together with methods for calculating cost-effectiveness of mitigation actions will considerably improve the current situation.

Moreover, the added value of WA5.2 is to provide the necessary whole-system approach and leverage of the results from all the IPs by following up noise control in the different technical demonstrators.

Reduced speed limits or night-driving bans to mitigate N&V annoyance are now increasingly implemented. Such measures reduce the transport capacity on the main railways in an unacceptable way. Reducing N&V annoyance is therefore a key factor for the success of European concepts and strategies to provide a sustainable and high-capacity transport system.

The ERRAC Noise and Vibrations Roadmap 2030 has defined the goals for future research:

- by 2030, noise mitigation measures will be integrated naturally in all relevant processes of the railway;
- the European railways will strive towards noise and vibrations no longer being considered a problem for the railways and their neighbours, meaning that noise levels are socially and economically acceptable and allow 24-hour passenger and goods operations by 2050.

6.5.2.2. Technical objectives

The overall objectives are:

- to further develop practically useful methods for predicting noise and vibration performance on a system level, including rolling stock, infrastructure and the environment, to ensure correct decisions on sources that need to be reduced to achieve a reduction in the overall levels;
- to calculate the effect considered and integrated in all relevant TDs within the different IPs of S2R;
- to provide scientifically based methods for improved procedures to be used in TSI certification.

The work area will include exterior noise, interior noise and ground vibration. It will particularly focus on five areas:

1. exterior noise sound emission and prediction, including source contribution separation, to support future updates of TSIs for noise;
2. interior N&V predictions for comfort and attractiveness for passengers;
3. traffic scenarios including freight segment to reduce disturbance for residents;
4. auralisation and visualisation of N&V scenarios for future railway systems, and demonstration of mitigation methods;
5. improving prediction models for ground vibration impact studies.

At the core of this framework are predictive schemes for interior and exterior noise as well as ground vibrations. Such schemes in combination with accurate and robust source assessment methodology are required to assess the effect of noise mitigation measures as well as different scenarios for effective noise management on the system level. This in turn is a requisite to arrive at cost-effective noise control solutions on the system level. Within the project, auralisation methodologies are also developed for assessment of the expected impact of solutions developed on vehicle and system levels as well as on the European level.

6.5.2.3. Technical vision

The end results of this work area should contribute to strengthening the rail sector by improving passenger comfort, facilitating efficient product development and allowing capacity increase. Railway vehicles are normally developed and produced in small series with extremely long life cycles compared with other vehicle types, such as cars, trucks and buses. The small series, together with interests in reducing development times, call for accurate and robust prediction tools to limit the need for prototypes and testing. Improved as well as novel approaches for virtual design and testing combined with introduction of new technologies for noise and vibration mitigation in a European context are necessary for the success of the future railway system.

Acoustic design targets are supposed to be defined as a responsibility of each TD for subsystems within both the infrastructure and vehicle parts. The targets should have a follow-up to enable the desired overall noise reduction of 3–10 dBA to be achieved, depending on the combination of infrastructure and rolling stock and on the particular running conditions.

The topics included in WA5.2 cover basic research and dedicated innovative solutions as well as building on a solid basis of existing technologies and methods to be improved.

In particular it is of great importance to have resources to carry out a scientifically based systematic validation of methodologies, to acknowledge and point out inherent uncertainties in the state of the art, and to allow virtual certification.

Innovative elements are included in a wide range of topics from novel capacities for auralisation and visualisation for the public of progress in the N&V areas, simulations with advanced numerical methods for virtual design as well as new materials.

Improved certification methods for TSI testing, including separating the contribution of the rolling stock from that of the infrastructure, are of great importance. They will ensure that the required noise levels are not obtained only on special low noise-testing tracks. With the development of separation techniques, the actual noise levels from new rolling stock that the population is exposed to on normal operational tracks can be calculated and communicated, e.g. in an auralisation and visualisation studio, to citizens.

The long-term goal, to be emphasised in a S2R2 project, is to move the technology and the simulations a step further to replacing costly on-track testing with fully virtual approval for certification as well as customer acceptance of both noise and vibration.

