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Multi-Annual Action Plan

Part B - Technical Content

Draft for adoption by the S2R Governing Board

Brussels, 14 November 2019

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Glossary

Abbreviation	
AC	Alternating Current
ATO	Automatic Train Operation
B2B	Business to Business
BIM	Bridge Information Models
CBTC	Communications Based Train Control (Urban rail)
CCS	Control Command and Signalling
CDM	Conceptual Data Model or Canonical Data Model
CER	Community of European Railway and Infrastructure Companies
CFRP	Carbon fibre reinforced plastic
DERMS	Distributed Energy Resource Management System
DG MOVE	Directorate General for Mobility and Transport
DG R&I	Directorate General for Research & Innovation
DRIMS	Dynamic Railway Information Management System
EC	European Commission
EIM	European Rail Infrastructure Managers
EMC	Electromagnetic Compatibility
EMS	Energy Management System
EMV	EuroCard Mastercard Visa
EN	European Norm
ERA	European Railway Agency
ERP	Enterprise Risk Planning
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ETCS	European Train Controlling System
EU	European Union
FMEA	Failure Modes And Effects Analysis
FMECA	Failure Mode Effects And Criticality Analysis
FP6, FP7	EU Sixth and Seventh Framework Programmes for Research
FRP	Fibre reinforced polymer
GNSS	Global Navigation Satellite System
GSM-R	Global System for Mobile Communications – Railway
H2020	Horizon 2020, EU framework programme for Research and Innovation
HVAC	Heating, Ventilation, Air Conditioning

HSL	High Speed Lines
HST	High Speed Trains
HW and SW	Hardware and Software
IA	Integrated Assessment
IAM	Intelligent Asset Management
IATA	The Air Transport Association
ICT	Information and Communications Technology
IM	Infrastructure Manager
IP	Innovation Programme
IPR	Intellectual Property Rights
ISA	Independent Safety Assessor
ISMES	Intelligent System Maintenance Engineering and Strategies
ISO	International Standardisation Organisation
IT	Information Technology
ITD	Integrated Technology Demonstrator
JTI	Joint Technology Initiative
JU	Joint Undertaking
KPIs	Key Performance Indicators
LCC	Life Cycle Cost
LTE	Long-Term Evolution (standard for wireless communication)
MoU	Memorandum of Understanding
MS	Member State
MTBF	Mean Time Between Failures
NFC	Near Field Communication
OCORA	Open CCS On-board Reference Architecture
PI	Performance Indicator at local Traction TD or Traction component level
RCA	Reference Command Control Signalling Architecture
R&I	Research and Innovation
RAM4S	Reliability Availability Maintainability, Safety, Security, Sustainability, Supportability
RAMS	Reliability and Maintainability System
RCF	Rolling Contact Fatigue
RCM	Reliability Centred Maintenance
RCMS	Rail Corrugation Measuring Systems
RDERMS	Railway dedicated Distributed Energy Resource Management System
RFID	Radio Frequency Identification
RIMMS	Railway Integrated Measuring and Monitoring System

RS	Rolling Stock
RU	Railway Undertaking
S&C	Switches & Crossings
S2R	SHIFT2RAIL
SiC	Silicon carbide
SIL	Safety Integrity Level (according to IEC 61508 standard)
SME	Small and Medium Enterprise
SPD	System Platform Demonstration
STM	Specific Transmission Module
TAF	Telematic Application for Freight
TAP	Telematic Application for Passengers
TCMS	Train Control and Monitoring System
TD	Technology Demonstrator
TEN-T	Trans-European transport network
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
UIC	International Union of Railways
UITP	International Association of Public Transport
UNIFE	Association of the European Rail Manufacturing Industry
UNISIG	Union Industry of Signalling, UNIFE sub-group
WMMS	Wayside Measuring & Monitoring Systems
WP	Work Package

About the MAAP

The S2R Multi-Annual Action Plan, hereinafter MAAP, consists of three parts:

- Part A – Executive View, adopted by the S2R JU Governing Board on 27 October 2017 by Decision N°7/2017;
- Part B – Technical Content, the present document;
- Part C – MAAP initially adopted by the S2R JU Governing Board on 27 November 2015 by Decision N°15/2015, which remains a reference document with regard to the provisions of assets in the specific context of demonstration activities. (Part A) provides an executive view of the

The MAAP Part A clarifies the S2R vision and its contribution to delivering European Union societal goals. It identifies the associated set of twelve new capabilities (Innovation Capabilities) S2R will help the railway 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 planned in the MAAP – Part B, 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, It explains how the MAAP and its detailed activities (as set out in the present 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 to the railway industry and to 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, the MAAP Part B – Technical Content, focuses on the re-prioritised R&I activities included initially in the 2015 MAAP and ensures adequate alignment with the MAAP part A. The MAAP Part B is based on the legal commitments undertaken by the Members other than the European Union (hereinafter the Members or Industry Members or Other Members) of the S2R JU in their respective revised Membership Agreements signed with the S2R JU, following the adoption of GB Decision N°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, the MAAP Part B introduces a demonstration plan by Technological Demonstrators and incorporates new ideas/solutions/technologies, which became relevant for the S2R Programme since the last edition of the MAAP. The MAAP Part B summarizes the major demonstrations and technology developments resulting from the research and innovation work. For each Technical Demonstrator (TD)/Working Area (WA), a link with the Innovation Capabilities of the MAAP Part A has been made. The demonstration activities for each specific technological objective are presented with a focus on the activity to be carried out and with the Technology Readiness Level (TRL) and the market application expected for the demonstrators

These demonstrations will enable a more appropriate quantification of the impact of each new technology, either alone or in combination with other innovations by promoting the realization on integrated technology demonstrators (ITDs). ITDs will combine the testing of different solutions in a single demonstrator, which will allow for a more collaborative system approach towards innovation, breaking down possible silos between sub-systems, and enabling the identification at an early stage of compatibility issues in the integration of different solutions.

Finally, the 2015 MAAP will remain as MAAP Part C as it contains references with regard to the provision of assets in the specific context of demonstration activities

This MAAP does not have the objective to set up the research and innovation activities to be undertaken or continued in the next Union's programming period, but *inter alia* to bridge the current S2R Programme towards research and innovation as from 2021.

Section 1 – Overview on the Programme scope and structure

1. Summary of Major Demonstrations and Technology Developments

Demonstration activities are a priority within Shift2Rail, as they shall provide evidence of the impact on passenger mobility and freight transport of the technological and/or operational innovative solutions resulting from the research and innovation work performed within the Shift2Rail Programme. They are complemented by relevant business cases developed within the CCA activities.

These are concrete actions in order to deliver upon the EU policies and market needs, under a coordinated framework of EU funded activities where each project leverage from each other enahnacing not only the R&I quality but also the overall European knowledge.

They will enable the entire rail sector to visualise and concretely test the transformations that they are able to create. Demonstrations will also enable a more appropriate quantification of the impact of each new technology (either alone or in combination with other innovations). Demonstration activities will also help at providing a first estimate of the potential for improvement in the sector at the levels of regional, national and EU transport network, which can be expected as a result of the relevant innovations.

The realisation of those key demonstrations will contribute through several "building blocks" to reaching those rail new capabilities, as described in the MAAP Part A and futher depicted in the Section 2 below for each of the Technology Demonstrators and Work Areas.

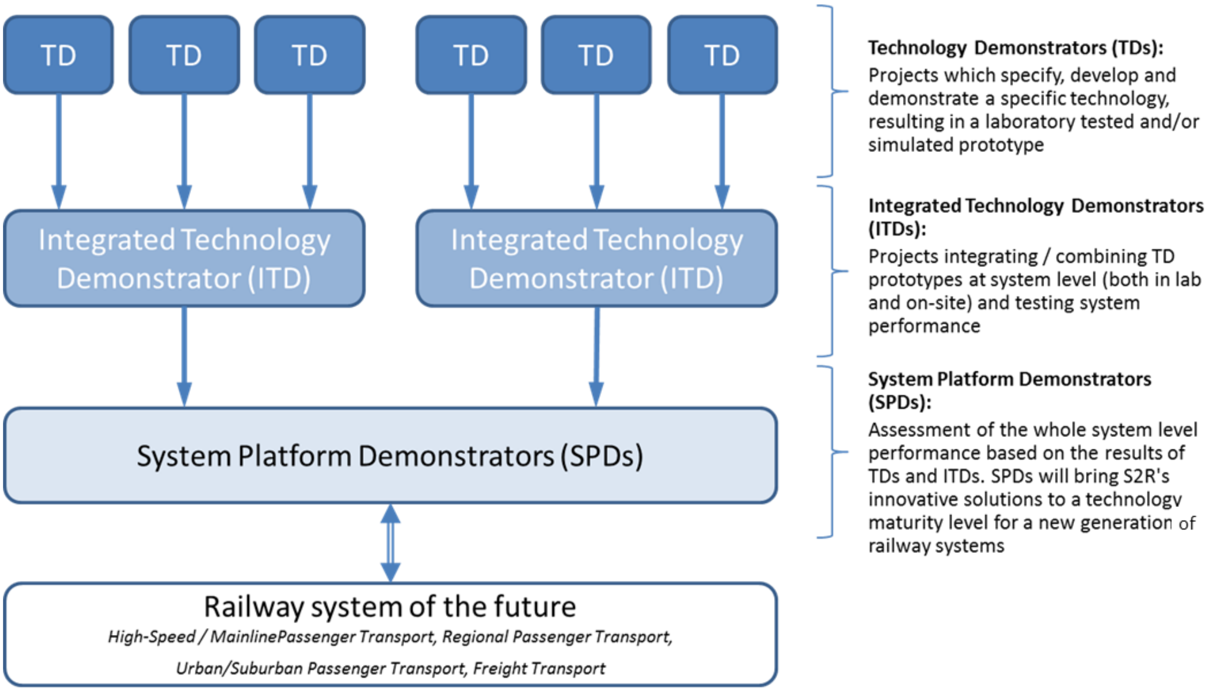
It will also enhance the perceived innovation potential of the sector and revitalise the industry by attracting the next generation of top graduates from universities across Europe.

Shift2Rail is fostering synergies across sectors and iniatives, learning fom other sectors and exporting knowledge and technology to the overall EU mobility and transport. The S2R Programme will scout progress and developments in different fields and consider how such eveolutions will be embedded in rail systems, as relevant. It will include synergies with other national and European funded research and innovation, start up and international programmes.

Shift2Rail will also promote the realisation on integrated technology demonstrators (ITDs), which will combine the testing of different solutions in a single demonstrator, resulting therefore in economies of scales for the project development. This will allow a more collaborative system approach toward innovation, breaking possible silo between sub-systems developers. It will also help identifying at an early stage possible issued of compatibility in the integration of different solutions.

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

Figure 1: Structure of Demonstrators within Shift2Rail



Technology Demonstrators (TDs)

Technology Demonstrators will focus on the development or adoption of innovative technologies and models *within* the rail sub-systems identified in the Innovation Programmes. They will enable ground-breaking progress in key areas such as traction, automatic 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 and/or hardware systems.

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

Integrated Technology Demonstrators (ITDs)

The ITDs will allow for the testing of combinations of components and sub-systems already verified and validated within the Technology Demonstrators within virtual or physical railway environments for demonstrating the innovation potential of the components in different sub-systems and systems, taking into account functional and operational specifications and the technical interfaces among the various TD.

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

System Platform Demonstrations (SPDs)

Ultimately, Shift2Rail will carry out proof and analysis of rail systems, design and functions on fully representative innovative railway configurations in an integrated environment, simulating real operational conditions.

1.1. The System Platform Demonstration scenarios

The System Platform Demonstrations will be created among the main rail market segments to simulate and test the interaction and impact of the various innovative systems resulting from the Shift2Rail 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) which are critical for the sector: safety, security, energy, digitalisation, etc.

The design of demonstration platforms will take into account the specificities of each market segment, its particular challenges and needs as well as the promising market opportunities. Based on this initial assessment, the SPDs will demonstrate how the correct aggregation of different innovations can greatly contribute to improve the performance of the sector. This will be based on an analysis of detailed 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 the same TD are relevant for more than one of the different railway transportation segments. Results of one TD may therefore be demonstrated in more than one SPD if considered that these results correspond to the business needs of several rail market segments.

The exact definition of each SPD is part of the work to be done in the S2R System Integration working group of the JU taking into account the input from the broad stakeholder community (S2R user Requirements and Implementation working groups) as well as, where relevant / available the first results of the S2R lighthouse projects, funded under the H2020 first call. This is also expected to be the subject of activities carried out as a result of the 2015 S2R call for projects.

Overview of the key challenges for each of the SPDs defined in the S2R Master Plan:

High-speed passenger rail

High speed has been a very successful and innovative rail market segment for several decades, and is often the preferred choice for long distance national and international travel. The technical and technological challenges related to high-speed and mainline rail are not just related to developing new types of rolling stock that provide comfortable transportation 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, as well as shared track and corridor operations.

Regional passenger rail

Regional rail is already serving as a backbone of the European transport system, expanding massively in past years. However, this segment remains affected by competition with the private car and by the life cycle cost of operation compared to bus services. The core challenge for this market segment is mainly to offer increased capacity to ever-increasing number 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 share or not the infrastructure with mainline traffic. What is mostly at stake is making these services more attractive to customers, through increased reliability, frequency and speed and cutting costs, as well as an improved coordination with other public transport services and a better integration in regional mobility strategies.

Solutions with overall low life cycle costs are also needed for regional network having 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 private car in more and more congested and polluted areas. These market segments are also experiencing growth, which will be important to manage through innovative solutions. They are also one for which existing rail infrastructure is not used according to its potential for supporting more sustainable land use and transport policies. Cost effectiveness and increased attractiveness are also important challenges, requiring higher scales of proven, affordable technology and 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 are all making 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 increases productivity, reduces cost, optimises network capacity, and enables better quality of services through optimised logistic services and rail technology and that realise the full potential of digitalisation, appropriately meeting the customers' requirements.

1.2. Integrated railway System Architecture and Conceptual Data Model

S2R innovations shall challenge or provide opportunities for an overall system optimisation.

The railway sector needs to develop an encompassing new Railway Functional System Architecture, integrating the different railway subsystems – not only CCS but starting from it – with a modular approach, 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 not only to be modular but also scalable in time, with new technologies/features added in an agile manner. Technologies foreseeable by 2022, with the compatible introduction of new TSI and beyond, begin with the integration of S2R interoperable solutions as Intelligent Mobility Management (enlarged TMS), wireless Train Control and Monitoring System, 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 produce a “system of systems” approach.

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

This activity will contribute to achieve a major railway system transformation avoiding to define a single target system, that would possibly creating a new legacy, but offering the opportunity to modular evolution driven by ambitious end-users needs and R&I targets. R&I on a new integrated railway system architecture could contribute redefine the way railway operate and is managed, providing to this transport mode the new capabilities, as described in the MAAP Part A.

In this respect, during the ERA CCRCC2019 event, the European Commission presented its vision towards

- One European CCS system
- An adaptable CCS system
- Harmonisation of operations
- Optimised traffic management

where the S2R JU shall

- *in the short term,* provide a focus for coordination and programme management of wider CCS outputs through IPx,

- *in the long term*, bringing together the manufacting industry, railways operators and infrastructure managers, provide, in particular, trackside modular architecture: specification development, prototyping, and demonstrations in view of railway functional system architecture.

In this respect, the S2R JU shall work undert the oversight of the European Commission together with ERA, in its role of ERTMS system authority, 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 requires active intervention. It does not happen by itself. Deployment of this complex array of innovation involves a coordinated effort to guarantee an adequate level of consistency and achieve the Single European Railway Area. This active role demands the capacity to recognise the steps required in the process, the funding needs, and the essential system of systems interaction and complexity of railway in all its segments and its components. This role should be as close as possible to the market, while providing the necessary independence under a joint governance.

Joint and coordinated deployment is predicated on a sound appreciation of the business case for change, both at 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 deployment will also rely on interfaces with a range of organisations beyond the railway, a collaboration strategy at the European level is also required.

The economic benefits of delivering the S2R Programme targets have been identified by the impact assessment of the S2R JU proposal:

- *An 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;*
- *Creation of additional GDP at EU level worth up to EUR 49 billion in the period 2015-2030, and spread among a large number of Member States;*
- *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 worth around EUR 1 billion in the first 10 years and then, through continued implementation, worth around EUR 150 million per year.*

The need for coordinated Deployment will build upon the initiatives of the European Commission in this respect, such as the European Deployment Plan for ERTMS, as well as experience from other modes of transport – e.g. air traffic management – or sectors.

Section 2 - Detailed Technical Content

1. IP1 – Cost Efficient and Reliable Trains

Context and motivation

The ambitious objectives set out in the Shift2Rail 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, such as:

- The long life cycle of railway vehicles, which can last for more than 30 years tends to slow down the introduction of new developments;
- Due 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 apply economies of scale and to obtain an adequate return on the investment on new innovative developments;
- The complexity of the whole railway system and the fragmentation of responsibilities makes preferable “service proven” solutions rather than new innovative ones;
- High initial investment costs and long-term spending on maintenance lead to conservative approaches in the railway sector.

Commercial pressure and political long-term vision have pushed the evolution of rolling stock in the last few years, but the aforementioned limitations have prevented industrial innovation to achieve its full potential, and have also often made it difficult for technically sound research developments to make their way to the real applications. In practice, innovation has most often been incremental, and so have been the benefits achieved by its implementation.

A sector-wide collaboration initiative like Shift2Rail offers the right environment to overcome this situation by:

1. Incorporating the standardisation perspective from the beginning of the activities, involving all stakeholders from the specifications phase, in order to ease the penetration of new technologies;
2. Incorporating cutting-edge technologies already in use in other sectors into railway vehicles;
3. Identifying incipient technological opportunities that could bring considerable benefits if they are used in trains;
4. Bringing new technologies to high TRL through longer lasting actions

With this view in mind, the IP1 of Shift2Rail is committed to develop the technologies for the next generation of railway vehicles that fulfil the expectations set at the Shift2Rail Master Plan.

Objectives of the IP and expected results

Taking the high-level objectives set out in the Shift2Rail Master Plan as a starting point, and considering the role that rolling stock plays within the whole railway system, the high-level objectives for 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 the travel disruptions for passengers by increasing operational reliability and availability of vehicles, either through the use of fundamentally more reliable components or system/subsystem architectures.
3. Reduce life cycle cost of the vehicle fleets (reduction of initial investment, maintenance, energy consumption …) and of other subsystems of the railways interacting with the vehicle (e.g. reduction of track damage).
4. Increase energy efficiency of the vehicle through more efficient components and vehicle mass reduction.
5. Promote the modal shift thanks to more attractive and comfortable vehicles, more punctual services and cheaper tickets.

Fulfilling these objectives will guarantee that the Shift2Rail global objectives are achieved.

The high-level objectives need to be achieved through specific actions. Concretely, the following technology developments can be expected to result from the work in 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 buried magnets architecture, a step change in energy efficiency will be achieved as 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 through very simple physical architectures. The targeted full connectivity of rail vehicles will enable the awaited digital railways. A new function-centric approach together with higher standardisation levels will lead to cost efficient solutions and improved interoperability. New generation TCMS will allow current bottlenecks 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 bodyshells will be using composite or other lightweight materials. No rail vehicles are currently built from such materials, and such a 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 huge possibilities for a new design philosophy in collaboration with IP3. The main innovations in running gear lie in

the possible combinations of new architectural concepts, 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 give major capacity gains in terms of mass and volume in running gear, paving the way for a fresh revisit of 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 using sensitive edges and light curtains are part of this new development.
7. New modular concepts of train interiors will allow operators adapting the vehicle layout to the actual usage 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 units (HVAC) with natural refrigerants will be developed in order to reduce the climatic impact of artificial refrigerants.

Although the activites of this TD concerning traction power focus on the enhancement of electric driven systems, the S2R JU undertook explorative research also on alternative fuel green technologies, as not all the network is electrified. This lead to a concrete collaboration with the Joint Undertaking on Fuel Cell and Hydrogen, with train manufacturers, operating companies, infrastructure managers and fuel cells and hydrogen providers working together.

The following table 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, lighter running gear and brakes will allow for new vehicle designs with more space for passengers.
	Better control on 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 for flexible accommodation of the capacity of the line at peak times. The factors that increase operational reliability mentioned below will also increase moderately the capacity of the line.
Operational reliability increase	Fundamentally more reliable technologies and components	Key elements and systems that are known to be more prone to operational failure (TCMS, traction …) based on novel technologies which show a better fundamental reliability, combined with extensive tests done through the virtual certification platform.
	Fundamentally simplified architectures, or architectures more suited to keep operation in case of failure	Train communications and control architecture, linking the functioning of all vehicle subsystems, based on new technologies allowing much lower physical complexity leading to much higher reliability. Similar concept to be applied to brakes and others.

Objective	Result	Practical (concrete) Challenge
Railway system life cycle cost reduction	Reduction in the capital cost of the vehicle fleets	New vehicle subsystems and components with better overall performance not showing any increase in cost. Better authorisation processes relaying on virtual methods rather than on on-track tests. Reduced number of required vehicles per fleet thanks to the better reliability, shorter repair times and coupling flexibility between fleets.
	Reduction in the need of vehicles for a given capacity	Vehicles with increased availability, directly related to the deliverables shown in section "Operational reliability increase"
	Reduction in the cost of maintaining the vehicles	Intrinsically more reliable system architectures and component technologies. Simplified repair processes. Better and more standard sensoring to detect condition. Vehicles with lower axleloads, 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	As defined in the next lines
Mass reduction and energy efficiency	Reduction in the mass of the vehicle	Reduced weight of most bulky elements (Carbody, runningrunning gear, traction …) combined with new, intrinsically lighter, architectures
	Reduction in energy usage for heating	HVAC-units with natural gases will allow the introducion t ofheat pumps with reduced energy consumption
	Increase in the energy efficiency and reduction of energy losses	Increase energy efficiency in traction / braking. Reduction of thermal losses (i.e. 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, carbodyshell and doors

Past and ongoing European & national research projects

The IP1 of Shift2Rail will be supported to a great extent by many of the projects funded by the EU research programmes in the last few years. Shift2Rail 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 section devoted to each technology demonstrator, but some of the most relevant ones to the activity proposed in Shift2Rail are briefly introduced here:

The outcomes from European research projects ***MODTRAIN*** (looking for innovative modular vehicle concepts, in particular for knowledge developed on auxiliary power systems, interface to 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* Technology Demonstrator within IP1. The ***RAILENERGY*** and ***OSIRIS*** projects oriented to energy efficiency of trains offer the first building blocks to develop the major technologies (new semiconductors, motors …) that will be used to build the traction systems of the future in Shift2Rail.

In the same way, the *TCMS* Technology Demonstrator will also take into account outputs from ***MODTRAIN*** as well as ***INTEGRAIL*** (addressing railway information systems and their integration within the major railway sub-systems – important also for the *Data management Shift2Rail System Integration Activity*). 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 Technology Demonstrator.

Future composite Carbodyshell to be developed in Shift2Rail will strongly rely on the results achieved in the FP7 project ***REFRESCO***, whose aim is 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 developed 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 Technology Demonstrator*.

The ***MODBRAKE*** project, which was oriented to develop modular brake system architectures, will be an input for the development of new generation brakes in Shift2Rail.

The ***ROLL2RAIL*** IP1 "lighthouse" H2020 project, which successfully finalised in 2017, was oriented to kick-start many of the work lines of Shift2Rail and to mitigate potential risks at an early stage. The results of ***ROLL2RAIL*** have been incorporated to IP1 and constitute an essential element towards the success of the programme.

Finally, the IP1 projects, and their respective complementary actions, are covering the next steps of technological development. The outcome of the projects lays a solid basis for the IP1 activities included in the AWPs still to come.

Set-up and structure of IP1

Structure of the IP

Technologically speaking, trains are very much structured into subsystems, each of which are usually responsible for different functions in the vehicle. The realisation of these functions tends to be related to a specific type of technology that is able to provide a given performance at subsystem level. This functional division of the vehicle is presented in Figure 2 and has been used as basis for the division in Technology Demonstrators (TDs) in Shift2Rail. Thanks to this strong function/subsystem/technology relationship, specialist teams will be able to develop the specific technologies to achieve the highest performance levels.