Interaction with other TDs

The basic idea for handling noise and vibration control in S2R is that the development of low-noise solutions is embedded into each TD, not as a separate project. This is a preferred approach in order to ensure new-low noise technologies are compatible with all other constraints of a system. The overall effect of the improvement on system level is, however, evaluated and analysed in CCA Work Area 5.2. Hence close cooperation with the TDs controlling the main sources is of great importance for WA5.2. In the figure below, connections for the major sources included in S2R are depicted.

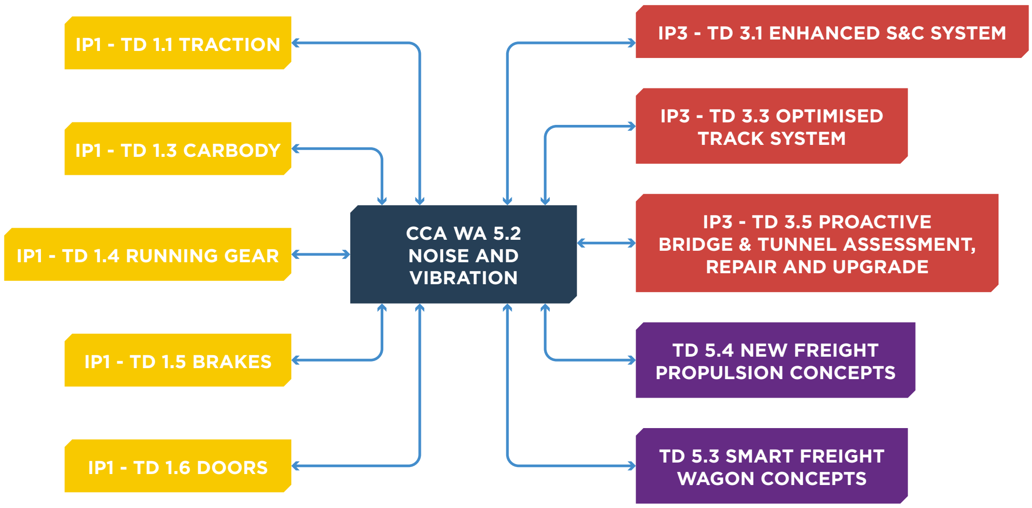


Figure 55 / ***Interaction with other parts of S2R***

6.5.2.4. Impact and enabling innovation capabilities

The most important impact is to show the effect of S2R development on reducing noise and vibration levels for real traffic scenarios that the public is exposed to. The table below shows the impact of WA5.2 on overall objectives.

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	• Obtain more cost-efficient N&V mitigation methods thanks to proper ranking and system-level analysis • Increase passenger comfort and attractiveness of railways with improved interior noise and vibration
Compliance with EU objectives	• Avoid limiting capacity owing to restrictions on noise • Develop simulation methods for virtual design and testing
Degree of maturity of the envisaged solutions	Bring the models and tools to TRL 5

This WA will contribute to enabling four innovation capabilities as follows.

INNOVATION CAPABILITY	WA 5.2 NOISE AND VIBRATION
6 – Service operation timed to the second	Enhancing capacity – avoid limiting capacity due to restrictions on noise
7 – Low-cost railway	• Lower investment costs – more cost-efficient N&V mitigation methods with proper ranking and system-level analysis. Reduce the most important source at minimum cost • Reduced operating cost – N&V-related track access charges can be reduced
11 – Environmental and social sustainability	Increased passenger comfort and attractiveness with improved interior and exterior noise and vibration
12 – Rapid and reliable R&D delivery	improved authorisation methods including source separation and moving towards virtual certification for the future

Planned achievements

Analyse, report and advice on the progress of reduction of noise in S2R on the system level, i.e. including both rolling stock and infrastructure and considering cost-effectiveness.

Develop improved tools and methods for simulation of railway N&V in order to reduce uncertainties in ranking of sources in the design phase.

Develop scientifically based methods to improve TSI noise authorisation methods, aiming in the long term for fully virtual certification for new rolling stock in Europe.