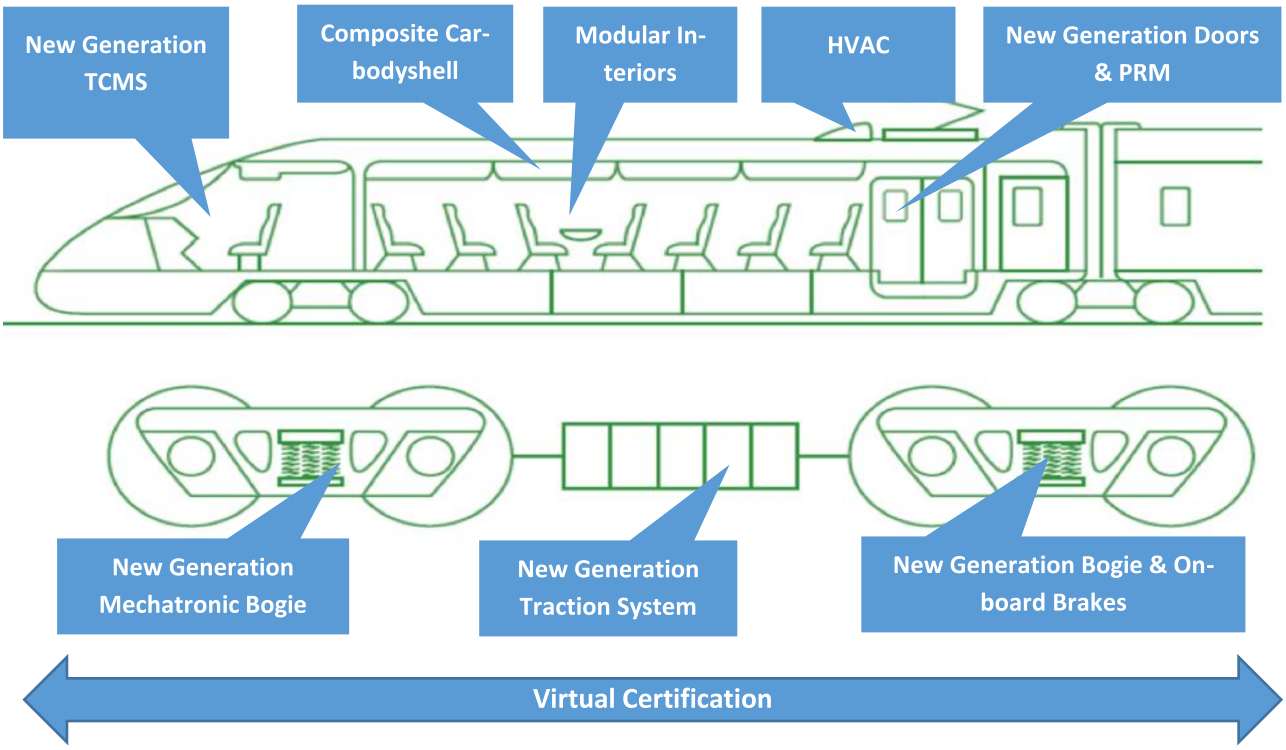


Figure ***2***: Train functional breakdown into subsystems

The choice of topics for work in IP1 has been made considering:

1. *Technological opportunities applicable to rolling stock subsystems*: Progress in 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 system and have a meaningful impact a system level.

This approach leads to *parallel developments covering the different functions* to be provided by the vehicle, *which converge at a later stage into an integrated assessment (IA)* that constitutes the final quantitative measurement of the success of Shift2Rail

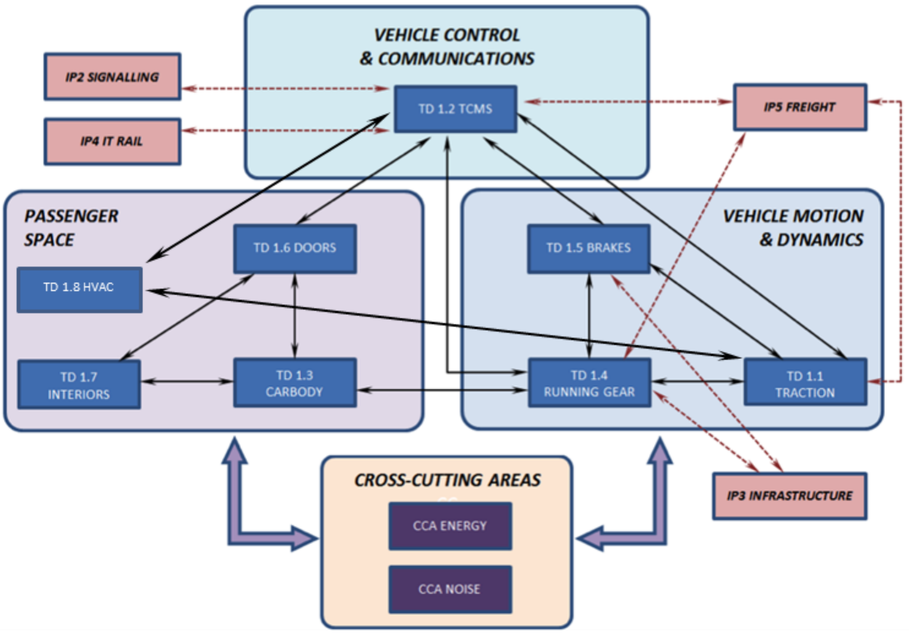
As the technologies proposed are in general function-oriented, they generally refer to a specific piece of equipment. However, in some cases, they have applicability to different TDs. A few examples of *inter-related technological developments* are:

- Drive-by-wire (TD1.2) TCMS and fail-to-safe electronic control for brakes (TD1.5) concepts rely on innovative safety critical electronics and software technologies
- Wireless TCMS (TD1.2) concepts and the standard running gear sensoring (TD1.4) rely on wire-less communications solutions
- Composite material technologies are present at carbody (TD1.3), doors (TD1.6) and running gear (TD 1.4) areas of work.
- The virtual certification simulation framework and its train virtualisation (TD1.2) mean 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 big part of the development effort is to be developed within the TDs, the development will be coordinated with other relevant activities within Shift2Rail, exploiting synergies when possible, and in all cases working together towards the achievement of the same railway system-level performance objectives

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

Figure 3: IP1 TDs and map of inter-relationships



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

1.1. TD1.1 Traction Systems demonstrator

1.1.1. Concept

The Traction Drive sub-system is one of the main sub-systems of a train as it moves the train converting energy from an electrical source (directly or via a chemical source) into a mechanical one.

In electric trains, the physical scope of such a sub-system starts from the pantograph and ends with the motorized 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.

Current electronic technology used in Traction Drives is based on Silicon material such as the IGBT power semiconductor devices used as an electronic. However, this technology has major limitations leading e.g. to high losses, too many failures, heavy and large size equipment. The new emerging SiC technology provides high-speed switching capabilities with a low on-resistance.

The Traction Drive TD carries out the necessary work in 4 major phases to bring to the market a new generation of traction drive equipment:

1. **Capture** necessary know-how in SiC technology, energy storage, wheel motors.
2. **Progress and implement** new methodologies, tools, norms & standards on reliability, noise, virtual certification, smart maintenance.
3. **Develop** new Traction component and sub-systems including using the SiC technologies. Develop new traction architectures allowed by the new technology. Develop a traction system based on independently rotating wheels.
4. **Demonstrate** key achievements on four Rolling Stock Demonstrators and finally implement physically the news equipment on a tramway, metro, a regional train and a HST.
5. **Conclude** on technical benefits.

1.1.2. Technical Objectives

The high-level objective of this Technical Demonstrator (TD) is to develop the new generation of Traction Drives using the new electronics materials becoming available. This TD will mainly bring to the railway market the SiC (Silicon Carbide) technology. The following represent the main technical objectives of this TD:

1. Increased reliability and less service disruptions.
2. Reduction of the weight and volume of large equipment and increase the space for passengers or provide more space for energy storage systems on board.
3. Reduction of noise emitted by Traction Drive Equipment
4. Reduction of energy consumption resulting also to reduction of maintenance costs
5. Development of harmonized rules for certification

1.1.3. Technical vision

Our vision is the following:

- SiC based Traction system aligned with the Urban markets;
- SiC based Traction system aligned with the Regional market;
- Traction system based on independently rotating wheel for HST;
- Breakthrough on aero-acoustic, electromagnetic and EMI noise reduction methodologies and prediction tools
- Breakthrough on High reliability design methodology, simulation and test tools for Life Cycle Estimation of Critical Power Traction Electronics Components in Real Operational Conditions, condition based maintenance, applied to Traction TD development
- Breakthrough on Validation and Virtual Certification methodologies, updated regulations, simulation tools and test bench to reduce test ring certification tests, cost and duration

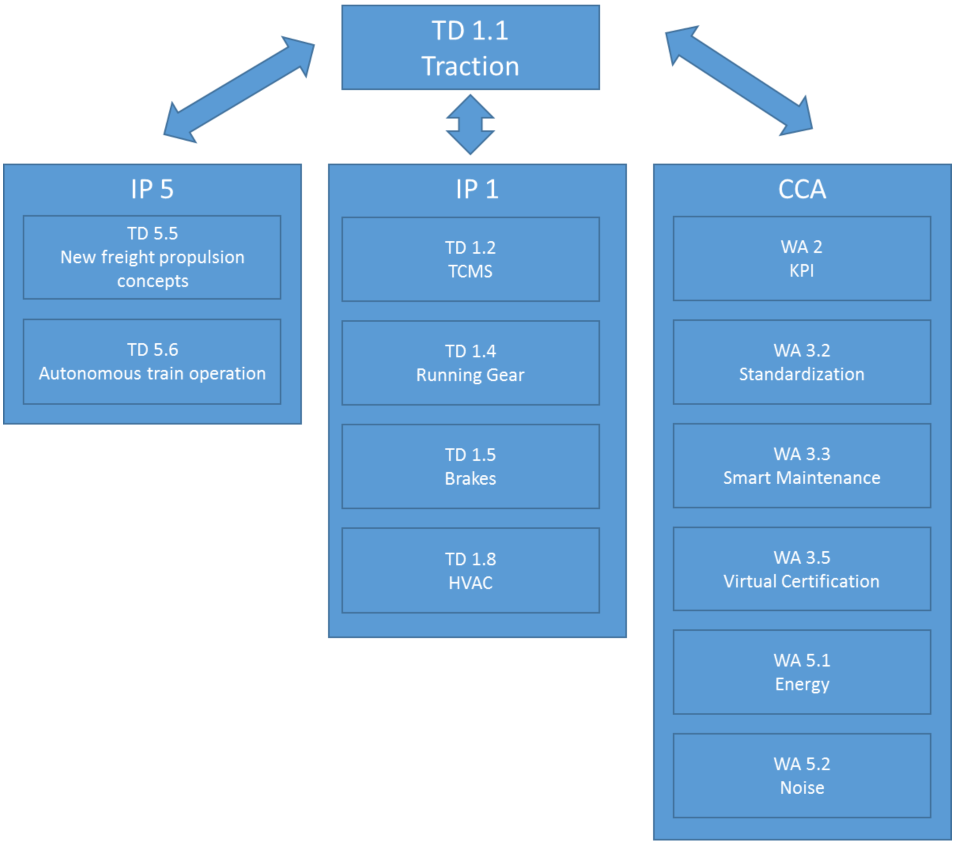
The following table presents the steps of progress targeted within the Traction TD work:

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 semi-conductor technology
Good energy efficient traction systems based on Si IGBT semiconductors	Very high energy efficient traction systems thanks to new SiC semi-conductors very low losses technology
Current traction systems based on Si technology leads to too much noise emission (electro-magnetic and cooling). Too late discovery of noise problems 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
Too low reliability and no capability to predict life time of semi-conductors 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 standard in SiC semi-conductors	European and Worldwide standardisation especially on packaging of semi-conductor chips
Complicated and non-harmonised (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 of energy consumption) and with more capacity trains by combining these two concepts

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

- IP1: Traction TD has links with
  - TD1.2 TCMS
  - TD1.4 Running gear
  - TD1.5 New braking systems
  - TD1.8 HVAC
- Of other IPs:
  - TD5.5 New freight propulsion concepts
  - TD5.6 Autonomous train operation
- Of Cross Cutting Activities: links with regular exchange on:
  - WA2 KPIs
  - WA3.2 Standardization
  - 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

<table>
<tr><th>Strategic Aspect</th><th>Key Contribution from the TD</th></tr>
<tr><td>Support the competitiveness of the EU industry</td><td>
Keep the European Traction industry in the technology race versus Japanese who have taken some advance in SiC technology and applications
Develop high added value and competitiveness of Traction industry including new design methodologies and tools (noise, reliability, virtual certification tasks), validation of Traction components or systems
Develop and promote European/ Worldwide standards on new SiC semiconductors Technology
Harmonise and simplify 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 system)
Proof tangible benefits for the end user:
Increase of operational reliability (less service disruptions) through more robust and validated Traction systems
Support Train capacity increase because of lighter and smaller Traction equipment, Traction new solution for low floor HST.
LCC reduction (through virtual certification, higher reliability, lower energy consumption and less maintenance)
Additional advanced maintenance services through high added value functionalities like traction system and components remote failure diagnostic and health monitoring

</td></tr>
<tr><td>Compliance with EU objectives</td><td>
Promotion of modal shift: A big impact brought by the implementation of these new technologies towards better train punctuality and adding new accessibility to train with “at same level” between station platforms and train floor.
Support to capacity increase: as mentioned above this is allowed by more flexible traction component implementation in the train and less service disruptions.
Greening of transport through energy consumption reduction thanks to high efficiency components like e-transformers and SiC based traction inverters
</td></tr>
<tr><td>Degree of maturity of the envisaged solutions</td><td>Currently most of the proposed technologies are at low TRL levels. At the end of Shif2Rail it is targeted that the successful concepts are brought to TRL 7 (prototype demonstration in real operational environment). In parallel to Technical developments, marketing studies, norms and regulation work will prepare a favourable environment to have economic viable new solutions for industry and operators.</td></tr>
</table>

This TD contributes to enable the following **Innovation Capabilities**:

Innovation Capability	***TD1.1 Traction***
4- More value for Data	*BB1.3 High reliability & availability traction* Traction 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* Traction TD is focused on the energy saving thanks to intrinsic Traction technologies (like SiC based semi-conductors) and weight savings.
7- Low Cost Railway	*BB1.1.1 New Power Electronics* *BB1.1.2 Independent wheel traction* *BB1.1.3 High reliability & availability traction* *BB1.1.5 Virtual certification of traction* *BB1.1.6 Standardization of key traction components* Traction TD is not specifically oriented on low cost but on high KPI performances (weight, volume, physical energy savings, low noise, high reliability & availability) at optimised LCC (minimization of Capital Cost, Maintenance cost, energy cost on a 30 years basis). Moreover Traction TD works on pre-standardisation and virtual certification leading to lower cost as soon as common approaches are agreed between stakeholders of Railways.
8- Guaranteed asset health and availability	*BB1.1.3 High reliability & availability traction* Traction TD is directly providing optimized maintenance via its smart maintenance workstream and provides therefore indirectly minimised disruption of train operation via higher reliability & availability.
9- Intelligent Trains	*BB1.1.3 High reliability & availability traction* Traction TD is preparing more communicant trains including smart maintenance and data for energy management.
11- Environmental and social sustainability	*BB1.1.4 Traction EMI & acoustic noise reduction* Traction TD works on Energy savings, lower CO2 emissions by various solutions like higher intrinsic efficiency, higher energy.
12 - Rapid and reliable R&I delivery	*BB1.1.5 Virtual certification of traction* *BB1.1.6 Standardization of key traction components* Virtual testing and efficient implementation processes speed up production and deployment of new products. Virtual certification methodologies about simulation and validation processes to reduce costs for the stakeholders. There is close cooperation within the sector for standardisation and testing.

1.1.5. Demonstration activities and deployment

Demonstration activities

<u>**Generic description of the demonstrations**</u>

The objective of the demonstration is to generate physical demonstrators, integrated in rolling-stock, suitable for performing track tests, either in commercial lines or test rings (TRL7 demonstrators).

The works are done in three steps: integration of traction equipment into four different Rolling Stock trains, assessments and a final step on demonstration conclusion.

In particular the demonstrators will focus on obtaining experimental results to obtain:

- New traction components performances and behaviour.
- New control strategies performances and behaviour.
- Traction local performance: acoustic noise level, reliability/availability (failure rates, aging, etc.), energy, etc
- Traction EMI levels.

Additionally, the real experimental results will be used to compare with the results obtained previously in virtual certification platforms (virtual certification SW, simulation tools and HIL platforms) in order to validate and assess the accuracy of such platforms.

All the prototypes will be tested on test track or commercial lines in different segment applications, as outlined in the next pages.

<u>**New SiC based traction converter for Metro application (TRL7)**</u>

The objective is to generate a physical demonstrator of a metro train integrating a SiC based traction system, suitable for performing tests on the field, either in 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 concrete metro application will be selected. In order to minimize and rationalize the vehicle costs it is intended to use the same train as ITD for the IP1 TD1 Traction and IP1 TD2 TCMS field validation tests on metro application.

<u>**New SiC based traction converter for Regional application (TRL7)**</u>

A fully functional prototype of SiC based traction converter for the Regional train will be assessed.

The contribution from major operator members is needed for this task to bring all needed support like validating the test plan and participate to conclusions and KPI final quantification.

<u>**New SiC based traction converter for tramway application (TRL 4-5)**</u>

Demonstration of traction converter prototype foreseen.

New Traction converter for HST application (TRL7)

The final demonstration and assessment of a low-floor, independently-rotating-wheel distributed traction system TRL7 prototype for a HST train will be done.

The following table summarises the foreseen demonstrators of TD 1.1:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Traction	New Technology Traction Systems	Implementation of a SiC traction inverter on a tram.	Tram	5	New Power Electronics: SiC Technology demonstration
		Full demonstration on trains	Metro Regional	6/7	New Power Electronics, High reliability & availability 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 360km/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, standardized methodology for reliability stress tests, remote diagnostics, health monitoring.
	Virtual validation demo	Virtual validation of a Power module or Traction converter	Generic	5	EMC state of the art and gap analysis, requirement and concept specification including interfaces to simulator for virtual certification and norms & regulation recommendation

Planning and budget:

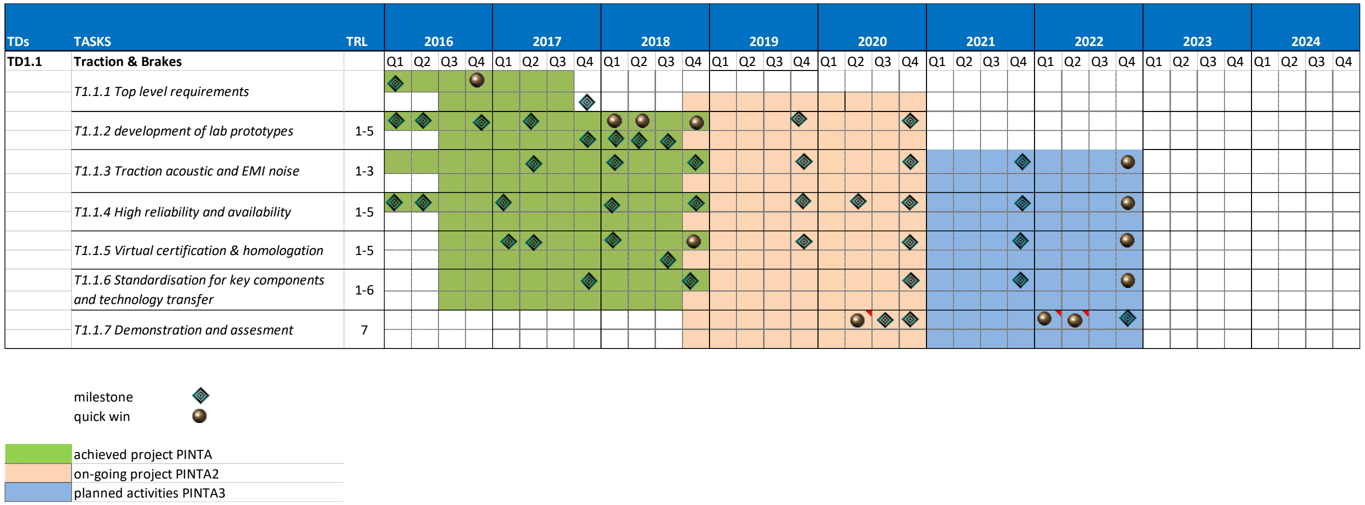


Table 2: TD1.1 quick wins

When	What	Contribution to MAAP
Q1 2018	Tramway converter based on SiC	Proof of technological feasibility
Q2 2018	Sub-Urban Lab Converter (prototype)	Proof of technological feasibility
Q4 2018	Prototype of a SiC based converter for Metro	Proof of technological feasibility : opens the way towards high TRL application in metro segment
Q4 2018	Final validation test report of Power Modules and Final motor/ wheel integration analysis and validation plan for independently rotating wheel traction system	Proof of technological feasibility : opens the way towards high TRL application in High-speed segment
Q4 2018	New methodologies for validation	
Q2-2020	TRL4-5 Demonstrator on SiC Traction Tramway	
Q1-2021	TRL7 Demonstrator on Wheel motor HST	
Q1-2021	TRL7 Demonstrator on SiC Traction for Regional	
Q2-2022	TRL7 Demonstrator on SiC Traction for Metro	

Table 3: TD1.1 milestones

When	What
Q4 2019	WP4 Requirement specification for climatic conditions, contribution to the ECPE 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 demonstration in InnoTrans 2020 S2R JU stand
Q4 2020	WP9 Final Conference

The estimated total budget for Traction TD is around 75M €.

1.2. TD1.2 Train Control and Monitoring System Demonstrator

1.2.1. Concept

The Train Control and Monitoring System (TCMS) is the brain and the communications' backbone of the train, critically affecting the vehicle performance. In fact, it:

- Integrates and manages all on-board information. Makes train control decisions considering the global state;
- Performs communication between equipment, vehicles, consists and between train and ground (except signalling related), and;
- 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 but that date back to early 1990s, with embedded limitations such as on 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, 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 achieve capacity targets, reducing the life-cycle costs of the assets while increasing performance.

The introduction of **complete interoperability** from the TCMS perspective, including the virtual coupling together with the functional open coupling concepts will mean the, 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 the consists run together, as coupled, but without any physical connection, thus consists manufactured by different companies and with different interfaces could 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 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 the Innovation Programme 2 (TD2.8 – Virtually Coupled Train Sets) the concerned TCMS infrastructure is targeted by this TD.

1.2.2. Technical Objectives

The following represent the main technical objectives of this TD:

1. Reduce the amount and weight of cabling for train control by half (Save 10 km of cable in each 20 m railcar). Reduce the space used by electronics hardware by 25%
2. Ability to implement SIL4 functions in the TCMS to perform additional safety-critical tasks.
3. Reduce the operational unavailability of the TCMS by 50%
4. Ability to couple any pair of multiple unit of different types, a feature currently totally non-existent and can significantly increase line capacity (by 5 % more trains per hour)
5. Support technologically the development of the “virtual coupling” concept, which can dramatically increase the capacity of lines
6. Reduce cost, time and effort in project engineering, integration and authorisation phases by 50%
7. Reduce maintenance and operation cost of TCMS by 50 %.