Promote new technologies to be studied for applications to reduce N&V.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Noise and Vibration		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WA5.2	5.2.1 Technical assessment and integration on system level	-																◆												
	5.2.2 Evaluation and monitoring of impact on traffic noise	-																												
	5.2.3 Exterior noise simulation model and separation																													
	5.2.4 Interior noise simulation model																	◆												
	5.2.5 Ground Borne Vibration Prediction Methods																													
	5.2.6 Sources and sub-assemblies characterisation methods																	◆												
	5.2.7 New methodologies and technologies	-											○			◆														

- ◆ milestone
- ○ quick win
- lighthouse projects
- contracted activities
- future activities

*Table 116 / **WA5.2 milestone***

WHEN	WHAT
Q4 2019	Targets for noise levels from all relevant S2R TDs are set and agreed.
Q4 2019	Baseline performance including all noise systems in S2R calculated
Q4 2022	Final assessment of the progress on noise and vibration in S2R performed
Q4 2022	Exterior noise source separation methods presented.

The estimated total budget for WA5.2 is around EUR 8.0 million.

6.6. WA6 Human capital

6.6.1. Concept

Two major developments will have an impact on the workforce (human capital) in the future railway system:

- demographic change in the workforce,
- massive introduction of technical innovations (e.g. digitisation and automation).

The overall objective of this work area is to study the effects of these developments on human resources and manage the changes on the human capital side (e.g. changes in job profiles, skills and organisation) of the sociotechnical railway system. Emphasis will be given to the effects of demography and technical developments on the workforce. However, the effects on the railway customer will also be considered.

6.6.2. Technical objectives

WA6 has the following objectives.

1. Study the impact of demographic change and the massive introduction of technology on human capital in the rail sector.
2. Develop a concept for the management of changes on the human capital side (e.g. changes in job profiles, skills and organisation).
3. Recommendations for human-centred design.

6.6.3. Technical vision

The technical vision of human capital for the rail sector is to support the availability of an adequate number (quantity) of staff in the railway system who are adequately trained (quality) to make the most of the new opportunities provided by the S2R technical innovations.

Interaction with other TDs

The implementation of human capital requires a close cooperation with all S2R TDs, especially those that contribute to digitisation of the rail system, such as ATO, Smart Planning or TMS.

6.6.4. Impact and enabling innovation capabilities

Human capital addresses the following S2R objectives of the Master Plan as shown in Table 117.

Table 117 / ***WA6 links to Master Plan objectives***

STRATEGIC ASPECT	KEY CONTRIBUTION FROM THE WA
Support the competitiveness of the EU industry	Innovative technologies such as digitisation and automation will influence future job profiles and skills, which will give the opportunity to make a step-change in the job market by providing training and opportunities to move to more attractive job profiles and to train experts with specific skills
Compliance with EU objectives	It will support the lifelong learning principle by providing training and means to adapt to the skills needed for future jobs
Degree of maturity of the envisaged solutions	The work area analyses the impact of the new technologies on aspects of human capital, and develops preliminary ideas for the changing job profiles

Furthermore, human capital will contribute to enabling 12 innovation capabilities as follows.

INNOVATION CAPABILITY	HUMAN CAPITAL
1 – Automated train operation	Customer-oriented design of mobility services will lead the railways to provide excellent service within the overall mobility chain and increase the attractiveness of the system
2 – Mobility as a service	Customer-oriented design of mobility services will lead the railways to provide excellent service within the overall mobility chain and increase the attractiveness of the system

INNOVATION CAPABILITY	HUMAN CAPITAL
3 – Logistics on demand	Planning and scheduling are synchronised in real time to customer demand. This will change the task of the planner considerably and technical innovations will allow for new freight rail opportunities
4 – More value from data	This allows the customer and the rail system to communicate intelligently with each other and increase the attractiveness of the railway system for customers
5 – Optimum energy use	The design of user-centred decision-support and assistance tools helps train drivers to choose the most energy-efficient way of driving
6 – Service operation timed to the second	Increased punctuality due to a sufficient number of adequately trained personnel
7 – Low-cost railway	Consideration of human capital early in the design process allows reduced time and cost of product deliveries and fewer subsequent (costly) modifications
8 – Guaranteed asset health and availability	Sufficient and adequately trained staff will be able to deal adequately with the new technology behind the assets (machine learning, artificial intelligence, big data).
9 – Intelligent trains	Sufficient and adequately trained staff will be able to deal adequately with the new technology behind intelligent trains (automation).
10 – Stations and smart city mobility	Human capital ensures that the needs of the customer are taken into account in the design of stations and smart city mobility
11 – Environmental and social sustainability	The aim of customer-oriented design is to increase the attractiveness of the rail system and shift the modal split towards the railways
12 – Rapid and reliable R&D delivery	The consideration of human capital early in the design and development process of new technology increases user acceptance and adoption of innovations and can speed up market introduction of innovations

6.6.5. Demonstration activities and deployment

The result of this work area will be a concept for the management of these changes on the human capital side (e.g. changes in job profiles, skills and organisation) of the sociotechnical railway system, imposed by the massive introduction of technical innovations. Furthermore, WA6 will result in recommendations for system design that place the human rather than technology at the centre of the design process (human-centred design, design thinking). An optimal match between human needs and system design will culminate in safer, healthier and more attractive workplaces for the whole workforce (i.e. white- and blue-collar workers).