1.2.3. Technical Vision

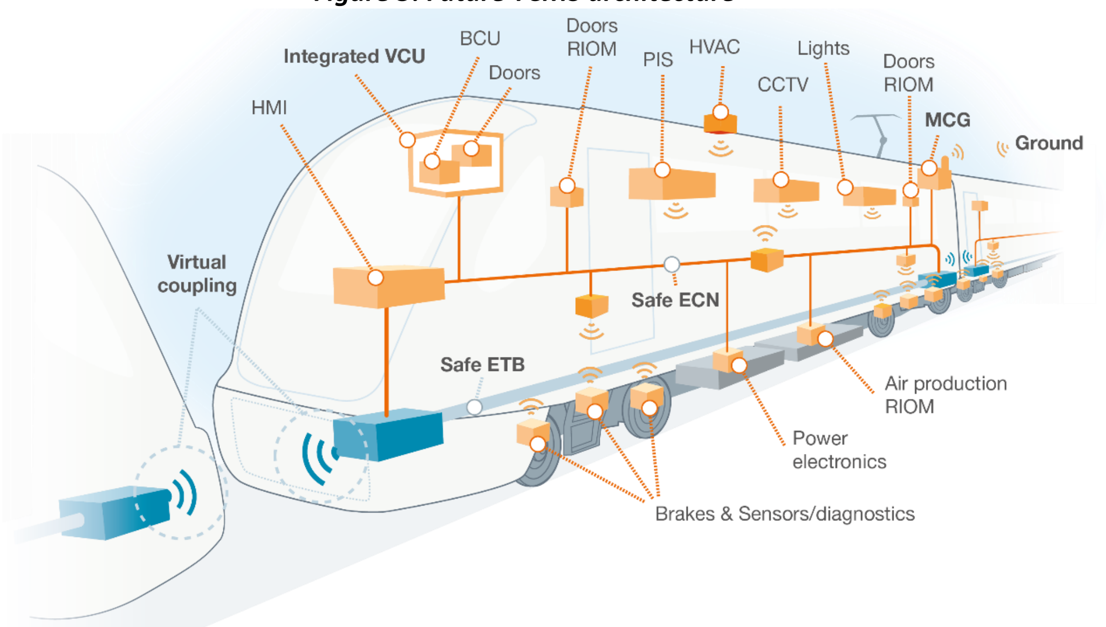
The next generation of the TCMS is based on new architectural principles around a function-centric approach, supported by new technologies and well proven concepts from other sectors, where safety, security, performance, interoperability, connectivity, cost-efficiency and dependability are the master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

Thus, the technical vision for the new generation of the TCMS proposed in Shift2Rail is based on the following:

- Dependable wireless communications intra-consist (WLCN), between consists (WLTB) and between trains (VCTS);
- Standardised and secure train-to-ground link to make vehicles full players of a digital railways 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 SIL4;
- Application (function) profiles definition and standardisation;
- Functional open coupling (FOC) as the definitive way to achieve the full functional interoperability between consists, and;
- 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 implies a lot of cabling and connectors, and is an important source of failures. Impaired data transmission through the auto-coupler.	Wireless TCMS to reduce cabling and remove the need of a physical contact in the auto-coupler, improving reliability and performance.
TCMS up to SIL2. Safe train lines still needed.	"Drive-by-date" concept: TCMS to provide SIL4 capabilities which allows the integration of safety-critical functions. Wired logics replaced by processors and/or FPGA.
Architecture based on numerous CPUs (one or more per subsystem) distributed along the train. Any software change in one of the subsystem requires a new commissioning as applications interface directly with the communication buses.	Architecture based on a functional distribution among a reduced number of CPUs, where each function interfaces the TCMS through a standardised framework; only re-commissioning towards the framework is needed then.
Long and costly on line debugging and commissioning processes. Integration tests require 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 internet and hardware-in-the–loop.
Interoperability is impaired by incompatible coupling vehicles. They not only require having identical physical interfaces, but also require having compatible TCMS application software (i.e. same on-board services, software versions and functions).	The deployment of the wireless TCMS, 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 connection (e.g. energy metering). Roll2Rail will propose a standard which will require further implementation and validation.	A standardised train-to-ground communication will assure 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



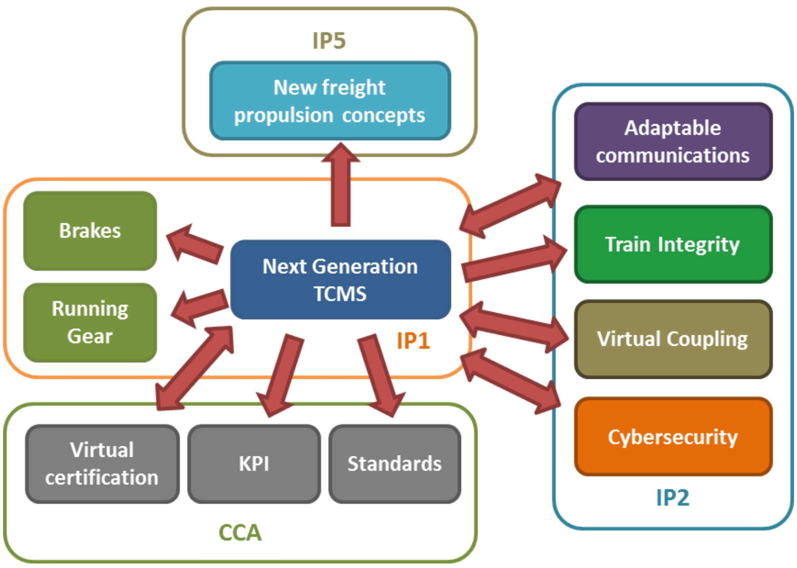
Interaction with other TDs (of the same IP and/or of the other IPs)

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:

- IP1 – TD1.4 "Running Gear": To support the data transmission for new sensor concepts and the safe management of new mechatronics.
- IP1 – TD1.5 "Brakes": Providing safety critical architectures and protocols interfacing the brake system to support the brake-by-wire concept.
- IP1 – TD1.8 "HVAC": Standardisation of data interfaces of HVAC unitsIP2 – TD2.1 "Adaptable Communications": There are clear synergies between TD1.2 and TD2.1. The communication system for signalling should be complementary to the one for TCMS, sharing most of the infrastructure, concepts and protocols. Coordination and cross-feeding of both TDs are crucial to succeed.
- IP 2 – TD 2. TD 2.2 Railway capacity increase (ATO up to GoA4): supported with description on the defined interfaces for the ATO system.
- IP2 – TD2.8 "Virtual Coupling": TD 1.2 expects to receive requirements from the "Virtual Coupling "TD, to be considered in the development of the technologies, devices and software. Wireless components realized in TD 1.2 will be then delivered, once tested, to TD2.8 for possible integration and demonstration, if required.
- IP2 – TD2.11 "Cybersecurity": Because having one unique approach in railway telecommunications seem to be a wise option. The starting point for both TD will be the findings of Roll2Rail (GA 636032).
- IP2 – TD2.5 "Train Integrity": TD1.2 plans to develop a safe train inauguration with the creation of a safe train topology database (TTDB), to be straightforwardly reused by T2.5 as the TTDB contains the required information for the train integrity in a safe (SIL4) way.
- IP5 – TD5.5 "New freight propulsion concepts": Providing support to the wireless communication along long freight trains.
- CCA: During the life of the TD values concerning KPI and proposals for standards will be delivered to CCA (WA2 & 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, being the TCMS system 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 new generated TCN standards.

Figure 6: Interaction with other TDs and IPs



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

1.2.4. Impact and enabling Innovation Capabilities

The new TCMS specific benefits have a major impact in the Shift2Rail system-level KPIs. The relative weight of the benefits provided by this work are estimated (over a total of 100%) in the table below which 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	• Technological leadership supported by a combination of radical innovation (Wireless TCMS, drive-by-data concept, distributed processing for higher reliability ….) and technical standards, setting an effective advantage for the European industry • Tangible benefits for the end user: o Increase of capacity (potentially up to 20%): Due to flexible coupling between units and also to the reduction of service disruptions causing line blockages and delays. o Increase of operational reliability (potentially up to 50%): Due 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 the reduction in the number of components. o Reduction of life-cycle costs (potentially up to 30%): Due to reduced engineering, testing and authorisation efforts, integration of multiple functions (Inc. safety-critical ones), reduced weight and improved maintenance. o Additional performance and service through TCMS covering fail-safe functions, flexible coupling of trains, train-to-train and train-to-ground communications.
Compliance with EU objectives	• Promotion of modal shift: A big impact brought 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 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 in TRL 1, 2 (Principles observed and the possibility of using them formulated). At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 6 or 7.

This TD will contribute to enable five Innovation Capabilities as follow:

Innovation Capability	***TD1.2 TCMS enablers***
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 for 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
6-Service Operation Timed to Second	*BB1.2.1 Wireless TCMS* Allows and supports advanced health monitioring systems, provides on-board infrastructure for CBM
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, less failures and lower repair times, leading to smaller fleets. Quicker and cost-effective virtual certification.
8- Guaranteed asset health and availability	*BB1.2.1 Wireless TCMS* Provides higher TCMS availability and on-board infrastructure for CBM
9- Intelligent Trains	*BB1.2.1 Wireless TCMS* Infrastructure to support train intelligence
10- Stations and Smart 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 TD 1.2 TCMS to the different ITDs of Shift2Rail are shown in the following table:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
Train Control & Monit. System (TCMS)	Wireless TCMS	Radio techn., architecture and protocols	Metro	6/7	Incorporate wireless technologies to the 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 train lines, connecting safety functions up to SIL4 (incl. signalling).
			Regional	6	
	Functional distribution architecture	Specification, architecture and interface definition	Metro	6/7	New architectural concept based on standard framework & application profiles, distributed computing to allow execution of compliant functions on end devices distributed along the vehicle meeting different safety & integrity requirements
			Regional	6	
				5	Support the 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 ITD are foreseen for the TCMS: One regional ITD involving different members in order 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, incl. wireless features (T2G and WLTB), SIL4 capability, and the new functional distribution architecture, integrating innovations from other TD (e.g. running gear monitoring & traction) in the TCMS of metro vehicle will also be done.

Two wireless communication networks will be deployed on two regional consists by different members in order to allow for additional interoperability tests when coupled together. Technical solutions to demonstrate the T2G on a regional ITD will be developed. The regional demonstrator will test the coupling of units in laboratory and Wireless T2G and Wireless Consist Network 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 other train operating company outside the JU membership if necessary.

All the principal elements required for rapid market uptake of this R&I 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, and;
- Development supported by technical standards, which will increase the confidence of future clients and facilitate the quick deployment in new projects.

The concerned standardisation groups and committees like the IEC TC9 WG43 in charge of the IEC 61375 series, ETSI, or 3GPP will be fed with the results of TD1.2, making – among others – it possible also to fulfil the mandate from ERA to finalise the standard in order to refer it from the Loc&Pas TSI.

It can be expected that between three and five years after Shift2Rail the new developments will be implemented in a high percentage of all new vehicles (estimated in the range 40%-80% of all new projects in Europe and 30%-60% of all new projects world-wide).

Planning and budget:

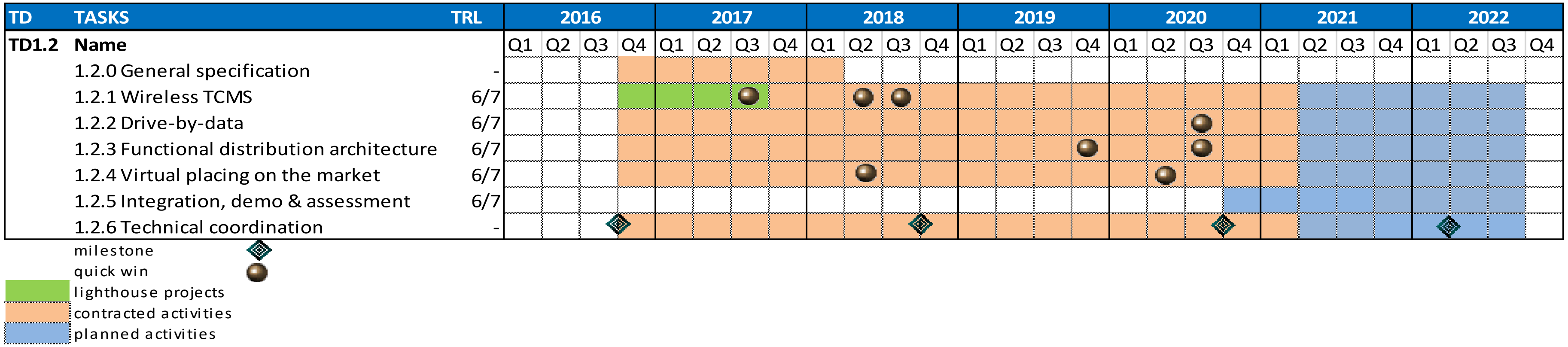


Table 4: TD1.2 quick wins

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 later tested on a real vehicle.
Q2 2018	Interoperability tests of the new train-to-ground communication based on the IEC61375-2-6.	Opens the door to implement further applications using the train-to-ground link and assures the interoperability. This quick win is key to integrate the vehicle into the digital railways world.
Q2 2018	Implementation of the ECN/ETB conformance testing	As ECN/ETB are the basement of the other technologies developed within Shift2Rail having the conformance testing ready broadens the range of potential suppliers, improves competition and reduces costs.
Q2 2018	Wireless ETB (WLTB) tested on a real vehicle	Fundamental step before prototyping equipment to be deployed in the ITDs. Final validation of technologies.
Q3 2018	Connected Trams at Innotrans 2018	Full train connectivity (T2G & T2T). First steps towards the Virtual Coupling.
Q4 2019	Functional Open Coupling proof of concept	To achieve the complete interoperability, increase line capacity and flexibility and to mean 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 is supposed to dramatically reduce the costs of commissioning.
Q3 2020	Prototype of SIL4 capable ECN/ETB	Means an important intermediate step to allow the removal of cabling, reducing weight and complexity and the integration of the new safety electronics of brakes.
Q3 2020	Prototype of a vehicle control unit implementing the functional distribution middleware	Functions of different nature and safety levels could then be integrated in the control unit to reduce the number of onboard electronics and facilitate exchangeability and recomissioning.

Table 5: TD1.2 milestones

When	What
Q3 2016	Start of Shift2Rail TD1.2 activities with the 2016 call 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 prototypes implementation phase (bottom part of the V-model).
Q3 2020	Start of the refactoring and integration in 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 ride of the V-model).

The estimated total budget for TCMS TD is around 48.8 M€.

1.3. TD1.3 Carbody Shell Demonstrator

1.3.1. Concept

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

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

Recent years have seen the progressive incorporation of non-metallic parts in the 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 metallic parts but in lower proportion than in the past.

In the Aeronautical industry there has been an increase in the use of non-metallic materials for structural components. There has also been a corresponding increase in the knowledge of composite material behaviour and the fulfilment of all issues in relation to composite materials regarding safety.

Therefore, it seems logical that such developments could be made in the rail industry, and this project specifically focusses on the primary structure of the carbody.

The main innovation of this technology demonstrator is the use of composite materials in a hybrid carbody, where the technical and commercial issues will be also investigated. The current performance of the metallic primary structures in terms of safety, durability and maintainability will also be achieved with the technologies developed and evaluated with this demonstrator.

1.3.2. Technical Objectives

The following represents the main technical objectives of this TD:

1. Between 15 and 30% of weight reduction.
2. Energy savings in operation of 2-12%, resulting from the weight reduction.
3. Improvement of maintainability, coming from new concepts.
4. Introduction of a specific health monitoring system for the structures.

1.3.3. Technical Vision

Aluminium carbodies were firstly single-walled and then double-walled extrusions, in order to improve stiffness and also avoid extra reinforcements.

Progress has also been made in steel carbodies, with continuous reductions in steel sheet thicknesses and 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 in primary structures.

The current state-of-the-art includes the latter and the inclusion of different assembly methods apart from welding, as riveting and bolting, to reduce costs and manufacturing time.

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

Also manufacturing processes of composite materials have evolved from completely manual manufacturing to more automatic processes. New processes allow more repeatability and thus more control on quality.

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

The following table summarizes how this TD will progress the state-of-the-art and overcome today's limitations and difficulties:

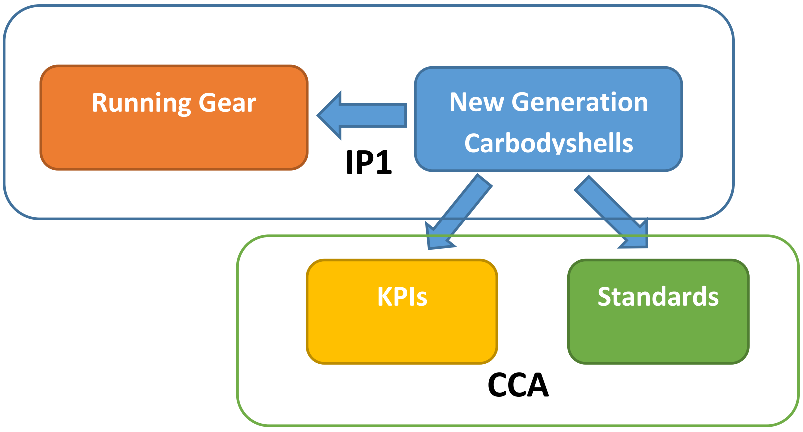
State-of-the-art	New Generation Carbodyshells
Full steel carbodies, made of thin steel sheets, cast parts, extrusions or formed sheets. No proportionality between density and strength of base material.	New carbodies with reduced weight.
Full aluminium carbodies, made of extrusions, sheets, and/or reinforcements. More effective in manufacturing but with similar final weights than steel. A loss of interior space due to the necessity of having high inertias in the aluminium.	New carbodies with important reductions of weight that also have the possibility of having a high percentage of the insulating material in its interior.
Primary structure of steel and aluminium carbodies as mentioned above, where metal or composite secondary structures are joined. The design of those joints supposes important reinforcements in some cases.	As composite materials are created in the manufacturing process, possibility of more integrated and less reinforced structures.

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

- IP1 – TD1.4 "Running Gear": There are activities in both TDs that present commonalities, such as the development of running gear subsystems made of advanced new materials. The validation processes employed for allowing the use of both carbody and running gear structures will have many points in common.
- CCA: Along the duration of the TD, values concerning KPIs and proposals for standards will be delivered to CCA.

Figure 7: Interaction with other TDs and IPs



1.3.4. Impact and enabling Innovation Capabilities

The new Carbodyshells specific benefits have a major impact in the Shift2Rail system-level KPIs. The relative weight of the benefits provided by this work is estimated (over a total of 100%) in the table below which provides an overview of the effects generated at 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 of the payload or technical equipment weight up to the TSI limits. An increased train capacity will allow dividing the maintenance cost into more passengers per train while keeping the price of maintenance.
Improvements in manufacturing technologies	It is also expected that replacement of some composite parts within the carbody could be quicker and less costly than welded metallic parts (repairing of certain metallic structures can be somehow complex). Depending on the chosen raw materials, it is expected that processes used for forming composites can compete with those use for metals.
Integrating functions in the parts made of new materials	Train functions like the thermal isolation (as an example) can be integrated in a carbody made of several materials, mainly composites, thus saving space and weight. Additionally, integrating functions like air conduction, piping, etc… can make the whole carbody system less prone to corrective maintenance.
More attractive products	Vehicle structures made with these new materials will benefit from an improved space within the vehicle and therefore passenger comfort. Also a reduction of the time-to-market in both manufacturing and operation (repairs) periods are expected.
Development of new skills in the Railway Industry	These technologies will have impact on the way railway vehicles are produced and maintained, keeping the value added by the conventional metal constructions and adding the new value coming from industries that are already producing systems for the aerospace and automotive industry.
Side positive effects for suppliers and research institutes	The need of the physical characterization of composite material systems will bring activity for industries and research centers specialized in composite materials that are already working for other sectors, now gaining experience in composite railway structural applications.

This TD will contribute to enable two Innovation Capabilities as follow:

Innovation Capability	*TD1.3 Carbodyshell enablers*
5- Optimum Energy Use	*BB1.3.1 Composite-hybrid carbodyshell* Increase of the space available within the vehicle by reduction of the structure sections with the aid of new materials, together with the mass reduction allowing more passengers or equipment up to meet the normative axle load.
7- Low Cost Railway	*BB1.3.1 Composite-hybrid carbodyshell* Integrating functions like air conduction, piping, etc., can make the whole carbody system less prone to corrective maintenance, thus modularity involves less inspection and part replacement time. It is also expected that replacement of some composite parts within the carbody could be quicker and less costly than welded metallic 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 Shift2Rail are shown in the following table:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Carbody shell	New materials in train carbody structures, in order to reduce weight and/or improve manufacturing process cost effectiveness	Full high speed intermediate coach of a Talgo 350 type train.	High Speed	5/6	The demonstration activity will have the following objectives for all the TD1.3 demonstrators: • Demonstration of the new materials adaptability for the function intended in the carbody structure. • Demonstration of the joining techniques between the new materials (composites) and also between composites and metals. • Explanation of the completion of the objective of weight reduction (between 15% and 30% forecasted). • Explanation of the manufacturing, maintainability and reparability concepts for railway environment. • Proposal of the standardization and certification approaches (design, calculation, manufacturing, repair, etc…), and the common specifications for future composite material based architectures.
		Coupler end of a Siemens Velaro high speed train made of Carbon Fibre Reinforced Plastic		3/4	
		End structure of an underframe area (called "headstock") for an end car of a Bombardier metro train	Metro	3/4	

One of the main purposes of the Demonstrators is to validate methods (design, calculation, manufacturing and testing) leading to a future creation of standards that allow an easy and economic certification of the vehicles.

All the principal elements required for rapid market uptake of this research and innovation has been taken into account.

These are:

- The use of manufacturing and testing techniques that have been long used in the aerospace industry and other industries in relation with composite materials, especially those that could match the costs targets typical of the railway industry.
- Hi-tech materials that have proven excellent fatigue and serviceability properties in other sectors.

It can be expected that between three and five years after Shift2Rail new standards are already in place that allow simplify the implementation of these new structures.

Planning and budget

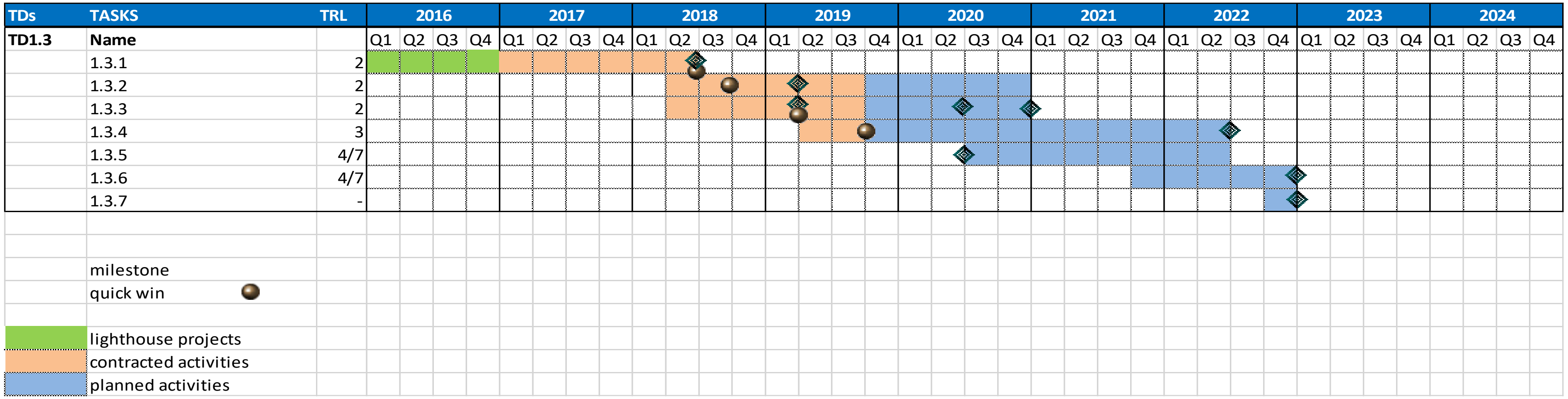


Table 6: TD1.3 quick wins

When	What	Contribution to MAAP
Q2 2018	Technical specification of all the physical demonstrators	First tangible objective that establishes the procedure to continue works in the coming years.
Q3 2018	Demonstration of all the material alternatives found for each part of the carbodies (zones that will be metallic, 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, it will assign the right material to the right place within the carbodies, giving the first estimation of mass reduction and manufacturing technique to be used.
Q1 2019	Conceptual design of the carbody or parts	This is the starting point of 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, where the safety levels of the composite or hybrid assemblies have to be assessed, in order to keep or improve those safety levels that the current state-of-the-art metallic assemblies already have.