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA6	**Human Capital**		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	6.0.1 Job Profiles	-												◇			◆													
	6.0.2 Qualifications and skills	-												◇			◆													
	6.0.3 Flexibility and agile organisations	-															◆													
	6.0.4 Customer-oriented design of mobility	-																												

◆ milestone
quick win
lighthouse projects
contracted activities
future activities

*Table 118 / **WA6 milestones***

WHEN	WHAT
Q4 2019	Defined job profiles
Q4 2019	Final skills and qualifications
Q4 2019	Concept for agile organisations

The estimated total budget for WA6 is around EUR 520 000.

7. IPX - Rail system architecture and exploratory research for disruptive innovation

Since the start of its activities, the S2R Programme has highlighted in various manners the need to assess projects' and solutions' interdependencies and the capacity to become more agile to adapt to market changes. These are driven by new technologies, infrastructure managers' evolving cost-driven needs and, to a certain extent, final users' (passengers and freight) needs and expectations as reflected in the programme by some operators.

These initial needs were channelled in the establishment of a Governing Board group, the System Integration Working Group. Nevertheless, priority was given to launching the S2R R&I activities and addressing the programme-related issues, that are common in complex intertwined activities.

During 2017, the S2R Programme Office brought forward the concept of a system-of-systems approach, implemented also in other sectors, to ensure that the needs of the different actors in the value chain were duly taken into consideration in a functional approach to the new systems and solutions.

In this respect, more concrete reflections on new whole-system approaches started on the control and command and signalling side, following the work initiated in 2018 by some IMs with an RCA and recently by some RUs with an OCORA. This also continues work started almost a decade before on the euLynX activities. During 2019, the S2R Programme agreed to launch more structured activities related to the development of a CDM that will contribute to overcoming data and systems fragmentation with a view to producing a system-of-systems approach. The developed approach is expected to become the standardised way for existing and new systems to interact, ensuring their interoperability through digital continuity.

A series of activities under IPx would support the achievement of such a system-of-systems approach, and with these S2R is looking beyond currently planned technology applications (of the TDs described in Section 2) and integrating them with disruptive innovations. In this context, arising and promising disruptive technologies are investigated (e.g. AI, robotics), as they would enable new concepts for the future train-centric autonomous railway vehicles, for automation systems and maintenance, for MaaS, for industry 4.0 (automated industry and industry as a service), for railway clouds and for decentralised ownership, which will also contribute to shaping the new railway architecture.

The work was kick-started in 2019 to create a first version of an integrated railway functional system architecture and introduce a structured approach to the functional evolution of rail systems. The objective is to provide the sector with a shared path and vision of the future operations of rail systems, under the policy leadership of the European Commission and in strict coordination and collaboration with the European Union Agency for Railways. The project will build on the progress achieved within different stakeholder groupings and standardisation activities, starting with the integration of RCA and OCORA into S2R and looking at euLynX, railML, RailTopoModel (RTM), Industry Foundation Classes (IFC) Rail and considering new initiatives (e.g. SensorML, TransducerML, MaaS API, etc.). The work is divided into two streams:

- CDM, defining a common railways dictionary, defining description methods and tooling;
- system architecture, developed according to the system-of-systems approach and integrating, within S2R, the members and actors currently not directly involved in the JU, under a common vision of the future.

In order to create a reference architecture for railways and ensure its wide adoption, IPx will work in conjunction with all IPs and CCAs and liaise with the S2R Programme Board to streamline change management within the running projects.