Table 7: TD1.3 milestones

When	What
Q2 2018	Demonstrators specifications
Q1 2019	Demonstrators studies on material and manufacturing alternatives
Q1 2019	Demonstrators conceptual design
Q2 2020	Structural and non-structural assessment + noise & vibration harshness
Q4 2020	End of design for manufacturing (drawings & specifications)
Q2 2020	Start of demonstrators manufacturing
Q4 2022	End of validation tests
Q4 2022	Final report

The estimated total budget for Carbodyshell TD is around 26,7 M€.

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 is small without compromising safety and comfort.

The work to be developed in this Technology Demonstrator includes:

- New sensor architectures and functionality to monitor both running gear and track.
- Light weight and optimised materials validated and certified for the running gear environment.
- The definition and validation of actuator technology to control running gear and wheelsets. The development of a new noise and vibration assessment methodology.

The next generation of running gear solution needs to deliver reduced infrastructure / wheel wear and damage, whilst providing higher 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 reduced 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 steps in the long-term future and this will be considered from the specification stage.

New innovative running gear solutions support to improve capacity, to reduce the life-cycle costs and to increase performance.

1.4.2. Technical Objectives

The following represent the main technical objectives of this TD:

- Weight reduction which will facilitate a reduction in the engineering and integration effort and generate energy savings through the whole life cycle
- Lower unsprung mass: this will help reduce track damage, wear and vibrations, which will contribute to a reduction in system cost of up to 20%
- Reduction in wheel & rail wear (especially RCF) through improved (controlled) performance on straight as well as curved track including wear-resistant materials, which will contribute to a cost reduction of up to 20%
- Improved ride conditions through the usage of active/semi-active suspension systems
- Reduction of running gear associated inspection and maintenance by monitoring which will contribute to a maintenance cost reduction of up to 20%
- Reduction of costs for running gear sensor equipment by 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 running gear
- More efficient authorisation with a reduction of up to 30% in cost, time and effort

1.4.3. Technical Vision

Running gear systems deliver a balance between reliability, comfort and performance, whilst ensuring safety. The scope for improvements in performance and reduction in wear and damage to the vehicle / track interface using conventional systems is small without compromising safety and comfort. The next generation of running gear solution needs to deliver reduced infrastructure / wheel wear and damage, whilst providing higher reliability and availability, with lower maintenance costs.

The work to be developed in this Technology Demonstrator includes:

- New sensor and health monitoring architectures and functionality to monitor both running gear and track.
- Light weight and LCC-optimised materials validated and certified for the running gear environment.
- The definition and validation of actuator technology to control running gear and wheelsets.
- The development of a new noise and vibration assessment methodology.
- To make a breakthrough in the performance of the authorisation process.

The approach begins with a thorough review of the specifications and requirements of running gear of the future. In the second phase technologies are individually developed covering the whole development process from basic research, lower level specifications, technology development, prototypes and laboratory tests, confirming their performance and gaining a more comprehensive understanding of these technologies. Next, specifications and architectures at a whole system level are re-assessed and the most adequate solutions for the different types of service and operation conditions are proposed. The final tasks are twofold:

1. A number of different running gear solutions bringing clear contributions to the Shift2Rail global Key Performance Indicators (KPIs) are verified using demonstration scenarios.

2. Technical standards based on the technologies proposed are developed in order to promote future deployment.

Additionally, the authorisation process needs attention in order to get the innovations introduced within the operational environment.

State-of-the-art	New Generation Running Gear
Trailer Bogies designed for 20 tons axle load are approximately 6.5 – 7 tons in weight and contain around 90% of steel	Future Trailer Bogie concepts around 5 to 5.5 tons in weight, with functional integration of suspensions, frames, wheelsets and brake equipment and lightweight materials. Further reduction coming from new running gear concepts
Different requirements are implicitly/historically considering steel as preferred material (e.g. fire regulations, maintenance, inspectability, fatigue resistance)	Harmonized requirements and design principles applicable for materials other than steel allowing new lightweight components and/or concepts to be applied in running gear.
Architecture based on steel material capabilities	New materials allowing functional integrations and new running gear concepts /architectures including mechatronics
Traditional break-down of component 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 light weight solutions
Uncertainty about the benefits of lightweight design and materials in Running Gear	Clarity about the 'which, where and how light solutions' and their benefits (Technology Roadmap)
Sensors specially developed or customized for running gear applications, produced in small volume and with high costs	New standardised sensors fit for purpose in the running gear application that can be produced in large volume at a lower cost.
Expensive cabling in the running gear because of the necessary mechanical protection of the cables	Wireless sensor network in the running gear
Energy supply to the sensors via cables from the car body, leading to complex cabling inside the running gear and to the car body.	Sensors with efficient energy management and energy harvesting inside the running gear or even the sensors.
Specific and different solutions for communication and integration in the train level systems exist.	Clear standards for interfaces to train level systems and to maintenance systems enabling compatible running gear sensors.
Self-guiding: Due to wheel conicity, solid axles automatically steer themselves on curves. For independent guided wheels, the guiding mechanism changes the angle of attack to try to maintain 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 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 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.

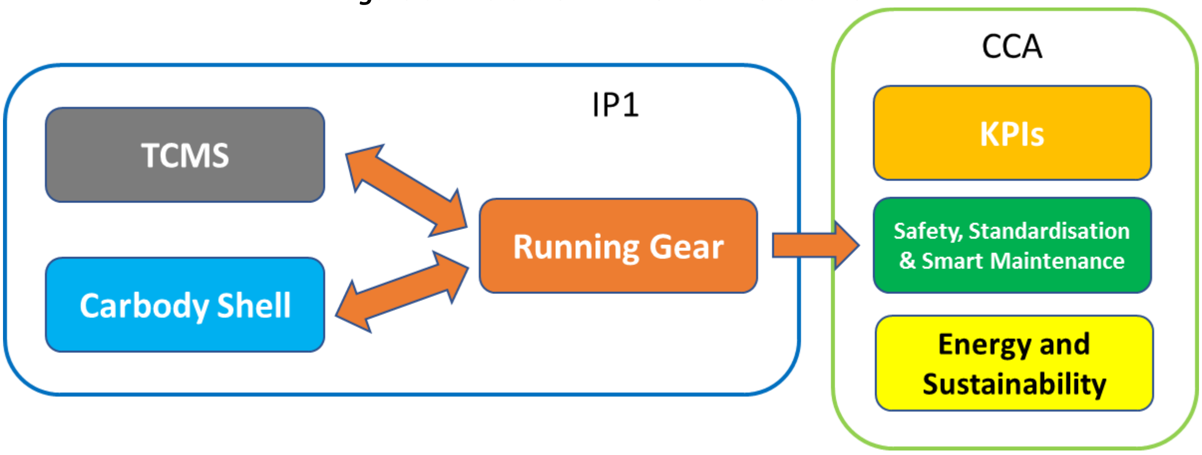
Virtual certification: Today, the authorisation process for putting new rolling stock into service is largely based on full-scale field and line tests, which is expensive, time and capacity consuming. Moreover, it can only be performed at the end of the design process. There is hence a clear need for a reduction of the duration and cost of the process.	The main target is to validate practically an overall industrial virtual certification process and to unfold it on real cases, demonstrations of the approach (TRL6/7).

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

- IP1 – TD1.3 "Carbody Shell": There are activities in both TDs that present commonalities by developing carbody shell made or partly made of advanced new materials. The validation processes employed for allowing the use of both carbody and running gear structures will have many points in common.
- IP1 – TD1.2 "TCMS": The system architecture for any running gear and infrastructure monitoring will be based on standardised interfaces of TCMS.
- IP3 – Infrastructure: Next generation passive/active suspension and curving control designs enable radical new thinking in wheel/rail conditions for reduced wear and damage (including RCF) on curved and straight track as well as other high cost infrastructure components such as switches and crossings. It is very important to consider cost savings in infrastructure to demonstrate the benefit of new running gear development.
- CCA: Along the duration of the TD, values concerning KPIs and proposals for standards will be delivered to CCA.

Figure 8: Interaction with other TDs and IPs



1.4.4. Impact and enabling Innovation Capabilities

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

Strategic Aspect	Key Contribution from the TD
Improved services and customer quality	Improved passenger comfort as well as increased availability
Reduced system costs	Overall enhanced curving and ride performance of future generation running gears. Running gear maintenance cost reduction as well as reduced wheel and track LCC.
Simplified business processes	Reduction of the Time and Cost for the validation of light weigh materials, sensors and active control systems
Enhanced interoperability	Enhanced standardisation of sensor architecture and interfaces. Standardized HW and SW communications protocols.

This TD will contribute to enable five Innovation Capabilities as follow:

Innovation Capability	***TD1.4 Running Gear enablers***
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 to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a condition-based maintenance. Development of new health monitoring systems and innovative algorithms that allows a condition based maintenance of the track.
2 – Mobility as a Service	*BB1.4.1 Bogie Sensors and mechatronics* Establish an accepted general framework to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a condition-based maintenance. Development of new health monitoring systems and innovative algorithms that allows a condition based maintenance of the track.

4 - More value from data	*BB1.4.1 Bogie Sensors and mechatronics* Establish an accepted general framework to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a condition-based maintenance. Development of new health monitoring systems and innovative algorithms that allows a condition based maintenance of the track.
5 – Optimum energy use	*BB1.4.2 New materials for bogies* Light weight and optimised materials validated and certified for the running gear environment
6 - Service timed to the second	*BB1.4.1 Bogie Sensors and mechatronics* Establish an accepted general framework to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a condition-based maintenance. Development of new health monitoring systems and innovative algorithms that allows a condition based maintenance of the track.

7 - Low cost railway	*BB1.4.1 Bogie Sensors and mechatronics* Establish an accepted general framework to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a condition-based maintenance. *BB1.4.2 New materials for bogies* Light weight 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 about simulation and validation processes to reduce costs for the stakeholders. There is close cooperation within the sector for standardisation and testing.
8- Minimal disruption to train services	*BB1.4.1 Bogie Sensors and mechatronics* Establish an accepted general framework to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 a 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 to develop health monitoring systems (HMS) for condition based maintenance (CBM) and interface with TCMS. Focus on bogie sensoring open standards 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 & refined methods for prediction & evaluation of new / improved noise control measures. In addition, noise optimised wheel development.
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 about simulation and validation processes to reduce costs for the stakeholders. There is close cooperation within the sector for 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 Shift2Rail are shown in the following table:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Running Gear	Sensor and health monitoring functionality	HMS architecture, innovative algorithms, certification process and interface with TCMS	Regional, High Speed, Metro, Freight (Loco)	6/7	Running gear sensor open standards. Solutions for safety critical and non-safety monitoring systems.
	Active Suspension and control technology	Development, certification and tests new active suspensions and radial steering		6/7	Solutions for suspension & 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 degradation and lower railway system LCC.
	Virtual certification	methodologies about simulation and validation processes	Generic	6/7	The progressive use of simulation will enable an improved certification process to reduce costs for the stakeholders.

A key contribution from Shift2Rail is to provide new or revised standards for these emerging innovations to ensure they can be certified for future rail contracts, specifically:

- Technical specification
  Technical specifications: 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 requirements in the recent TSI connected with sensors in running gears. Identify necessary new standards.

- Optimised Materials
  There will be standards such as fire, fatigue, or inspection which need to be adapted due to the new materials and their specific characteristics. New standards may be required. An example would be FRP material characteristics (ballast impact).

- Active Suspension and control technology

Some requirements of recent TSI, connected with static/dynamic tests to be performed during authorisation of future trains would be updated or modified. Related standards, such as EN 14363 and related, could also be revised accordingly.

- Noise and Vibration reduction:
  This TD will provide valuable input to future revisions of the Noise Technical Specification for Interoperability (TSI) since the running gear is the major contribution to pass-by noise at most normal running speeds.

- Virtual certification
  The progressive use of simulation in several cases to be defined (cross acceptance, vehicles with small modifications, out-of-the-range modelling of physical tests, etc.) will enable an improved certification process. One can expect a reduced time-to-market railway offer, more interoperable rolling stocks, cost savings for the stakeholder and the end-users.

In order to guarantee a rapid market uptake after Shift2Rail, 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 running gear generations in terms of competitiveness and reliability. Additionally, the technical standards will contribute to swifter development of new running gear as well as faster market introduction.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
TD1.4	**Running Gear**		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
	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 HMS	Specification and requirements for sensors and HMS architecture, innovative algorithms, certification process and interface with TCMS
Q4 2018	New, non-conservative materials for wheels	The main advantages of such a wheel are lighter, less wheel wear, less tendency of polygonization and low noise emission.
Q4 2018	Composite running gear frame components	New designs of frames components using materials to meet light-weight strategies. Performance of bench tests of the manufactured components.
Q4 2019	Methodologies about simulation and validation processes	Definition of an improved overall industrial virtual certification method for running gears, following the guidelines established by EN 14363:2016 in order to reduce on-track tests in favour of increasing simulations and bench test
Q3 2021	Universal Cost Model 2.0	Improvement of the UCM results from Roll2Rail to create an open tool for the rail way industry - making the UCM more user friendly, more consistent and more simply.

Table 9: TD1.4 milestones

When	What
Q4 2017	Start of Shift2Rail TD1.4 activities with the 2017 call projects (PIVOT and related OC)
Q4 2019	PIVOT and OC ending. Start of PIVOT2. Manufactured prototypes of the running gear technical work streams or ready for manufacturing
Q2 2023	PIVOT2 ending. S2R programme ending. Final Report

The estimated total budget for Running Gear TD is around 23.9 M€.

1.5. TD1.5 Brake Systems Demonstrator

1.5.1. Concept

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

The main tasks of a brake system in rail vehicles are:

- to reduce the speed of a travelling train or vehicle in accordance with the operational conditions and to stop it completely if necessary
- to keep the speed of the travelling train or vehicle constant when travelling down gradients
- to secure standing (stopped) trains or vehicles against unintentional movement for a limited time
- to 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 railways today's brake controls still rely on hardwired and/or pneumatic signals and on pneumatic brake controls to achieve the required safety (SIL4 is required on the overall brake system level). The core of today's brake system ensuring safety is still based on dissipating kinetic energy during braking into thermal energy with friction brakes.

Through R&I activities, next generation brakes systems overcome current limitations through introduction of adhesion management solutions brake energy recuperation technologies, brake control solutions embedded in TCMS solutions of the future and the use of electro mechanic brake systems overcoming pneumatic and/or hydraulic solutions.

Also in the scope of future brake systems are autonomous train operation scenarios, the support for virtual certification of brakes and efficient brake systems for freight train scenarios.

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

1.5.2. Technical Objectives

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

1. Ability to implement high safety relevant brake control functions in hardware-software architecture compliant with High Safety Integrity Level (SIL3-4)
2. Ability to connect the brake control unit (BCU) to the next generation Train Control Network TCN (as defined in TD1.2) supporting critical safety functions to enable objective 2.
3. Improvement of braking degradation in poor adhesion condition, from 25% prescribed by UIC 541-05 leaflet to 15%
4. Innovative friction pair solutions, lightweight (e.g. ceramic) brake discs, improved LCC
5. Enhanced, failsafe electro-mechanic brake system
6. Standardisation of the brake system assessment processes
7. Methods and tools for virtual certification of brake system

1.5.3. Technical Vision

Pneumatic systems (or hydraulic systems) are mature technologies dominating the market, but future brake systems follow four mega-trends:

- 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, suspension.

The wheel to rail contact usually not only causes a significant uncertainty when predicting braking distances, but is a general bottleneck with regard to the achievable braking performance of the train and, to a substantial degree, for the traction effort as well. Due to environmental as well as technical reasons the conditions for this wheel to rail contact are very often different and cannot be predicted exactly. They very 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, like headways, punctuality and especially safety.

Managing especially low or insufficient adhesion conditions can reduce braking distances. Hereby it is important to minimize the variation under comparable conditions. Such a future adhesion management significantly contributes to a capacity increase in railway operation.

Compared with conventional grey cast iron brake disc ceramic brake discs weight around 50 percent less reducing the critical unsprung mass of wheelsets and contribute to reduce the rotating mass. Further advantages of ceramic disc brakes and further advanced friction pairing solutions are reduced fading and higher thermal stableness, 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 due to intrinsic inaccuracies and to temperature and ageing related drifts, pneumatic controls do not take advantage from the accuracy offered by typical electronic controls. These disadvantages underline the immediate demand for improvements to close the backlog to other industries. Those have finally managed to transfer the safety-related functions to an electronic and software-based system architecture which is compliant with the required high Safety Integrity Level (SIL3-SIL4). This would not only allow taking benefit from the higher accuracy and from advanced emergency braking concepts but it also allows exploiting the advantages of the next TCMS generation to substitute hardwired signals as well as BCU communication protocols of current railways custom networks (MVB, TCN) by using safe ethernet communication as defined in TD1.2 TCMS

Today pneumatic and hydraulic solutions are dominating the market. Mainly the hydraulic version has the advantage of high force density whereas the pneumatic one offers a relatively simple activation of the braking power. In any case elaboration of concepts for pneumatic and hydraulic systems is necessary. With regard to ecological and maintenance issues the latter ones are even more 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 LRV applications the possibility of eliminating the complete oil management chain would be given. A second application scenario in the scope of Shift2Rail is metro.

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 programs defined on a common European basis. The goal is to reduce time and cost for authorization processes.

State-of-the-art	New Generation TCMS
Safety braking related functions (safety brake, safety brake weighing) still assigned to traditional pneumatic systems. Due to intrinsic inaccuracy and to temperature and ageing related drifts, the pressure values provided can differ from the expected value which can lead to increased braking distances or can cause sliding.	Electronic HW-/SW platform designed to manage all braking functions (service, holding, emergency, safety brake, wheel slide protection), compliant with the high safety levels SIL3 and SIL4, ensuring a more accurate control.
BCU communication protocols based on current railways custom networks (MVB, TCN), safety related commands being hardwired	Next generation TCMS ethernet communication not as diagnostic media only, but used as full operational communication system according to the required SIL levels.
Significantly changing conditions for the wheel-rail contact, influencing many rail traffic characteristics, including safety and punctuality. Low adhesion causes lower acceleration and longer braking distances, high adhesion results in increased wear and tear and noise. Sanding and WSP are far from the optimum considering the technical options available today.	New technologies help to compensate the variance of the adhesion characteristics and, combined with a more sophisticated WSP technology, allow reducing the braking distances in bad adhesion conditions and to improve the overall train safety, finally reducing the wheel's LCC.
Ceramic brake discs are actually used on an automotive sector premium level only.	Ceramic brake discs are also introduced to the railway business reducing the life cycle costs significantly by providing a life time design.
LRVs use hydraulic friction brakes, while high speed, regional, metro and freight 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 as compact as to substitute the hydraulics in LRVs and competitive enough to be introduced to other vehicle types, allowing better control and diagnosis.
Time consuming and costly assessment due to high complexity of European plus national regulations, inconsistencies and/or interpretation divergences.	Definition of an assessment process, with standardised and EU-wide accepted criteria including a standardised test programme in order to reduce the time and cost for authorization processes.

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

The main interactions are:

- IP1 - TD1.1 "Traction": There is a strong interdependence between acceleration and deceleration. Blending technologies and use of ED brake are examples of a tight interaction between traction and braking.
- IP1 - TD1.2 "TCMS": The TCMS is the backbone 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.
- IP3 – Smart Metering for Railway Distributed Energy Resource Management System (TD3.10) could prescribe the effect of brake energy recuperation into the energy flows of the entire railway system (energy return back from train to infrastructure) and thus, to significantly contribute to energy managements strategies via the appropriate train-driving

- IP5 Brakes for Freight Scenarios: Some of the technologies developed in IP1 TD1.5 “Brakes” can be applied as well in IP5 freight. Examples are advanced friction brake technologies, electronic brake control applied in electro pneumatic brake solutions for IP5 freight and brake functions like automated brake test.
- CCA: During the life of the TD values concerning KPI and proposals for standards will be delivered to CCA (WA2 & WA3).

1.5.4. Impact and enabling Innovation Capabilities

The new brake system specific benefits have a major impact in the Shift2Rail system-level KPIs. The relative weight of the benefits provided by this work is estimated (over a total of 100%) in the table below which 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	• Technological leadership supported by a combination of ○ radical innovation (high safety level electronic solutions finally leaving behind the remains of our ancestors’ brake system, quasi elimination of the bottleneck of low adhesion) ○ exploiting technological enhancements in related systems (e.g. TCMS, TD1.2) • Tangible benefits for the end user: ○ Increase of operational reliability through less operation restrictions under poor adhesion and through better diagnostics of the brake components ○ Support capacity increase through higher track throughput enabled by shorter and/or more reliable braking distances LCC reduction due to better diagnostics, lower energy consumption and introduction of life time brake components
Compliance with EU objectives	• Promotion of a modal shift by implementation of these new technologies to help avoiding service disruptions and adding new features • Support the increase of the capacity • Greening of the rail transport through reduction of the energy consumption by reducing the rotating mass of brake discs., Elimination of any oil in LRV brake systems
Degree of maturity of the envisaged solutions	• High safety relevant brake control functions in hardware-software architecture • Brake distance degradation improvement • Development of a weight reducing life time Ceramic brake disc • Development of a drive-by-wire, mechatronic brake actuator • Reduction of Time and Cost of Brake System Assessment

This TD will contribute to enable five Innovation Capabilities as follow:

Innovation Capability	***TD1.5 Brake System enablers***

1-Automated Train Operation	*BB1.5.1 Safe control & adhesion management* Support of safe braking under all conditions without driver surveillance; Brake System electronics capable for ATO and higher safety level electronic solutions for Brake Control
5-Optimum Energy Use	*BB1.5.1 Safe control & adhesion management, BB1.5.2 Efficient force generation* Optimized energy efficient brake system solutions due to higher safety level electronic solutions for brake control, innovative friction pair solutions and electro-mechanic brakes for railway applications
6-Service operation timed to the second	*BB1.5.1 Safe control & adhesion management, BB1.5.2 Efficient force generation* Support of safe braking under all conditions without driver surveillance; Brake System electronics capable for ATO
7-Low Cost Railway	*BB1.5.3 Authorization process* Reducing cost by air-free train solutions (getting rid of pneumatic components in a train): higher safety level electronic solutions for brake control and electro mechanic brake for railway applications
9 – Intelligent Trains	*BB1.5.1 Safe control & Adhesion Management, BB1.5.2 Efficient force generation* Support of safe braking without driver surveillance; Brake System electronics capable for ATO and higher safety level electronic solutions for Brake Control
11-Environmental and social Sustainability	*BB1.5.1 Safe control & adhesion management, BB1.5.2 Efficient force generation* More efficient and silent braking by optimised use technology (innovative friction pair solutions, electro-mechanical brakes)

1.5.5. Demonstration activities and deployment

The following table summarises the contribution of TD 1.5 Brakes to the different ITDs of Shift2Rail:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Brakes System	High Safety Level electronic Solutions for Brake Control	Specification, Concept, Demonstration, Verification	Regional	7	An electronic hardware-software architecture, compliant with High Safety Integrity Level (SIL3-SIL4), particularly oriented to be applied in Brake Control solutions, where the safety functions allocation will be transferred from traditional pneumatic components to electronic modules
			Urban	7	
	Adhesion Management	Specification, Concept, Implementation Verification	Generic (KB) and Urban/Regional (FTI)	5/6 (KB) and 7 (FTI)	Safe braking under all adhesion conditions, especially low adhesion situations. Show the function of a new adheison 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-Mechanic Brake for Railway Applications	Specification, Concept, Demonstration, Verification	Urban/Regional	6	Development and test of a mechatronic brake actuator for railway applications
	Certification Process incl. Virtual Certification	Specification, Concept, Demonstration, Verification	Generic	4	Based on the results of Roll2Rail project the requirements, the standardized criteria and an implementation strategy for assessment of future brake systems will be defined. In addition, new methods and their implementation strategies for the virtual certification of brake systems will we investigated and defined. Certification process of adhesion management testing environment

Planning and budget:

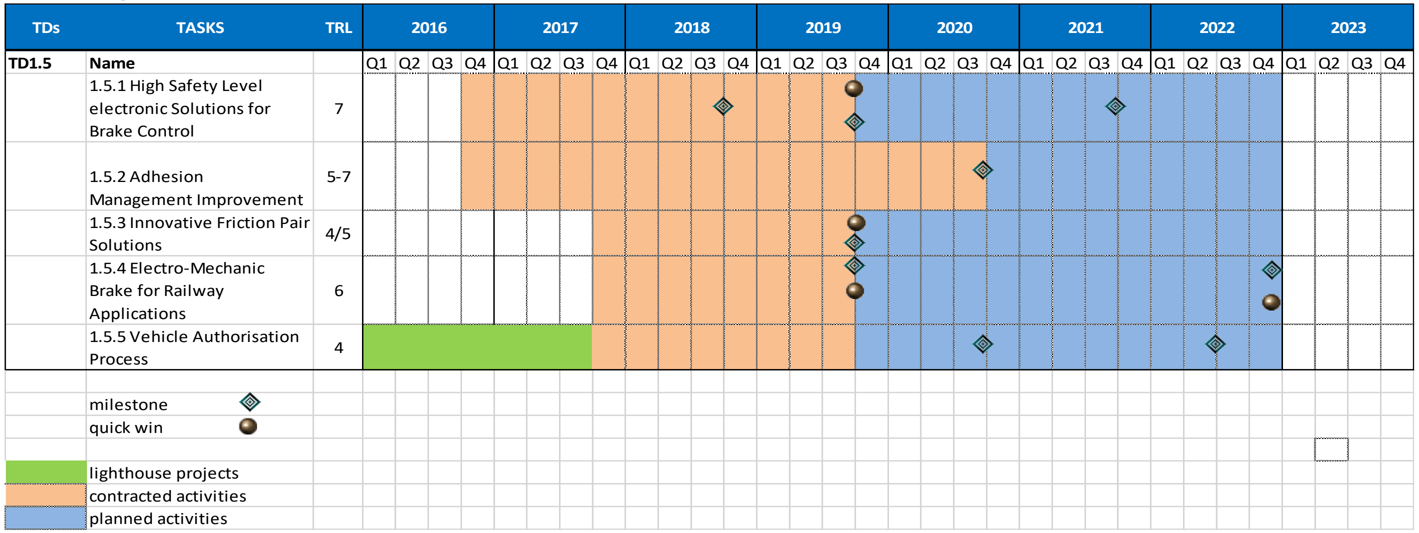


Table 10: TD1.5 quick wins

When	What	Contribution to MAAP
06/2018	Demonstrator WSP 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 definition for a brake system safety architecture integrated in the future TCMS
09/2019	Concept development actuator	Improvement of electro-mechanic brake actuators and expansion of the range of train applications
09/2019	Innovative Friction Pairing solution tested	Contribution to enhance braking performance and lower the wear
09/2019	Demonstration SIL3/4 electronic HW	Design and test of future electronic HW for the brake system considering the outcome of TD1.2 – TCMS interface
12/2022	TRL6 Demonstrator EM-Brake	Demonstration and validation of an 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 tests in Dynamometer test
09/2019	TRL4 Demonstrator SIL3/4 Brake System Electronic HW
09/2019	TRL4 Demonstrator EM Brake
09/2020	As a first example the virtual certification of a Wheel Slide Protection System shall be performed
09/2020	Adhesion Detection System installed
09/2021	Sil3/4 Electronics integrated in future TCMS
12/2022	TRL6 Demonstrator EM-Brake actuator

The estimated total budget for Brake TD is around 30.8 M€

1.6. TD1.6 Doors and Access System Demonstrator

1.6.1. Concept

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

- Contribute to the comfort
- Optimize the dwell time consumption to getting on and off the train
- Support the demands of people with reduced mobility (PRM)
- Guarantee the passenger safety

Today, Access System is still based on:

- For the leaves: 2 aluminium or stainless steel skins with aluminium pillars and beams in between as structural parts and with PU foam or aluminium honeycomb as insulated materials
- Accessibility: moveable sliding steps (bridging plates) without height adjustment, often without horizontal stroke adjustment and with some accessibility barriers like protrusions, upstands etc.

Through R&I activities, the next generation of Entrance System enhances **accessibility** while reducing disturbances to other passengers and operation, improves passenger **comfort** thanks to an improved thermal and acoustic insulation, reduce the **weight** with introduction of optimized metallic solution or introduction of plastic or **composite** solutions and introduce **new** functionalities thanks to new sensors and **modular design** in the direction of an **autonomous access system**.

The deployment of next generation Access System will contribute to achieving capacity targets, improved services and customer quality and enhanced interoperability

1.6.2. Technical Objectives

The following represents the main technical objectives of this TD:

1. Reach 3W/m²K as thermal performance
2. Increase door acoustic attenuation by 3dB, with priority given to high speed and regional trains on both thermal and acoustic behavior.
3. Reduce vertical and horizontal offsets and gaps to 10 mm instead of 50 mm, as permitted today and reduce all additional accessibility barriers lit protrusions at door sills
4. Reduce the number of noise producing PRM devices by an estimated number of approximately 10% of the actual 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 System with improved leaf in term of weight, thermal and acoustic insulation with adaptive gap fillers and with new functionalities.

The technical vision of the new generation access system proposed in Shift2Rail is based on the following:

- Leaf based on composite technologies and/or on new architecture or new materials for metallic solutions
- Gap filler allowing level access to the train allowing easy and independent access
- Use of new sensors or use differently existing devices to upgrade access system functionalities, performances and safety to reach an autonomous access system.

State-of-the-art	New Generation Entrance System
Door leaf means two skins bonded on an aluminum frame with a foam filling (one front and 1 rear pillar, 1 lower and 1 upper beam)	New composite, metallic or plastic materials and new assembly processes which are presently not widely in railway applications will be developed. The aim is to find a compromise between the highest possible performance possible, which is expensive, and the best cost ratio. Targets to be achieved (in accordance to S2R MP and depending on market segments): • 3 W/m^2K for thermal performances • Increase sound reduction index by ≈ 3dB • Reduce the door weight by 10%.
At present there is no solution for an autonomous PRM boarding. 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 an unassisted and easy PRM access will be developed, looking for an economically viable solution
Today railway solutions for PRM such as specific buzzers, specific gap fillers or specific beacons are disturbing other passengers	Non-disturbing solutions will be developed, following the demands in terms of safety and non-disturbance.
Very few visual or sound information for passengers on the door	Interaction of door and passengers displaying real time visual or sound information to better guide passengers and improve the 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 DCU have to be changed.	A plug and play approach will provide a standard for device connectivity which results in: - a simplified validation process - more flexibility to change the functions of the door during the life time of the train.
Automatic but not autonomous door: a crew member or driver are responsible for door opening and closing though low information level and no direct view on the access system area.	Automatic and autonomous door which manages with its proper information and sensors safe and rapid opening and closing with a low involvement of driver or crew.

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

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 are:

- IP1 – TD1.2 “TCMS”: as the new TCMS architecture should impact Door Control Unit hardware and software
- IP1 – TD1.3 “Carbodyshell“: as the Carbody is one of the 2 main interfaces of the Entrance system and as a common introduction of composite solutions
- IP1 – TD1.7 “Modularity in Use”:
    - add requirements to design a door to facilitate the loading of interior modules
    - share technical watch about plug & play systems to design a modular leaf
    - share new needs from Cabin and Entrance system points of view in line with the targets of Autonomous trains and autonomous doors
- IP3 - TD11 “Future Stations“: as the station i.e. the platform is one of the 2 main interfaces of the Entrance system and as the future concepts of doors and stations will have to cooperate.
- CCA
    - Energy Efficiency
    - Noise and Vibration
    - KPI
    - Standards and Regulation

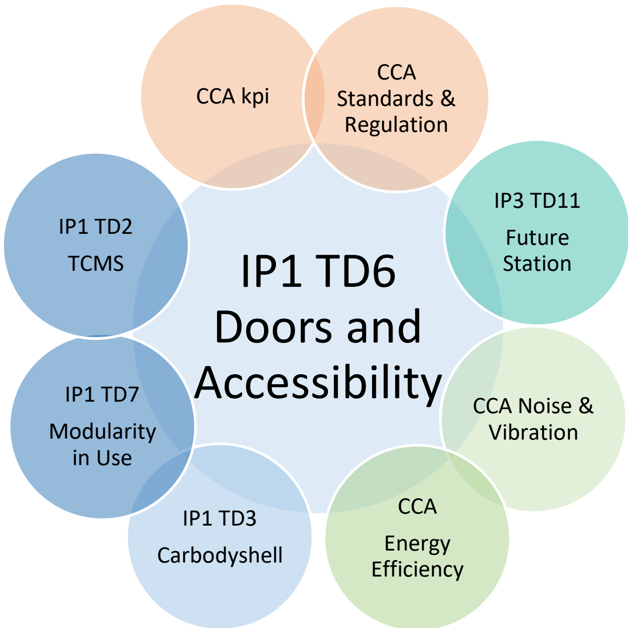


Figure 9: Interaction with other TDs and IPs

1.6.4. Impact and enabling Innovation Capabilities

The new generation Access System specific benefits have an important impact in the Shift2Rail system level KPI’s. The benefits provided by this work are estimated in the table below:

<table>
<tr><th>Strategic Aspect</th><th>Key Contribution from the TD</th></tr>
<tr><td>Competitive-ness of the EU industry</td><td><u>Technological leadership in train entrance system</u>
• The use of advanced material technology gives the European rail industry the opportunity to become the trendsetter for a new generation train access systems.
• Modular doors result in a significant reduction of LCC and will also help to technically differentiate from competitors.
• Innovation will become the key competitive edge for the European rail industry. This would allow to shift the actual mainly cost related competition with Asian suppliers to a technology based competition.
<u>Tangible benefits for the end user</u>:
• Convey the feeling and confidence of high level of comfort for passengers
• Support the capacity increase through lighter train access solutions
• Fulfill PRM specific needs in terms of mobility and passenger flow
• Combine visual and audible information considering sensory disabilities</td></tr>
<tr><td>Compliance with the overall EU objectives</td><td><u>Capacity increase</u>:
• Lighter door solutions will provide:
    o Increase in capacity
    o Improve the competitiveness => more passengers for the same cost
• A better PRM accessibility will provide
    o Better PRM Increase in capacity
• Autonomous door will provide
    o Better and safer flow management => increase in capacity
<u>Greening of transport</u>:
• Energy savings can be achieved through lighter materials and an improved performance of the entire door system</td></tr>
<tr><td>Degree of maturity of the envisaged solutions</td><td>Currently most of the proposed technologies have a TRL 1 or 2, which means the features have been observed in principle and the possibilities of using them are formulated.
The target of the TD Doors is to transfer successful concepts up to a TRL 6 or 7: Demonstration of prototypes in a relevant environment, respectively system prototype demonstration in an operational environment.</td></tr>
</table>

This TD will contribute to enable 8 Innovation Capabilities as follow:

Innovation Capability	***TD1.6 Doors and Access Systems***
1 – automated Train Operation	*BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions* Allowing a smooth and safer access by autonomous doors and improve crowd management
2 – Mobility as Services	*BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions* *BB1.6.2 Light Door and Improved Comfort (acoustic & thermal)* Ensuring good service conditions for all types of passengers and providing more 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 will improve entry surveillance and foster the development of an autonomous door
5 – Optimum energy Use	*BB1.6.2 Light Door and Improved Comfort (acoustic & thermal)* Lighter and better insulated doors improve energy efficiency
6 - Service operation timed to the second	*BB1.6.1 PRM Access, Safety and Door Entry surveillance Solutions* Autonomous access and autonomous door are key to ensure rapid and predictable boarding / alighting
7 - Low Cost Railway	*BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions* *BB1.6.2 Light Door and Improved Comfort (acoustic & thermal)* Optimized solutions (cost vs functions) per market segment including PRM autonomous access and lighter materials lead to overall cost reductions in the railway system
9 - Intelligent train	*BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions* Communication with all type of passengers including PRM to help boarding and egress
10 - Stations and "smart" city mobility	*BB1.6.1 PRM Access, Safety and Door Entry Surveillance Solutions* Optimizing passenger flow and dwell time

1.6.5. Demonstration activities and deployment

The following table summarizes the contribution of TD1.6 Doors and Access system to the different ITDs of Shift2Rail are shown in the following table:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Doors and intelligent Access Systems	PRM access and communicati ng door	Mock-up representative of improved bridging plate concept	Regional	5	Measure the improvement of an easy and independent access and egress to the train (residual gaps, slopes, upstands, protrusions…) Test the new door functionalities (platform detection, alert signals, security solutions, automatic opening and closing…)
		On line test of new door functionalities Functions will be added to the existing functions of the doors which will remain active during the tests.		7	Test of the new functions that will be implemented on the doors in operational environment
	Light and comfortable door	A recent generation of door opening and closing mechanism and the leaves will be implemented on a static regional train. 2 types of door leaves: - based on metallic solutions - based on composite solutions		6	- Test of the integrated door (operator + leaves): - Weight - Door operation (e.g. opening and closing time) - Mechanical, acoustic and thermal performances will be tested in laboratories - in representative mock-ups for mechanical tests and - tested alone for acoustic and thermal.

One ITD is foreseen for the New Generation Access System. The train will be a Regional one as it is the most appropriate type of trains for on-track testing to validate the newly developed systems. However, other train families like metros or commuter trains (design study or calculation and even in some cases, demonstrators / mock-up) will be considered and results for all market segments will be assessed during the projects.

The ITD will integrate all the developed systems like:

- New composite and / or metallic leaves will be first 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 a market introduction:

- Higher passenger comfort
- Better accessibility to the train for persons of reduced mobility
- Reduction of train weight and energy consumption
- Safer access with low surveillance by crew or driver

It is expected that the outcome will also impact TSI regulations and EN standards. Standardization committee like CEN TC256 SC3 WG27 in charge of EN14752 or other committees in charge of EN16584 series, EN16585 series and EN16586 series, will be fed up with the output and results of Access System activities (introduction of composite, new functionality, fully automatic doors…).

Track tests with the technical demonstrator will guarantee that new features can be considered as proven. It can be expected that immediately or in the next 3 years, the new development will be implemented in a large range of new vehicle.

Planning and budget:

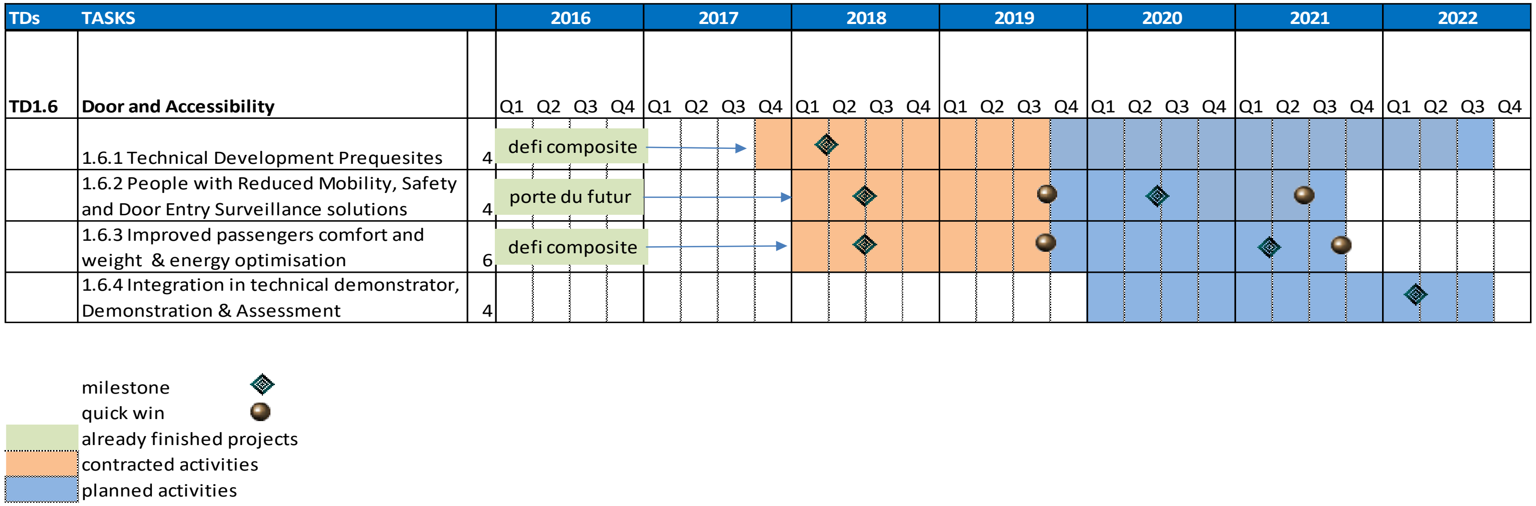


Table 12: TD1.6 quick wins

When	What	Contribution to MAAP
Q4 2019	concept of leaves	concept of improved leaves (acoustic, thermal and weight comparison for metallic leaves; new acoustic insulation concept,) including test results on different configurations and concepts implemented on panels (1m x 1m) or leaves
Q4 2019	concept of gap filler	concept of footstep (3D model - virtual mockup validated
Q4 2021	laboratory validation of bridging plate proto-type	validation of bridging plate and systems for an 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 Entrance System specification
Q2 2018	Specifications for an improved accessibility
Q2 2018	Specifications for both metallic-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 Doors and Access Systems TD is around 9,8M€.

1.7. TD1.7 Train Modularity In Use (TMIU)

1.7.1. Concept

The TD TMIU covers activities focused on the passenger saloon and the driver's cabin. The main objectives for passenger areas are:

- modulate the capacity of passengers,
- optimize the passengers flow,
- reduce the cost of interiors design and
- increase the attractiveness.

The main objectives of driver's cabin is to prepare the autonomous train:

- to be able to evolve the cabin during the life of the train,
- personalize the cabin to the user or operator,
- offer new functions and
- reduce the cost of operation.

The activities will consider the modularity and flexibility of the passenger lounge areas and driver's cabin with the use of standardized 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 organization/competences to be made to create train configurations meeting passenger and operator demands that are evolving during time.

Generally, the concept of modularity can be separated into 3 categories with a different purpose for each of them:

- The MID (Modularity In Design): the train is made of small independent modules connected between them to constitute the finished product.
- The MIP (Modularity In Production) which primarily relates to the manufacturing process to facilitate the implementation of equipment (comfort and/or services)
- The MIU (Modularity In Uses) which particularly relates to the facility 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 by flexible use of the driver's cabin.

The interior design of current Rolling Stock is not adapted to the amount of flexibility to meet the 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 (wall outlet, etc.). The driver cabin currently stays the same during the life-span of the train. It could be an obstacle to operate in the near future autonomous trains if the design of current cabins will not anticipate the change of 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 solution becomes quickly obsolete and does not meet the passenger and/or the operator expectations.

MIU concepts must allow coaches to be refurbished quicker than with current coach design and with reasonable costs. This will allow more frequent configuration changes to meet passenger requirements.

Concepts based on the Modularity In Uses approach will lead to genuine innovative solutions fitting the market needs and able to modify the configuration of coach interior and driver's cabin at an affordable cost.

1.7.2. Technical Objectives

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

The following represent the main technical objectives of this TD:

1. *Adapt the train interiors to increase **capacity***
2. *Reduce dwell time at stations by improving **passenger flow** in and out of train and between vestibule and saloon*
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 be able to reconfigure the passengers area inside a coach with regards to capacity:

- Few times per year: depending on the passenger capacity requirements or their passenger profile (e.g. commuter train for workers) or destination (e.g. ski trains).
- Every 5-6 years: on refurbishment (new design, new interior layout, etc.)

Also the atmosphere of the interior could be changed:

- Few times per year: depending of the seasons or the line travel (lighting, decors)
- Every 5-6 years: on refurbishment (new complete design)

In addition to that, work on this TD will allow to reconfigure passenger information support inside a coach more easily:

- Few times per year: depending on the passenger capacity requirements or their profile (adapt to the seat position or capacity)
- Every 5-6 years: on refurbishment (new design, easily updated, new connectivity, etc.)

Ensuring comfortable indoor climatic conditions (e.g. thermal comfort) regardless which interior lay-out is chosen stay essential:

- minor evolutions: move interiors partition walls, increase capacity or change the positions of the seat
- major developments: new design of the roof, new luggage rack location in height or new closed spaces added

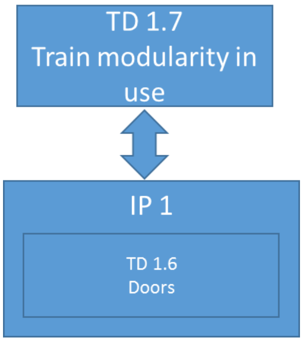
State-of-the-art	New Generation INTERIORS
Roll2Rail INTERIORS: improved methodologies to qualify comfort	Evolve interiors Design without degraded comfort or attractiveness for passengers. Roll2Rail will give to the TD the limit to stay and key to select ideas/concepts.
MODTRAIN – EUPAX / PrEN Design for PRM use: work on Interiors Design (Toilet, services, PRM requirements, …) but no result on Modularity In Use	These 2 European Projects (research and standard) have defined the needs of PRM. The TD will work on solutions to offer flexibility for railway operator to increase PRM accessibility (add quickly PRM seats or wheelchair user spaces for example) and it will give to the working group the available limits of design to select ideas/concepts
A complex industrial operation is necessary to change diagram during the in-service operating life	Research modularity: To increase capacity by 15% to 25% in a same train To reduce the cost of layout change by 50% To reduce the time of layout change by 50%
A limited evolution of the mechanic attachment units and electric connections	To set up a plug and play approach (mechanical and electric connections): To offer the possibility to change interiors design without the use of important external equipment To reduce cost operation (refurbishment) by 25% To simplify the validation process (standard)
No clear definition of "modularity": for who, for which benefits, …	Library and semantic search: To define common terminology in Europe To facilitate the understanding of target between an operator and a manufacturer
No standard of fixation (vs aeronautic with "Quick change" system)	Propose common standard of fixation system
EUROPEC "Flexible Rolling Stock": no enough experience to edit an European guide	Recommend new European standard by studies and mock up

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

TD1.6 Doors:
- add requirements to design a door to facilitate the loading of interior modules
- share technical watch about plug&play systems to design a modular leaf

- share new needs from cabin of future which could influence the command of the doors

Figure 10: Interaction with other TDs and IPs



1.7.4. Impact and enabling Innovation Capabilities

The improvement resulting from the content of this RIA aims to contribute to the achievement of the KPIs of the Shift2Rail initiative according to the following benefits:

- To increase easily and at low costs capacity of an existing train by 20% (Regional or Intercity train in main target)
- To increase passenger flow in and off trains to reduce by 15-20% dwell time in stations (Regional and long distance train in main target)
- To be able to carry out interior retrofit operations twice often during the life of rolling stock at the same LCC included driver's desk.
- To ensure that thermal comfort meets customer's demands and not only standards, especially when rebuilding a vehicle or changing shifting vehicle's use, e.gg from long distance to regional traffic

The following table summarizes the strategic impacts produced by the TD results. This is organised along three main aspects: the support to the competitiveness of the EU industry, the compliance with the EU strategic objectives, and the degree of maturity of the solutions envisaged to be realised and to be put into practice in the railway sector.