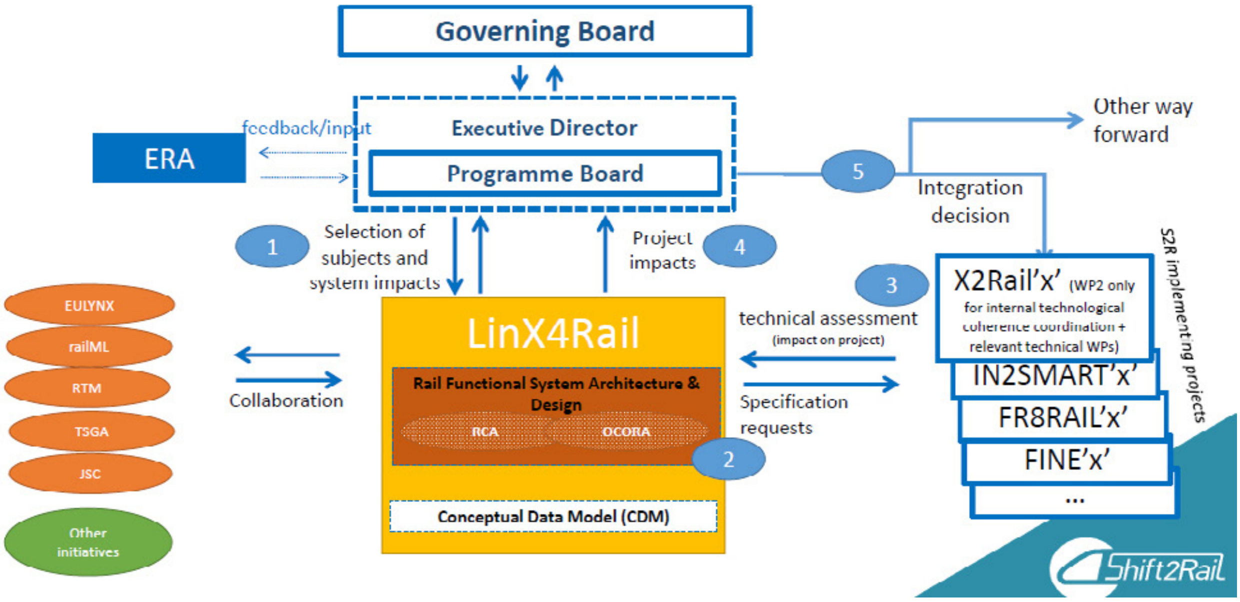


Figure 56 / ***Executive Director and Programme Board (ED PB) - change management process***

This work can become the basis for much more programme and rail sector integration, starting with achieving a European sectoral agreement on the way the system will be operated in the future, notably with the use of the ERTMS game changers. This would prepare the ground for multimodal collaboration, especially in areas dealing with similar aspects such as air traffic management and smart mobility. It will also provide a new set of business cases and potentially new services that implement a new system of system architecture and a new approach to sharing data, which will provide benefits and performance in S2R that would potentially override any concern about migration costs. The work would also consider initial integration at the European level, collaborating with ERA, for example with the ERA registers (e.g. European Register of Authorised Types of Railway Vehicles), and national vehicle and infrastructure registers, but also with the sectoral General Contract of Use for wagons and with government-to-business services.

As innovation does not necessarily stem from technical advances, the actions should also take a closer look at business innovation based on (access to and exchange of) CDM-enabled data and the system-of-systems approach to modularisation. The newly established markets will need to be analysed, taking into account the whole value chain, assessing the costs and benefits for different stakeholders and evaluating the new business opportunities.

In addition, with the first introduction of 5G mobile networks in commercial offerings, it will be important for the rail sector to get a better understanding of potential implications for the life-cycle cost of the infrastructure, especially in the context of reusing the existing (commercial) network and spectrum, and the implications for performance, security and safety. Besides supporting the main rail operations, 5G, combined with other radio access technologies, will enable new use cases, for example interaction with the general infrastructure and other vehicles, cooperative intelligent transport systems or machine-to-machine communication, that would need to be assessed.

While the LinX4Rail project remains at the core of IPx, S2R will continue exploring and evaluating new and disruptive technologies that might influence how the rail sector operates, changing business models, affecting the deployment of TDs and contributing to the main S2R objectives. For example, the work would look into further applications of AI (e.g. for image detection in autonomous train operations) and big data tools on railways; explore the new approaches to deployment of IT services, such as serverless computing, and the use of application frameworks; explore new IoT technologies, platforms and standards; and pave the way for applying these to the sector.

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