Strategic Aspect	Key Contribution from the TD
Support the competitiveness of the EU industry	• An operator selects interior design. Choices vary from one country to another and are also depending of the a type of exploitation. • Tangible benefits for the end user: ○ Increase the possibility to fit to the needs the passenger lounge area ○ Increase the possibility to adapt the driver cabin of a train to the profile line (from several driving assistant systems to automatic driving) ○ Reduce the cost of refurbishment ○ Increase capacity for new as well as existing train
Compliance with EU objectives	• Increase capacity: you can evolve the capacity of each coach • Increase attractiveness: coach interior and services on board can be adapted more quickly to evolving passenger requests and more economically than currently • Greening of transport can be achieved by optimisation of capacity
Degree of maturity of the envisaged solutions	• From TRL 3-4 (for new ideas) to TRL 5-6 • The first part of the work will explore available existing solutions, so a limited number of concepts will go to higher TRL (TRL 5-6) to finish in TRL 7-8

This TD will contribute to enable five **Innovation Capabilities** as follow:

Innovation Capability	***TD1.7 Train Modularity in Use***
1 – Automated Train Operation	*BB1.7.2 Driving cabs of the future* Driver cab of the future will enable to use the space of the driver cab for passengers when on ATO. Driver Cab will foster transition to ATO by flexible solutions.
2 – Mobility as a Service	*BB1.7.1 Interiors Modularities* Reconfiguring passenger information support inside a coach more easily
6 – Service Operation Timed to Second	*BB1.7.1 Interiors Modularities* Will increase passenger flow in and off trains to reduce dwell time in stations and increase overall passenger capacity. Higher availability by faster retrofitting
7 – Low Cost Railway	*BB1.7.1 Interiors Modularities* Easier refitting of interiors (standardized modules, faster procedures) will lead to decreasing cost.
10 – Stations and Smart City Mobility	*BB1.7.1 Interiors Modularities* Optimised passenger flow in- and outside the train 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 MIU:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Modular Interiors	New Passengers Interiors	A physical mock up of a piece of passenger room (real carbody of a vehicule) Virtual mock up for a complete modular train and simulation of passengers flow for one new interiors 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 users experiences on board thanks to modular interiors with several new diagrams to show the capability to evolve and develop new quick change systems (fast points) for interior finishes (lighting, decors, …) Study the capability to influence the passenger flow by the new interiors design
	New Driver's Cabin	virtual mock up for a complete modular train (3D model in Virtual Reality) included driver's cabin Innotrans 2020: demo with prospective design pictures	Regional	4/5	Study the capabilities of new users experiences on board thanks to modular driver's cabin with several new uses of the space for GoA2 to GoA3 and develop new driving HMI.

Planning and budget:

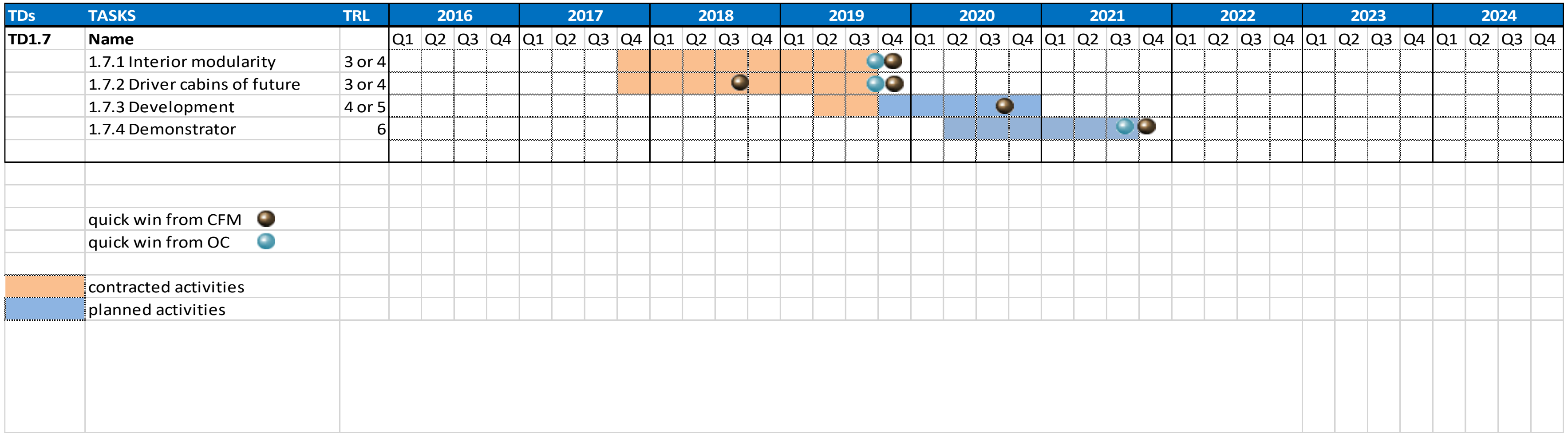


Table 14: TD1.7 quick wins

When	What	Contribution to MAAP
Q3 2018	T1.7.1: video/design view = the needs of operator (which modularity for the future, …) and the state of art (what we do in railway now and what the other industries do, technologies we can use to go further)	Faster adaption of interiors leads to less downtime. Better users experiences and easy adaption to users needs thanks to modular interiors Influencing passenger flow by the new interiors design.
Q3 2018	T1.7.2: video/design view = a video to explain the innovative approach of Cabin and several views or sketches of the results (depending of the confidentiality at this stage)	Modular driver's cabin allows additional use cases for cabin / passenger spacewith regards to ATO New approach to driving HMI.
Q3 2019	T1.7.1: video/design view/mock-up = new plug and play technologies, maybe mockups	Faster adaption of interiors leads to less downtime. Better users experiences and easy adaption to users needs thanks to modular interiors Influencing passenger flow by the new interiors design
Q3 2019	T1.7.2: design view/mock-up = illustration of studies about concepts	Modular driver's cabin allows additional use cases for cabin / passenger spacewith regards to ATO New approach to driving HMI.
Q1 2020	T1.7.3: Book of concepts with illustrations and mock-up	Further development of solutions to achieve above
Q3 2020	T1.7.4: first mock-up and/or prototypes	Setting up demonstrators to achieve above

The estimated total budget for Train MIU TD is around 3 M€.

1.8. TD1.8 Heating, Ventilation, Air conditioning and Cooling (HVAC)

1.8.1. Concept

Conventional "Heating, Ventilation Air conditioning and Cooling" systems (HVAC) within rail vehicles use artificial refrigerants that have a very high impact on the global warming (e.g. R134a). In order to limit the climatic impact from HVAC systems the European Commission passed in 2014 regulation Nr. 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 will be reduced to 21% (compared to the average consumption 2009-2012) until 2030. Rail service operators are forced to act quickly due to the long lifetime of rolling stock. Conventional refrigerants will become scarce and expensive within the near future. Hence new and redesigned trains have to be equipped with eco-friendly HVACs using natural gases such as air or CO2.

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

Regional and Urban railway vehicles have different requirements on HVAC systems since they are not required to keep year-round the same temperature but rather delivering a comfortable climate 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.

Hence there is a very strong need to develop HVACs with natural gases for new vehicles and redesign of existing vehicles and to provide suitable simulation and testing/assessment tools.

Since HVACs are integrated into the vehicle, connected to the energy supply and control and to be maintained by railway operators, the development of new HVACs requires the collaboration between vehicle integrators, HVAC-suppliers and rail service operators. Since these stakeholders take part in Shift2Rail IP1, this topic is well located here.

1.8.2. Technical Objectives

The following table represent the main technical objectives of this TD:

1. Push the development of eco-friendly HVAC systems with natural gases to overcome the limitation of artificial refrigerants within the European Union (40 %)
2. Gain a margin for European HVAC-suppliers in relation to developments outside of Europe (10 %)
3. Open the opportunity to develop new HVAC systems with low Life cycle costs that are optimal integrated in the vehicle (20 %)
4. Open the chance to standardise the interfaces to HVAC-components (compressor, heat exchanger etc.) in the beginning of the 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 in discussion, using the natural gases air or CO2. In contrast to conventional HVAC solutions HVACs with natural gases open the opportunity to integrate a heat pump for increasing the efficiency for heating, operating in a larger temperature range (R134a up to -5°C, CO2 up to -20°C, Air no limit). This is very important for hybrid vehicle with batteries, where the HVAC-energy consumption further reduces the operating km-range of the vehicle.

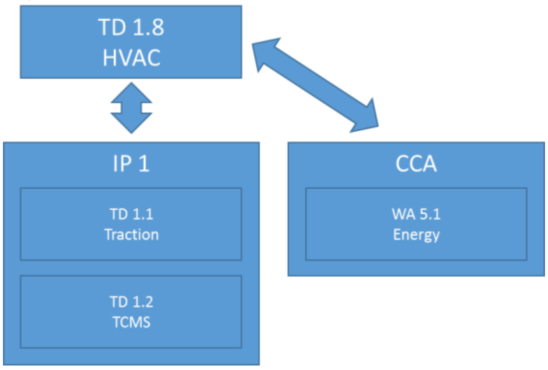
State-of-the-art	Eco-friendly HVACs
Use of artificial gases that have a very negative impact on the global warming	Use of eco-friendly natural gases like air or CO_2
Integration of a heat pump for energy saving economically not easy to achieve	Easy possibility to integrate a heat pump for energy saving
No standardised interfaces of HVAC-components like air compressor, heat exchanger etc.	Possibility for standardised interfaces of HVAC-components and connection to the energy supply and energy management system
Poor and long-lasting maintainability due to the need of collecting the refrigerant before disassembling the HVAC system	Easy and fast maintainability, no environmental impact of leakages

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

The main interaction envisaged with other TDs and/or IPs (see Figure 11: Interaction with other TDs and IPs**Error! Reference source not found.**), both from the point of view of technologies employed and of interaction in performance and objectives are:

- IP1 – TD1.1 "Traction": increasing HVAC efficiency impacts alternative traction systems (e.g. hybrid vehicles with batteries
- IP1 – TD1.2 "TCMS": standardised interfaces for control and monitoring of the HVAC-system
- CCA – WA5.1 "Energy and sustainability": Reduction of energy usage

Figure 11: Interaction with other TDs and IPs



1.8.4. Impact and enabling Innovation Capabilities

The TD has a major impact in the Shift2Rail KPIs:

KPI	Key Contribution from the TD
Life cycle costs	Reduction of energy costs
Reliability	Increase of availability due to shorter repair time
Support the competitiveness of the EU industry	Improve the competitiveness of European HVAC suppliers in relation to Asian suppliers
Compliance with EU objectives	Fulfilling the European requirements for the reduction of artificial refrigerants.

This TD will contribute to enable four Innovation Capabilities as follow:

Innovation Capability	*TD1.8 HVAC enablers*
5 – Optimum energy usage	Reduced energy usage of HVACs by 20 - 45% by means of integration of a heat pump
7 – Low Cost Railway	LCC-reduction due to reduced energy usage and standardised interfaces
8 – Guaranteed asset health and availability	Improved availability due to lower repair times and condition based maintenance
9 – Intelligent Trains	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 TD 1.8 HVAC. Based on the requirement specification existing HVAC prototypes with CO2-refrigerant are analysed with respect of fulfilling the requirements. Using this input the existing HVAC-prototypes are adopted or new built (Technical demonstrator). Finely the prototypes are integrated in vehicles and tested within a climatic chamber as well as in real operation. In addition simulations and pre-standardisations of interfaces are carried out as well as an evaluation and migration strategy. The strategy looks also at alternative refrigerants and at risks of different technologies.

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
HVAC	HVAC-Technology with natural gases	Further development of (1 or 2) HVACs with natural gases Simulation of the behaviour Standardisation of interfaces Integration in a regional EMU Test within a climatic chamber and in real operation	Regional	7	Further development, simulation and test of operation Standardisation of interfaces Reduction of climatic impact Reduction of energy consumption and costs

Planning and budget:

Table 15: TD1.8 GANTT chart

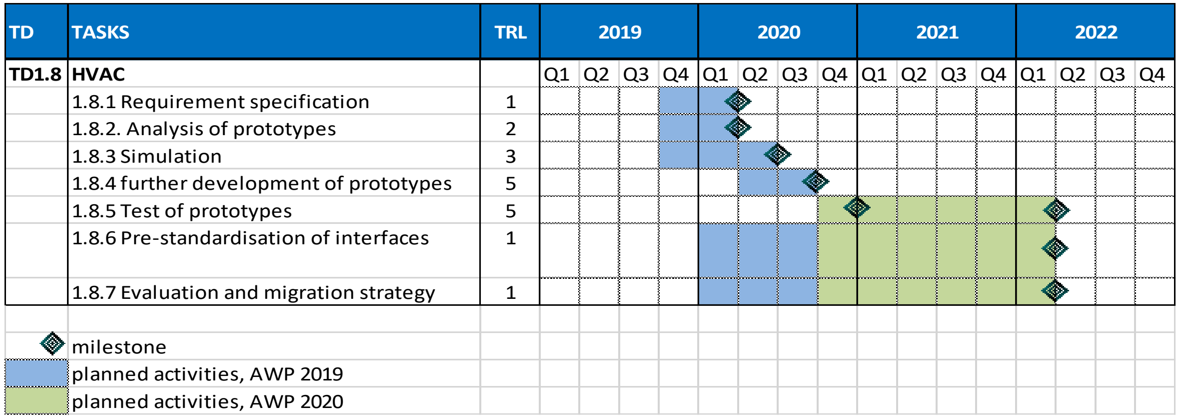


Table 16: TD1.8 milestones

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 TD 1.8 is around 5 M€

IP2 – Advanced Traffic Management and Control Systems

Context and motivation

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

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, as well as 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, 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 becomes 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 the ERTMS Game Changer to become a reality. It will enhance the overall line capacity and contribute to life-cycle cost reductions and global reliability of the railway system, while maintaining the highest level of safety, thanks to a better management of signalling and supervision systems on “static” infrastructure by supporting the development of an intelligent Integrated Mobility Management (I^2M) 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 main line railway ERTMS applications, with a view to extending the new signalling and traffic management system to all railway transportation 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 CBTC functionalities already applied in 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 main goals are to speed up the time to market, improve interoperability, offer improved functionalities and standardised interfaces, investigating modularity concepts, reduce costs (CAPEX and OPEX), and achieve an effective and reliable public rail transportation network with the capability to interconnect and interpenetrate urban rail and main line solutions.

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

IP2 works are at the heart of an integrated railway system having functional and conceptual links with innovative technologies coming, among others, from the implementation of a possible wireless TCMS or modular and scalable architecture approaches taking into account the work already started by some Infrastructure Managers with RCA (Railway Reference CCS Architecture) and by some Railway Undertakings with OCORA (Open CCS On-board Reference Architecture). This activity will be further developed to integrate, in particular within IP2 activities, the results of the S2R Call 2019 dedicated to kick-start 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 standardized 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 Trains' 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 process/tools to be applied – since specification up to commissioning phase – to key elements and systems the failure of which might cause major impact on line operation (e.g. signalling, telecom)
	Fundamentally simplified architectures, or architectures more suited to continued operation in case of failure	Train communications and control architecture based on new technologies allowing much lower physical complexity and enabling operation recovery in case of degraded modes.

Objective	Result	Practical (concrete) Deliverable
Railway system life cycle cost 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 a 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 which 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 of maintenance cost	By 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. A larger introduction of auto-diagnostic functions to detect the status of more critical components will allow a predictive (and optimised) maintenance.
	Reduction in the consumption of energy	By introducing an appropriate ATO functionalities (with Grade of Automation from 2 to 4) and Intelligent Traffic Management in all rail transport market segments

Past and ongoing European & national research projects

IP2 will ensure strong continuity with several ongoing or past projects (e.g.: TEN-T projects, NGTC, UNISIG activities in the framework of the Baseline 3 evolution, GSA projects like 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 WGs	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 evolution.
TD2.2 Railway network capacity increase (ATO up to GoA4 – UTO)	ATO over ETCS	The results of the TEN-T programme (GoA2 concepts and requirements) will be implemented (prototypes) and validated in order to provide a GoA2 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 applying the GNSS technology to the current ERTMS/ETCS core.
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 WG, including security by design aspects

Set-up and structure of IP2

Structure of the TDs

In order to address the challenges of IP2, eleven 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** (TD 2.1 Adaptable communications for all railways) able to overcome the shortcomings in current ETCS (European Train Control System) and CBTC (Communications-Based Train Control) 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.: 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" model vision, considering also the vision of "virtual network slices" being developed and deployed by 3GPP and the mobile operator community. Backward compatibility with ERTMS will be ensured.

- **Safe Train Positioning** (TD 2.4 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 possible add-on for fulfilling the scope), the use of other new technologies (e.g. inertial sensors, mobile network positioning) or of other on board existing 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 track-side conventional train detection systems (balises, track circuits, axle counters, etc.).
- The development of **smart object controllers** (TD 2.10 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 e.g. with 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 Traffic Management System** (TD 2.9 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 on area level, intelligent, automated and flexible dispatching systems including conflict detection and resolution) to allow for predictive and dynamic traffic management in regular and degraded situation. This Technical Demonstrator 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 Automatic Train Operation (ATO)** (TD 2.2 Railway network capacity increase (ATO up to GoA4 – UTO)) aims to develop and validate a standard Automatic Train Operation (ATO) with FFFIS interfaces up to GoA3/4 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** (TD 2.3 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 evolutions towards CBTC functionalities for Urban applications.
- **Safe Train Integrity** (TD 2.5 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 notably 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** (TD 2.8 Virtually – Coupled Train Sets (VCTS)) 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 currently provided.

Smart procurement and testing

- The development of a set of **standardised engineering and operational rules** (TD 2.7 Formal methods and standardisation for smart signalling systems) contributing 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** (TD 2.6 Zero on-site testing (control command in lab demonstrators)) comprised 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 comprised of sub-components of different suppliers. The test framework will also allow remote connection of different components/subsystems located in various testing labs.

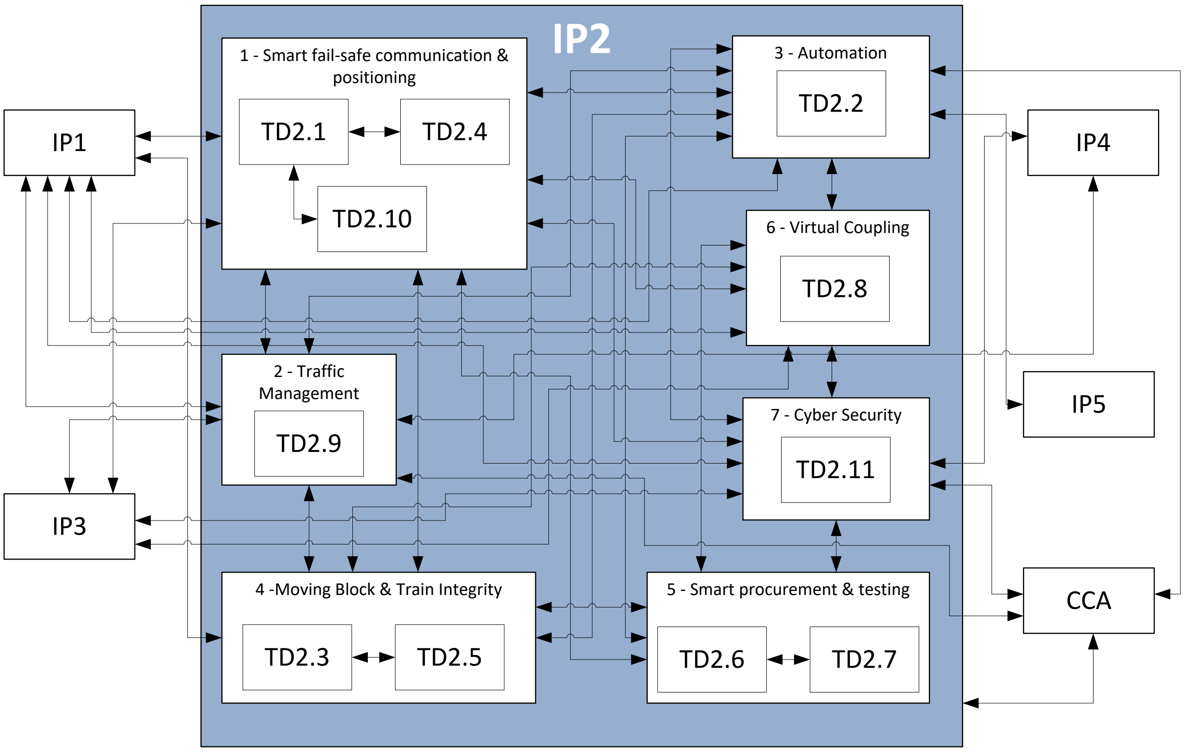
Communication Network and Security Systems:

- **Cyber-Security** (TD 2.11 Cyber Security) will aim to achieve the optimal level of protection against any significant threat for the signalling and telecom systems in the most economical way (e.g.: protection from Cyber Attacks and Advanced Persistent Threats coming from outside).

All the IP2 Research Areas and relevant TDs are closely linked between them. Strong connections are already foreseen towards other Innovation Programmes and/or Cross cutting activities.

Figure 12 shows the expected links and interactions between TDs of IP2, as well as with other IPs. ***Table 17*** also shows in detail the relationships for each TDs and also reveals the big challenge of IP2 which is to foster the evolution of a whole and interactive signalling system.

Figure 12: IP2 Research & Innovation relationships



The following tables show how tight are synergies within IP2 and with the other Innovation Programs in S2R, this is not withstanding the link that is . The tables also identify the main direction of the information foreseen to be shared between TDs and other IPs.

In addition, the existing interactions with other IPs and within relevant TD´s 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 17: Links & Synergies between TDs within IP2[1]

		TO \ FROM	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 each other and need to exchange deliverables, 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 to achieve 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 which allows the accomplishment of the target for other TDs. Synergies and a coordinated project planning is one of the most important key aspects for the achievement of the Master Plan objectives.

Table 18: Links & 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 have also potential relations with IP1 TD1.2 (Train Control and Monitoring System – TCMS). The purpose is to identify common requirements and solutions where on board signalling and automation systems have to communicate each other, with wayside systems and with the train. The approach is expected to foster standard solutions which means integration and cost reduction.

[1] **Legend: X:** bi-directional info exchanged**; ← ↑:** direction of the info exchanged

Table 19: Links & 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 relations with IP3 mainly for the aspects related to diagnostic, maintenance procedures and integration processes.

Table 20: Links & 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 relations are expected with IP4, one related to the interface of TMS with passenger information system and the other one for providing results of the Cyber Security Assessment for the Interoperability Framework.

Table 21: Links & 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 IP2 TD2.2 – Railway Network Capacity increase (ATO up to GoA4) and IP5 TD5.6 - Autonomous Train Operation in order to harmonize ATO overall development and functionalities for Freight application as well.

Table 22: Links & Synergies between IP2 TDs and CCA, 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 CCA and IN2Rail which impact mainly with supervision systems (wayside and on board) and Cyber Security. Sub-WA2 CCA KPI monitoring has also to interact with all IP2 TDs in order to manage and harmonize KPI process.

Table 23: Links & 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 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 radio technology evolution, as well as enabling new operating models that reduce capital investments and operational costs.

2.1.2. Technical Objectives

The following represent the main technical objectives of this TD:

1. Realising the potential of emerging railway applications with enhanced, flexible and superior communication services
2. Designing a "technology independent" system by decoupling the railway applications from the underlying radio access systems and consequently to introduce generic and flexible communication services. Allow future evolutions of the radio bearer technology with minimum dependencies or impact to 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 mainline, 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 1 shows the 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 track-side applications are depicted, including Automatic Trains Protection (ATP), Automatic Train Operation (ATO), Train Control & Monitoring System (TCMS) and critical voice 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.

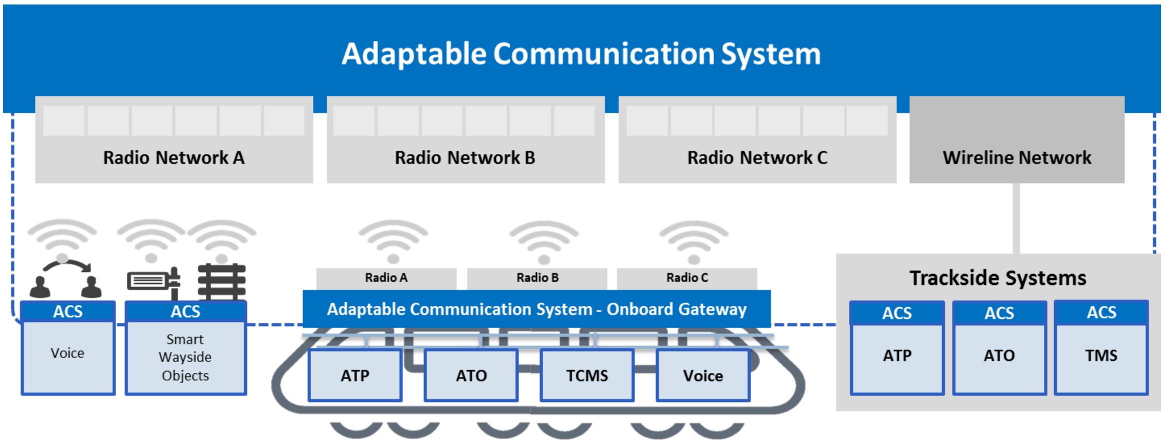


Figure 13: Functional diagram of Adaptable Communications System for all Railways

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 communications technology for servicing current and emerging operational needs of railways.

State-of-the-art	Adaptable Communication System
Monolithic communication system with direct interactions to railway applications	Decoupling of railway applications from the underlying radio systems using generic communication services leveraging IP based transmission
Limited communication features and capabilities constrain 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-RAT as well as inter-network handover and ubiquitous redundancy
Changing or upgrading the communication system forces costly changes or updates of the railway applications	The radio system and related upgrades of the radio technology becomes 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 foresee flexible operational models which fit the needs of the railway undertaking.
Proprietary and niche market solutions drive 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 (of the same IP and/or of the other IPs)

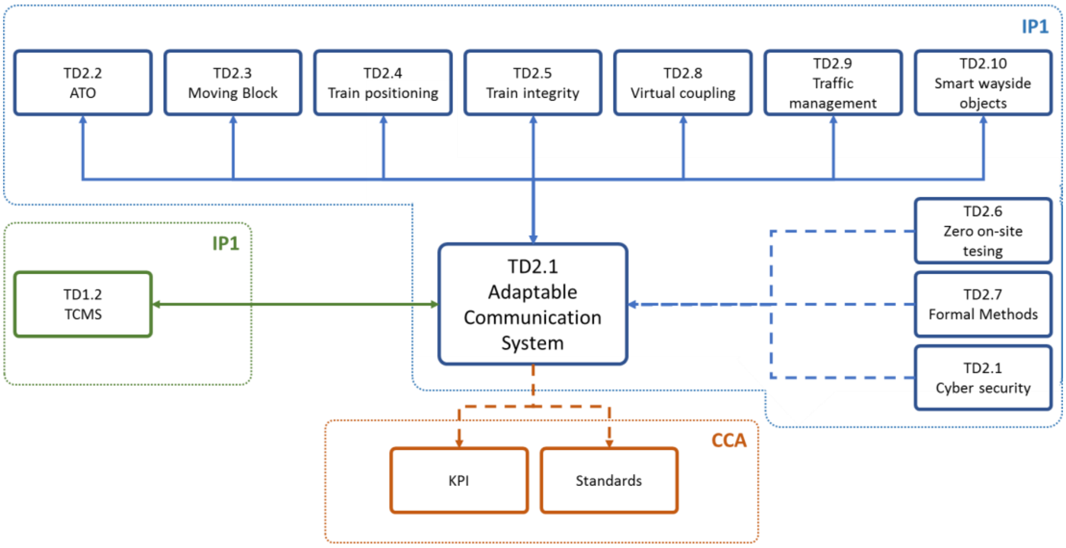


Figure 14: Interaction with other TDs and IPs

2.1.4. Impact and enabling Innovation Capabilities

The new Adaptable Communication System provides significant value and benefits to all of the proposed technology demonstrators of Shift2Rail. Benefits span 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 costs savings. The following table 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	• The adaptable communication system acts a key enabler for the complete rail system and provides the following tangible benefits to maintain and enhance the 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 SatCom into generic services to improve the communication performance and characteristics such as enhanced throughput, superior resiliency, transmission priorisation, enlarged coverage, etc. which enable new innovative railway applications ○ Support of new business models to provide communication services based on infrastructure or resource sharing up to network-as-a-service models. ○ LCC reduction (through sharing of the communication network or possibility to use public network in some conditions)
Compliance with EU objectives	• The communication technology is in constant evolution and the TD will take that situation into account: the modular architecture will allow applying the latest convenient technologies on emerging market, while nevertheless ensuring backward compatibility with already deployed ERTMS in Europe, allowing a migration phase. The radio bearer could be transparently selected and adapted according to the specific conditions to keep the costs as low as possible (ex: use of satellite communication in large area few populated, to save the cost of a wayside communication infrastructure)Enable a common communication system to address the requirements of all segments in the rail system with unified and cost-efficient communication services • Help to advance railway applications to achieve the goals around capacity increase, modal shift, more efficient railways • Leverage standardization, interfaces and architecture to ease and improve interoperability between different subsystems and the communication system
Achieve the Single European Railway Area	• Interoperability will be provided, including with a solution suitable for the urban/suburban domain; answering either to the needs of current and enhanced CBTC and ETCS solutions.
Degree of maturity of the envisaged solutions	• Although the radio technology and system foreseen 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 Shif2Rail it is expected that the concepts and functional prototypes are brought to TRL 6 or 7.

The Adaptable Communication System for all Railways provides communication services and associated benefits to basically all innovation capabilities. As such the building blocks

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

Can be added to the different rows per innovation capabilities.

This TD will mainly contribute to enable seven **Innovation Capabilities** as follows:

Innovation Capability	***TD2.1 Adaptable Communication System - TRL 5/6***
1- Automated Train Operation	Provide generic and enhanced communication services transparent and decoupled from to the railway application, including Automated Train Operation. As such the Adaptable Communication System is a key enabler for the Automated Train Operation application.
4- More value for Data	Act as communication backbone for the rail system and drive digitalization in railways to the next level while supporting adaptable, secure, resilient and scalable communication services.
6- Service operation timed to the second	Provide flexible and efficient communication services to support the information exchange between vehicles and traffic management to enable a consistent and real-time management of the rail system
7- Low Cost Railway	Rely on standardized 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 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 for all rail systems, including high-speed, regional, urban and metro rail

The above listed contribution to innovation capabilities represents only the main areas for TD2.1. Further contributions to other capabilities are expected, for example, Mobility as a service 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 CAPEX,OPEX and total cost of ownership reductions. Communication-as-a-Service becomes an integral part of the Mobility-as-a-Service capability. Furthermore the Logistics on demand innovation capability is also supported by the adaptable communication system with flexible and multi-purpose 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 standardized communication system.

2.1.5. Demonstration activities and deployment

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Adaptable Communication System for all Railways	Improved communication capabilities (throughput, 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 a 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 sharing options based on input parameters covering cost implications, technology options etc.

Planning and budget:

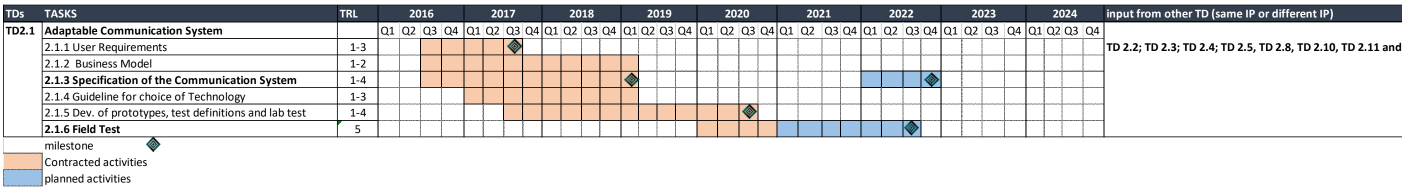


Table 24: TD2.1 milestones

When	What
3Q2017	User and System Requirements deliverable
1Q2019	Specification document deliverable
3Q2020	Lab test and validation of prototypes
3Q2022	Field test and validation of technology demonstrator
4Q2022	Update of specification document

The estimated total budget for Adaptable Communication System TD is around 26.4M€.

2.2. TD2.2 - Railway network capacity increase (ATO up to GoA4 – UTO)

2.2.1. Concept

Mainline ETCS applications (including suburban) are currently generally limited to non-automated train operation (GOA1 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 (EEIG) cover all Grades of Automation (GoA):

- GoA1: Non automated train operation (current situation): the train is driven manually; but protected by ETCS.
- GoA2: Semi-automated train operation: the train is driven automatically; but the driver is still in the cab to control the absence of obstacles in the track.
- GoA3: Driverless train operation.
- GoA4: Unattended train operation.

Even though the highest Grade of Automation 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 to urban systems, the situation for mains line systems is more complex, see list below:

- 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 is a lot of 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, road level crossings, footpath crossings, open station platforms, etc;
- Infrastructure Managers (IMs) and Railway Undertakings (RUs: train owners and operators) are often independent (at least in the European Union), and sometimes other parties are also involved, such as train leasing companies.

Despite the specificities of Main Lines, Automated Train Operation (up to GOA4) 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 GOA2) will enhance the time-table adherence and optimise energy consumption;
- For Freight lines, both on heavy haul railroads and low density traffic lines, ATO (at least GOA2) will provide a smoother operation, bring energy savings and permit an optimal efficiency e.g. allowing "meet-and-pass" operation whenever possible;
- For Urban and Suburban applications, Driverless (GOA3) and Unattended (GOA4) types of operation will allow for high performance for lines carrying intensive inner Suburban and cross-city services having the full advantage of ETCS (interconnections, train types diversity, interoperability, etc.)

2.2.2. Technical Objectives

The aim of this programme is to investigate, develop and validate Automatic Train Operation over ETCS up to GoA4. The actual objectives are:

1. To increase the transportation capacity on existing lines while limiting investment for new infrastructure;
2. To reduce the operating costs, save energy and have a 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 which are not interoperable. The existing systems are considering simple lines and operation schemes.

The progress will be to provide 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 main line operation (large interconnected network, different level of infrastructure fitment, lot of different train types not dedicated to a given line, etc).

Compared to the current state of the art in Railways, the following benefits are expected from IP2 – TD2.2:

Table 25: Benefits expected

	High Speed Lines	Low Traffic Lines / Regional Lines	Urban/Suburban Lines
Punctuality	Journey times less variable and closer to Time Tables	Journey times less variable and closer to Time Tables	Journey times less variable and closer to Time Tables
Operational headway	Less variability in actual Journey time permits the Infrastructure Operator to foresee fewer "reserve time" in the Theoretical Time Tables. This leads to a lower operational headway and will increase the line capacity	Less variability in actual Journey time permits the Infrastructure Operator to foresee fewer "reserve time" in the Theoretical Time Tables. This leads to a lower operational headway and will increase the line capacity	Less variability in actual Journey time permits the Infrastructure Operator to foresee fewer margins in the Theoretical Time Tables. This leads to a 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 foreseen in the Theoretical Time Table.	Less variability in actual Journey time permits the operator to reduce the Journey Times foreseen in the Theoretical Time Table.	Less variability in actual Journey time permits the operator to reduce the Journey Times foreseen in the Theoretical Time Table.
Energy consumption	The trains are driven according to optimum Speed Profiles that minimises the energy consumption.	The trains are driven according to optimum Speed Profiles that minimises the energy consumption.	The trains are driven according to optimum Speed Profiles that minimises the energy consumption.
The staffing costs	Driverless and unattended operations allow for reduction of the required operation staff, thus contributing to enhance Railway Transport Productivity.	Not an issue.	Driverless and unattended operations allow for reduction of the required operation staff, thus contributing to enhance Railway Transport Productivity.

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

IP2 – TD 2.2 is linked with the following TDs:

- IP2 – TD2.1: "Adaptable communications" for getting common telecommunication infrastructure for ATO data exchange;
- IP2 – TD2.3: "Moving fluid block" for common influence;
- IP2 – TD2.4: "Fail-Safe Train Positioning" for managing absolute positioning to be used for ATO functions;
- IP2 - TD2.5: "On-board train integrity" to manage automatic coupling and uncoupling;

- IP2 – TD2.6: “Zero on-site testing” to have the benefits of the results from this WP for ATO-TS and ATO-OB testing;
- IP2 – TD2.7: “Formal methods for smart signaling system” including to have the benefits of the results from this WP for ATO-TS and ATO-OB development;
- IP2 – TD2.8: “Virtually-coupled train sets” to increase operation performances with ATO managing virtually coupled trains;
- IP2 – TD2.9: “Traffic Management System” to consider standard interface with TMS. The trackside ATO management is considered to be a subsystem separated from TMS and connected to the TMS via standard interface of the Integration Layer which will be developed under TD2.9.
- IP2 – TD2.11: “Cyber system security including key management” to cover communication between ATO on board and wayside).
- IP5 – TD5.6 “Autonomous Train Operation” in order to get ATO specification for freight and to provide ATO prototypes to be tested on a pilot line dedicated to freight.

IP2 – TD 2.2 will also interact with IP1 (CONNECTA) in order to envisage standard interfaces with TCMS and rolling stock.

Finally, IP2-TD 2.2 will have links with “CCA Sub-WA5.1 Energy” and “CCA Sub-WA4.2 in order to identify information to be exchanged in addition to the ones provided by the “Traffic Management System” defined in IP2-TD2.9.

2.2.4. Impact and enabling Innovation Capabilities

Thanks to the operational headway reduction, it is expected that IP2-TD2.2 developments will bring 10 to 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, the characteristics of existing and new rolling stock are among the parameters that will have to be considered.

The consequence of the operation margin improvement is that the amount 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 a savings of between 12% and 20%.

The benefits associated to Staff Reduction depend also on the type of operation.

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

In GoA3/4, the staff reduction is, by definition, much more important; even if the operator must, in these Grades of Automation, still foresee people on site in order to manage the degraded modes.

ATO over ETCS (up to GoA3/4) will completely change the way future Railway Lines are operated.

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

- improve the services and the customer perception of quality by improving the punctuality and by increasing the transportation capacity in order to face the growing demand in public transport over the coming decades.
- Reduce the operation 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.

The TD2.2 provides interoperable solutions for automatic driving (up to GoA4). As such the following building blocks can be added to the different rows per innovation capabilities:

- 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.

This TD will mainly contribute to enable six **Innovation Capabilities** as follows:

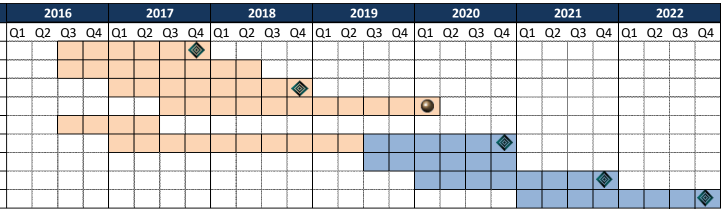
Innovation Capa-bility	***TD2.2 ATO (up to GoA4) - TRL 6***
1- Automated Train Operation	The TD 2.2 provides the following for GoA 2 and GoA3/4: • Interoperable specification (including interface specification) • Prototype development • Factory interoperability tests mixing solutions from different suppliers. • On site pilot tests. With these activities, TD 2.2 is a key enabler for the Automated Train Operation application.
3-Logistics on de-mand	Automatic Train Operation in GoA4 increase flexibility of railway operation in all market segments improving transportation capacity in real time according to the actual situation. It also reduce the recovery time after disruption.
5-Optimum enegy use	Automatic Train Operation in GoA2, GoA3 and GoA4 is based on optimised speed profile computation which guarantees on time arrival and minimising the energy consumption.
6- Service operation timed to the second	Automatic Train Operation in GoA2, GoA3 and GoA4 is based on optimised speed profile computation which guarantees on time arrival and minimising the energy consumption.
7- Low Cost Railway	Automatic Train Operation in GoA3/4 reduce the operation costs with a better use of the operation staff. In addition ATO in GoA2, GoA3 and GoA4 minimises the energy consumption re-ducing drastically the associated operation costs.
9- Intelligent Trains	TD2.2 provides the specification for the entire GoA4 solution based on intelligent unattended trains.

2.2.5. Demonstration activities and deployment

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	TRL	Focus of activity
ATO up to GoA3/4	Demonstrate the interoperability of GOA2 solution in factory	System Requirement Specification for GoA2 Test bench Interoperability	Urban High-speed Regional Freight	6	Two Reference Test Bench platforms will be used (1 from SIEMENS and 1 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 GoA2 solution on actual pilot train and line	System Requirement Specification for GoA2 Test bench Interoperability	Urban High-speed Regional	6	The tests will be hosted by NR on Hitchin test facilities (the pilot line) and on the Class 180 train (ALSTOM train with ALSTOM ETCS)
	Demonstrate the interoperability of GOA3/4 solution in factory	System Requirement Specification for GoA3/4 Test bench Interoperability	Urban High-speed Regional Freight	6	Two Reference Test Bench platforms will be used (1 from ANSALDO and 1 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 GoA3/4 solution on actual pilot train and line	System Requirement Specification for GoA3/4 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	input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.2	**Railway network capacity increase (ATO up to GoA4–UTO)**			
	2.2.1 ATO over ETCS - GOA2 Specification	3-4	**IP5 - TD 5.6**	
	2.2.2 ATO over ETCS - GOA2 Product Development	5-6		**IP5 - TD 5.6**
	2.2.3 GOA2 Reference Test Bench Demonstration	6		
	2.2.4 GOA2 Pilot Line Demonstration	7		
	2.2.5 ATO over ETCS - GOA3/4 Feasibility Study	3		
	2.2.6 ATO over ETCS - GOA3/4 Specification	3-4	**TD 2.1; TD 2.3; TD 2.4; TD 2.5; TD 2.6; TD 2.7; TD 2.8; TD 2.9; TD 2.11**	**TD2.1, TD2.4, TD2.9, TD2.11**
	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 26: TD2.2 quick wins

When	What	Contribution to MAAP
Q4 2018	"Semi-Automated" operation (GoA2)	Main outcome of this quick win is the availability of GoA2 products permitting: • to increase operation performances reducing the operational headway up to 30% ; • to reduce operation cost saving energy consumption by at least 15%; • To enhance the punctuality and to reduce the mean journey time.

Table 27: TD2.2 milestones

When	What
Q1 2018	ATO over ETCS GoA2 specification available
Q4 2018	ATO over ETCS GoA2 Reference Test Bench Results available
Q2 2019	ATO over ETCS GoA2 Pilot Tests results
Q4 2020	ATO over ETCS GoA3/4 specification available
Q4 2021	ATO over ETCS GoA3/4 Reference Test Bench Results available
Q4 2022	ATO over ETCS GoA3/4 Pilot Tests results

The estimated total budget for TD2.2 is around 22,48 M€.

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 Infrastructure Managers and Railway Undertakings as a way to increase significantly the capacity of railway lines which are already saturated or which 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 Technical Demonstrator 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 permits 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 Shift2Rail objectives.

Each of these areas can have an impact on services for customers.

- Higher Capacity enables an increase in the number of train services which can be run over given infrastructure.
- Lower Cost is of interest to all, and potentially enables upgrading of railways which 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:

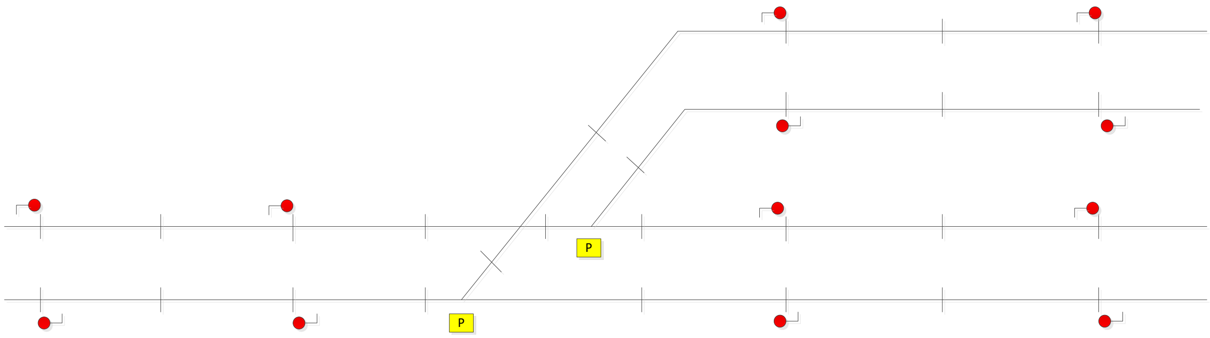
- Between equipment from different vendors;
- Between trackside and train-carried equipment;
- Between equipment owned and operated by different Railway Undertakings.

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 Main Line systems, traditional signalling systems have fixed blocks (Figure 15).

Figure 15: Fixed Block layout

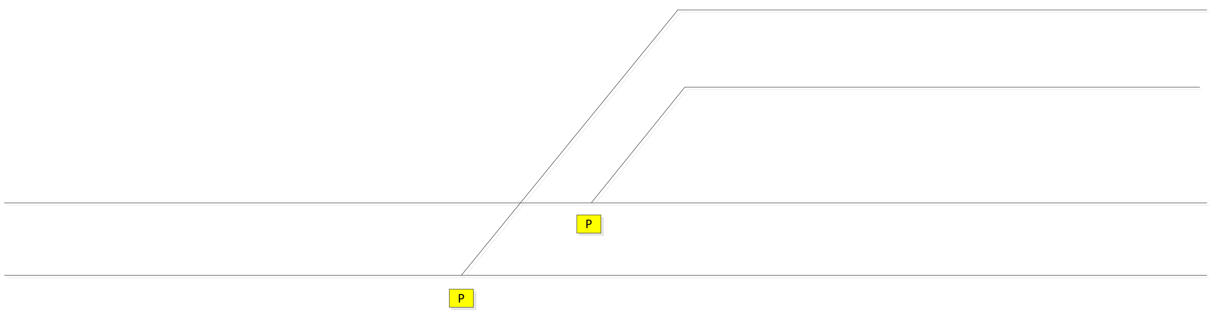


The blocks are fixed during the design of the infrastructure, and then hard coded into the infrastructure, for example by the application of track circuits or axle counters.

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 thence the traffic management system, 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 a 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 (of the same IP and/or of the other IPs)

Other TD	Main Outputs from TD2.3	Main Inputs to TD2.3
TD2.1 Communications	Communications requirements for Moving Block Signalling System, for example latency, frequency of messages.	Communications capabilities resulting from the work of TD2.1.
TD2.4 Train Location	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 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	No specific output from TD2.3.	Understanding of how Formal Methods could be applied to the specification of Moving Block Signalling Systems.
TD2.11 Cyber Security	No specific output from TD2.3.	Understanding of the impact of cyber security measures on Train-Trackside communications. It is likely that the impact of TD2.11 on TD2.3 will be via TD2.1 Communications.

Figure 17: Interaction with other TDs and IPs

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 ATO
- TD2.9 Traffic Management

The interaction with these TDs is summarised in the following table:

Other TD	Interaction with TD2.3
TD2.2 ATO	Collaboration with TD2.2 to understand how to build combined ITD showing ATO operation over Moving Block Signalling System.
TD2.9 Traffic Management	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 enable **Strategic Aspects** as follows:

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 of equipment fitted to the railway.

This TD will contribute to enable **Innovation Capabilities** as follows:

Innovation Capability	***TD2.3 Moving Block enablers - TRL6***
1 Automated train operation	• 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 It is expected that Moving Block will be integrated with ATO.
6. Service operation timed to the second	• 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 Moving Block will permit services to be timed to the second, provided sufficient communications bandwidth is provided.
7. Low Cost 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 Moving Block contributes towards lower cost railways by a reduction in the equipment fitted to the railway.
9. Intelligent Trains	• 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 Moving Block contributes towards Intelligent Trains, as within ETCS, each train manages its own movement within the overall Movement Authority.

2.3.5. Demonstration activities and deployment

Research Area	Specific Technical objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
Moving Block	Higher Capacity	Moving Block System Specification	Urban / Suburban	6	Create Technical Demonstrator for Urban / Sub-urban and High Speed railway environments. Links with TD2.1 Communications, TD2.2 ATO, TD2.5 Train Integrity. Enable maximum use of available infrastructure on capacity-constrained railways.
			High Speed Lines	6	
	Lower Cost	Moving Block System Specification	Low Traffic / Freight	6	Create Technical Demonstrator for High Speed railway environment. Links with TD2.1 Communications, TD2.2 ATO, TD2.5 Train Integrity. Enable maximum use of available infrastructure on capacity-constrained railways.
	Migration	Moving Block System Specification	Main line	6	Create Technical Demonstrator of an Overlay Moving Block Signalling System, focused on enabling migration from traditional signalling systems.

Planning and budget:

TDs	TASKS	2016	2017	2018	2019	2020	2021	2022	input from other TD (sa
TD2.3	**Moving Block**	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	
	Task 2.3.1 Moving Block Operational and Engineering Rules								TD2.5 Train Integrity
	Task 2.3.2 Moving Block System Specifications								TD2.1 Communications
	Task 2.3.3 Product Specifications								
	Task 2.3.4 Safety and Security Analysis								TD2.5 Train Integrity
	Task 2.3.5 Prototype Developments								
	Task 2.3.6 Test Specifications								TD2.7 Formal Methods
	Task 2.3.7 Technology Demonstrators								TD2.2 ATO TD2.9 Traffic Managem

Contracted activities
planned activities

The estimated total budget for TD2.3 is around 25,06 M€.

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 aimed to become an absolute positioning system, significantly reducing the number of the 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 from one side 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, MEMS). For reducing the modifications to the existing ERTMS standard and, thus, the impact on existing ERTMS solutions and on the planned ERTMS specifications roadmap evolution, the concept of Virtual Balise and the same ERTMS Location and Train Position Principles (i.e. LRBG and measured distance from the LRBG) shall 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 the ERTMS functions.

During the TD 2.4 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 evolutions, digital map evolutions).
The TD 2.4 Fail-Safe Train Positioning functional block will be defined and develop so as to (a) ensure backward compatibility at ERTMS subsystem level and at ERTMS constituent level and (b) interoperability at the ERTMS constituent level (i.e. on-board and trackside level) by the specification of the required FFIS.

Demonstrators will be developed to verify this TD 2.4 Fail-Safe Train Positioning in the context of High Speed, Conventional, Regional and Freight lines.

2.4.2. Technical Objectives

The following represent the main technical objectives of this TD:

1. Significant reduction of 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 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 in a way that it 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 characterize and assess the new technologies foreseen in TD 2.4 but not used in STARS with respect to the high demanding rail environments. 5. Based on the Public results of the GSA ERSAT-GGC Project, enhancements of the process and related tools for classifying railway track areas as suitable or not suitable for the placement of Virtual Balises will be designed and developed. 6. Definition and development of (a) models (suitable for railways environments) describing the local effects on the position accuracy, (b) simulators for supporting LAB Tests, and (c) adequate Test Suite for laboratory and field tests. The models will also take into account the Public results of important and railway representative projects such as STARS and ERSAT-GGC. 7. Study of different solutions to achieve train position functionality in railway environments, like single constellation and multi-constellation approaches, GNSS algorithm improvement, mono and multi-frequencies receivers, as well as 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, multipath, non-line-of-sight) at RF and observables level including contribution to MOPS error models. 9. Investigation on the use of RTK Method or alternative solutions in Railways 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 of 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

State-of-the-art	Fail safe Train Positioning
Train Localization by means of physical balises and the relative distances from the reference balises (LRBGs)	The main measureable advantage, in areas where satellite positioning is applicable, is represented by the significant reduction of the physical balises for the position referencing and, in combination with train integrity/ETCS Level 3, of the track side 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 of the operational performances (e.g. no delays caused by the application of brake commands due to vandalism acts, failure of physical balises, EMC interferences in the eurobalise airgap).
Train Detection through trackside signalling devices (track circuits, axle counters)	When the technology enables the track discrimination, fail safe train positioning based on GNSS and multi-sensor technology opens to 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 concepts of virtual balises, which would keep the ERTMS core largely unchanged, is significantly expected to 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	Fail safe train positioning functional block will be designed and developed to guarantee the ERTMS backward compatibility and interoperability. The interfaces of the fail-safe train positioning functional block, to be integrated as a functional block of the ERTMS/ETCS constituents, with impact of the interoperability requirements will be defined as FFFIS.

Figure 18: The vision technical vision

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

Interaction 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 provided by the following table:

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 a) the Track-side-to-Train communication (and vice versa) needs, and (b) the Train-to-Train 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 GoA4 – UTO)	Provide requirements and system behaviour (a) to identify possible synergies about track database management and (b) 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 (a) specifications and procedures for track database survey and constructions, (b) methods and tools for the track database construction and verification, (c) methods and tools for dynamically updating of 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 the Localization 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, GNSS technologies and a combined use of multi-sensor technologies. Investigation on the possible integration of the modelling tools and the simulators, developed in the context of TD2.4, into the TD2.6 verification infrastructure will be established.	Understanding 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	The identified formal and semi-formal methods and the related recommended environments will be evaluated for analysing a their possible applications in the recommended life cycle phases.	Cooperate to follow common methodology in writing documents (FRS, SRS) and / or modelling & 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 Cyber Security	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 foreseen in the ERTMS standard BL2 R2) exchanged thought 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 interferences on 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.

Figure 19: Interaction with other TDs and IPs

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 in fostering the application of new Train Separation systems like 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 sub systems (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 of equipment fitted to the railway, the effects of their failures, the consequence of vandalism acts on physical balises.

This TD will contribute to enable four **Innovation Capabilities** as follow:

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 of trackside train detection systems BB2.4_3 Interoperability with ERTMS/ETCS core
6- Service operation timed to the second	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
7- Low cost railway	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
9- Intelligent trains	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

2.4.5. Demonstration activities and deployment

Research Area	Specific Techn. 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 Trial Site. A Mermec Virtual Balise Reader / VBTS prototype, based on multi-sensor technologies will also be verified in 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.
Fail Safe train positioning	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 on the on-board EVC system	Low density traffic lines	4/6	Within X2Rail-2, the Fail Safe Train Positioning (FSTP) requirement, safety analysis and simulated testing environment are identified. The demonstrator at X2RAIL-5 has the aim to prove what simulating testing has shown as valid FSTP.

Fail Safe train positioning	Demonstrator of a Virtual Balise Reader / VBTS for HS/Mainlines, Freight and Regional lines	A LDS/Virtual-BTM prototype demonstrator with emphasis on application to Freight and Regional lines will be also developed. This demonstrator will be finally verified in real railway environment in selected regional line in the Czech Republic.	HS/Mainlines, 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				input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.4	**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		
	T2.4.1 – General Specification	NA																													TD1.2, TD2.1, TD2.2, TD2.3, TD2.5, TD2.6, TD2.7, TD2.8, TD2.11	TD1.2,TD2.1, TD2.2, TD2.3, TD2.5, TD2.6, TD2.7, TD2.8, TD2.11
	T2.4.2 – On site GNSS performance tests																															
	T2.4.3 – Analysis of the results of the GNSS Performance test activities																															
	T2.4.4 – Analysis of the technical solutions for optimizing the GNSS performances in railway environment and proposal for the demonstrators																															
	T2.4.5 – Proof of concept GNSS based localisation devices																															
	T2.4.6 – Process for validation in lab and on field																															
	T2.4.7 – Lab tests	4																														
	T2.4.8 – Update of the technical specifications according to the full test campaign results	4-5																														
	T2.4.9 – Development of Prototypes	4-5																														
	T2.4.10 – Field activities: integration and commissioning tests, validation and certification of the prototypes	4-7																														

milestone ◆
quick win ●

Contracted activities
planned activities

Table 28: 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 24,29 M€

2.5. TD2.5 - On-board Train Integrity

2.5.1. Concept

The 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 coherent way in relation to the movement of the remaining 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 becomes a need for the implementation of more efficient signalling systems based on concepts like Moving Block or Train Position delivered by on-board equipment. Systems based on these concepts will deliver very significant advantages in terms of capacity, shorter headways; capital and maintenance cost, removal of track infrastructure for block detection; resiliency, and others such us 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 fall back system or to confirm the train position in degraded situations.

In addition to the new functional and performance requirements, the On-board Train Integrity (OTI) could be the enabler in getting the economic sustainability of new railway lines, especially for freight and low density mixed-traffic lines. In these cases, the 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 anyway aimed to define and prototype an innovative on-board Train Integrity 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 goal of the solution must be:

3. Autonomous localisation of the train tail without interaction with trackside equipment;
4. 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;
5. Safe detection (SIL-4) of train interruption, filtering false alarms conditions;
6. Innovative solution to supply the required power for OTI equipment in freight convoy, where the solution will involve both the generation of energy and its possible storage.

The following table summarizes the **objectives** and related deliverables of this TD:

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's, maximising the possible interactions with IP2 TD4.	Specification, development and demonstration of on-board train tail detection, based on autonomous localisation (interactions with IP2 TD4 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: 1) wireless communication between the tail and the front cabin, without any trackside network support, in the case of absence of a hardwired train communication line. 2) Interface with TCMS network, maximizing the possible interactions with IP1 TD1.2.	Specification, development and demonstration of two different solutions for freight and passenger's convoy: 1) wireless communication between the tail and the front cabin. 2) 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.

Table 29: Objectives and Deliverables

2.5.3. Technical Vision

Train Integrity Monitoring System Working Group (TIMS WG) of the former EEIG ERTMS Users Group finalized its work on the TIMS Functional Requirement Specification (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 don't have electrical network, limits the introduction of ETCS L3 to passenger lines or corridors operated with state of the art trains equipped with a train bus system.

Analysing the patent applications in this field, they were more numerous in the early 2000s but were not followed by as many applications in recent years. The field in which most of the patent applications have been focused is related to the freight lines due 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 more 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 among them.

The following table summarizes how this TD will progress the state-of-the-art and overcome today's limitations and difficulties:

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 On-board Train Integrity 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 On-board Train Integrity system will be able to adapt to the various typology 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, due to delays. At present the performances are not satisfactory and are 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.
Higher cost of maintenance is especially unaffordable in freight and regional lines, due to the presence of equipment along the lines.	Removal of trackside costs and minimisation of costs on the on-board side.

Table 30: Comparison between state-of-the-art and future of On-board Train Integrity

This state of the art constitutes the baseline against which the project will compare its progresses.

Interactions with other TDs/ IPs (of the same IP and or of others 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 their right technical choices and to allow the 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 laboratory and in particular the suitability to operate in harsh environment, and in with high energy efficiency. The real environment will

be selected to demonstrate in particular the suitability of the candidate solution for freight & low traffic lines applications.

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:

- IP 2, TD 2.1 – Adaptable communication; (to investigate a possible common communication network solution to be adopted or with respect to be harmonized for data transmission along the train for performing OTI);
- IP2, TD 2.2 - Railway network capacity increase (to check possible interface with on board ATO to manage automatic coupling and uncoupling);
- IP 2, TD 2.3 – Moving Block (essential collaboration to provide the enable technology for ETCS lev.3);
- IP 2, TD 2.4 – Fail Safe Train Positioning (to investigate possible synergies with satellite-based localization solutions for OTI);
- IP2, TD 2.7 - Formal methods and standardisation for smart signalling systems (to verify application of formal methodology in the development phase);
- IP2, TD 2.8 - Virtually – Coupled Train Sets (VCTS) (to investigate solutions to achieve OTI through proximity functions/devices);

The expected relations with others TD, in terms of inputs and outputs, are summarized in the following table:

Other TD	Main Outputs from TD2.5	Main Inputs to TD2.5
TD1.2 Train Control and Monitoring System (TCMS)	Provide OTI requirements and system behaviour aiming to make TCMS suitable also for OTI purpose in passenger convoy applications.	Collecting information on TCMS functionalities and performances in order to investigate a possible integration with OTI in passenger convoy applications.
TD2.1 Adaptable communication for all railways	Provide OTI Train-to-Train communication requirements, for both wireless and wireline cases, associated to different application scenarios.	Information about possible TD2.1 communication solutions that could be integrated or harmonized in OTI architecture.
TD2.2 Railway network capacity increase (ATO up to GoA4 – UTO)	Provide information about OTI functional architecture and interface to be used for ATO, in particular to manage automatic coupling and uncoupling.	

Other TD	Main Outputs from TD2.5	Main Inputs to TD2.5
TD2.3 Moving Block	Provide information about OTI functional architecture and interface with the aim to integrate it in 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 the Localization also 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 Position System.
TD2.7 Formal Methods and standardisation for smart signalling systems	Provide a system view in order to take advantage from TD2.7 outcomes.	Cooperate to follow common methodology in writing documents (FRS, SRS).
TD2.8 Virtually – Coupled Train Sets (VCTS)	Provide information to understand how OTI information can be used inside a train consist virtually coupled (convoy of trains).	Requirements to be considered in order to define the needs to provide the Convoy Integrity for a convoy of trains.

Figure 1 - Interaction with other TDs and IPs

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 –adequately 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 "Train Integrity Product Classes", according to 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.
provide 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.
identify some new technology	To identify some new technology approaches and perform feasibility studies and research aiming for its application.
assess the products adapted	To assess the products adapted by the collaborating vendors and facilitate its integration into the demonstrators.
Demonstration simulation and in real systems 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 to the standardisation of Train Integrity function and certification of products.

This TD will contribute to enable **Innovation Capabilities** as described in the following:

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 seconds	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 both in terms of 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 the TD2.5 are listed below:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
On Board Train Integrity	Provide solutions for detecting the Train Integrity by means of On Board subsystems	On-Board Train Integrity Demonstrator for regional and freight application domains.	Regional, Freight	6/7	On-Board Train Integrity, wireless on-board communication and energy harvesting.

Planning and budget:

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022	input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.5	**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		
	task 2.5.1 Train Integrity Concept	2									
	task 2.5.2 Definition of Requirements	2								TD1.2, TD2.1, TD2.3, TD2.4, TD2.8	TD1.2, TD2.1
	task 2.5.3 Technology Research & Development	3-4								TD2.1	
	task 2.5.4 Adaptation of Existing Solutions	2-4									TD2.2, TD2.3, TD2.4, TD2.7, TD2.8
	task 2.5.5 Demonstration and Assessment	4-6								TD2.7	
	task 2.5.6 Standardization Proposal	6-7									

milestone

quick win

Contracted activities

planned activities

Table 31: 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 related results in it.	Demonstrator for freight application domain.

Table 32: TD2.5 milestones

When	What
M12	Concept
M24	Definition of Requirements
M42	Demonstrator implementation
M66	Site testing and preliminary safety assessment
M66	Standardization proposal

The estimated total budget for TD2.5: 9.95 M€.

2.6. TD2.6 Zero On-site Testing

2.6.1. Concept

System and Integration Test (SIT) is a fundamental method of system verification across many different industrial sectors. Various experiences show that the effort and time consumption for the SIT is about 30 percent up to 50% of the project time. Due to the complexity of signalling systems and the differences between sites, a large amount of tests must be carried out on-site. On-site tests take about 5 to 10 times the effort compared to similar tests done in the lab. Reduction of 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 to improve the lab testing capabilities by broadening the test scope as well as to decrease the number of onsite test cases until the normative and legislative borders 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 standardized method to derive and describe test cases;
- Fixing a common test process framework.

The planned system test architecture should allow for a 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 standardized 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 unique 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 for test case selection which need to be executed onsite as a minimum to provide sufficient evidence for validation;
- Definition of conditions under which a minimum of onsite tests can serve as a confirmation for the lab tests to be meaningful.

The treatment of these two topics requires close cooperation with European organisations dealing with the harmonisation of assessment and authorisation. Other industrial sectors like automotive and aerospace integrate and test as well complex, vital systems. Experiences and best practices developed in these sectors should be used to optimize the SIT 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 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 TD 2.6 Zero On-site testing is in defining a dedicated system test architecture providing the capability of interoperability as well as connectivity between the different systems and component necessary to be tested.

Further innovation is delivered in specifying standardized 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 will be taken into account and the methodologies analysed and provided shall be made available in the approach of TD 2.6.

A common test process framework will be key for improving the testing and the shifting of tests from field to the lab. The test architecture will be an essential part if 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 digitalization shall be taken into account.

State-of-the-art (ETCS Interoperability)	Zero On-site Testing
Definition of the scope of IOP testing, the overall process and embedding into other processes of assessment	• Assessment of todays practice of field testing • Benchmarking with automotive / avionics industries • Based on this distributed environment the within the TD defined test process will be verified and validated • In addition a clear distinction will be given 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 todays practice of field testing • Benchmarking with automotive / avionics industries • Definition/implementation of a dedicated system test architecture for lab testing supporting Zero On-sight Testing • The distributed test environment will give the possibility to integrate multiple test candidates based on standardized 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 standardized method to derive and describe test cases • Based on the results of TD 2.7 (formal methods) a formalized approach for data engineering as well as the derivation of test cases will be shown

Figure 20: Future Test based on Zero On-site Testing

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

Besides before mentioned interactions with other TDs/IPs the following ones are taken into account:

Other TD	Main Outputs from TD2.6	Main Inputs to TD2.6
IP2 TD 2.1 Adaptable communication		Standardized communication environment.
IP2 TD 2.2 Railway capacity increase (ATO up to GoA4)	Zero on Site Testing principle applicable for ATO.	
IP2 TD 2.3 Moving Block		Interface specifications to enable development of test environment.
IP 2, TD 2.4 Fail Safe Train Positioning	For understanding 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.
IP 2, TD 2.7, Formal methods		Will provide inputs to apply Formal Methods to the development of test cases and to prove specifications.
IP2, TD 2.8, Virtually-Coupled Train Sets	Test environment, test cases and methodologies.	Field Requirements to be done in the laboratory.
IP 2, TD 2.10 Smart radio-connected 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.
IP 2, TD 2.11 Cybersecurity		Provide input to ensure the security in the correct level for virtualization of test platforms and cloud management.

Figure 21: Interaction with other TDs and IPs

2.6.4. Impact and enabling Innovation Capabilities

Significant reduction of testing efforts and reduction of test on site are the main objectives of TD2.6. being supported by:

- Identification and analysis of best practices of automobile and aeronautics industry;
- Definition of a dedicated system test architecture and standardized interfaces for lab tests, including remote tests;
- Practical validation of test environments in all relevant configurations with product demonstrators;
- Specification of a standardized method to derive and describe test cases;
- Definition of common test process framework including real time distributed testing connecting existing test labs and e.g. on site tests (hybrid testing).

By the end of the proposed work the market will benefit from a 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 to standardise 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-RBC, interlocking to field elements, etc. This will be supported by the envisioned test environment.

Finally, increased in-lab-testing with support of simulators allows for much more faults in the system being detected as 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.

Impact on Shift2Rail Targets:

Capacity:

- Minor impact on this target. Only indirect, since it could help to bring new technologies, which have a direct positive effect on capacity, earlier into service;
- Less outage times in the field since time for field testing will be reduced to the absolute necessary minimum.

Competitiveness:

- Major impact on this target. Less impact on traffic due to faults in signalling systems and field testing, since more will be tested in the lab and test coverage, esp. fault insertion will increase with lab testing/ simulation;
- In addition it helps the European industry to deliver complex solutions with low LCC and low impact on operational traffic. New and more advanced technologies/ methodologies (like

Model based test design) will help the industry to work 'state of the art' and benefit from the growing number of tools.

Operational reliability:

- Major impact since outage time of lines which are in operation will be reduced: tests in field are significantly limited;
- Testing more in lab with support of simulators allows stimulating much more faults in the system 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 test (fault insertion, load) - Introduction of 'state of the art' technology in testing and benefitting from growing number of supporting tools. - Reduce the number of test resources needed to be built in different places.
Compliance with EU objectives	- Interoperability tests can be done more easily in the lab (adaptors/ simulators, etc.) - Standardization will be supported - Competition will be increased
Degree of maturity of the envisaged solutions	- The methods/ improvements will be proven in real pilot projects focusing on the new developments of other TD's.

This TD will contribute to enable 2 **Innovation Capabilities** as follow:

Innovation Capability	***TD2.6 Zero On-site Testing enablers***
7- Low Cost Railway	*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* By means of standardised methodology for performing lab test which reduce the overall CAPEX.
12- Rapid & Reliable R&D delivery	*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* By means of a well-defined and complete set of laboratory tests able to reduce time to market.

2.6.5. Demonstration activities and deployment

The following table summarizes the contribution of TD2.6 Zero On-site Testing to the different ITDs of Shift2Rail:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	TRL	Focus of activity
Zero On-site Testing	Definition of a dedicated system test architecture and standardized 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, currents requirements on system testing, limits of lab testing Defining 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 standardized 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
			Regional/Freight	6	
	Definition of common test process framework including real time distributed testing connecting existing test labs and e.g. on site tests (hybrid testing)	Definition of scenarios and common test process necessities; Definition of obstacles preventing the shifting of test; Definition of common interfaces and interconnections	Main Line	6	Test process description flexible for adaptation to new requirements ; Integrating the results of the open call ; alignment with IM experiences from current projects; Demonstrators showing the connectivity and the distribution capabilities
			Regional/Freight	6	

Planning and budget:

TDs	TASKS	TRL	2016	2017	2018	2019	2020	2021	2022	input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
			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		
TD 2.6	**Zero on-site Testing**									TD2.1, TD2.3, TD2.4, TD2.7, TD2.8, TD 2.10, TD 2.11	TD2.2, TD2.4, TD2.8, TD 2.10 - test environment, test process, test cases
	2.6.1 Assessment of status quo in field testing and benchmarking	N/A									
	2.6.2 Definition of test process	3									
	2.6.3 Define general test architcture	3									
	2.6.4 Define generic communication model	5-7									
	2.6.5 Develop / Validate Test environment	5-7									

milestone
quick win

Contracted activities
planned activities

Table 33: TD2.6 quick wins

When	What
Q2/2017	Benchmarking Report in Testing / System Testing
Q4/2018	Common High Level test architecture based on the test process agreed before. A major input is as well the current limitations of pre-forming 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 20.9M€

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 (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 signaling systems.

The **objectives** of TD2.7 are to use formal methods and standardisation in development of railway signaling systems to achieve:

- Increase know-how of formal methods use
- Increase market competition and standardisation
- Improve interoperability and reliability
- Reduced life-cycle costs in signalling system life-cycle
- Shortening the 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 practise approaches and results when available
- Compatibility with existing practise, observing existing framework of development in the rail domain
- Viability towards anticipated objectives and results
- Accessibility of proposed solutions to all stakeholders
- Applicability in other lines of activities within Shift2Rail
- Demonstrate formal verification of safety requirements to achieve significant reduction of effort and cost compared to traditional safety assessment

The following represent 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 reduction of effort and cost compared to 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** includes to promote standard interfaces (e.g. o RBC to RBC interface, Interlocking to RBC interface, Interlocking to point object controller interface, Interlocking to level crossing interface), since this is key to achieve more standard systems (with all 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 to agree 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 demonstrator(s), and a *one-formal-method-fits-all* 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, due to 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 standardized 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 standardized interfaces, which also enable more efficient use of formal methods with reduced development cost

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

The main interaction 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 e.g. software requirement specifications (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, 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 e.g. requirement specification and formal methods-based verification and validation and development.
- TD2.6 (Zero on-site testing): TD2.7 will contribute to use of formal methods to develop test cases and reduce on-site testing
- TD2.10 Smart wayside object controller: 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 standardized 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 • Enable 1st delivery of signalling system on-time and with correct functionality • Improve quality and efficiency of safety approval • Increase competition and reduce vendor lock-in
Degree of maturity of the envisaged solutions	• Formal methods are well established, but different formal methods have different TRL 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 TRL apply for standard interfaces. • The formal methods and standard interfaces will be applied in System Demonstrators.

This TD will contribute to enable two **Innovation Capabilities**, as described by the following table.

Innovation Capability	***TD2.7 enablers TRL3-7***
7 – Low Cost Railway	Demonstrate reduced LCC for signaling systems, through the following Building Blocks achievements: • *BB2.7_1 (TRL 3 to 7) Formal and semi-formal methods for requirement capture, design, verification and validation, proposing open standards.* • *BB2.7_2 (TRL 6) Standardisation of crucial interfaces between parts of selected state of the art interfaces (FIS and FFFIS).* • *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 signaling systems, through the following Building Blocks achievements: • *BB2.7_1 (TRL 3 to 7) Formal and semi-formal methods for requirement capture, design, verification and validation, proposing open standards.* • *BB2.7_2 (TRL 6) Standardisation of crucial interfaces between parts of selected state of the art interfaces (FIS and FFFIS).*

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 signaling 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 practise 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 contribution of TD 2.7 to its three demonstrators foreseen (within X2R-2, within an OC and within X2R-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, and;
3. Consider applicable technical standards, to increase the confidence of future clients and facilitate deployment in new projects.

Research Area	Specific Techn. 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 to 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				input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.7	**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		
	2.7.1 Formal metods	3--7																													TD2.4, TD2.5, TD2.8	TD2.2, TD2.3, TD2.4, TD2.5, TD2.6, TD2.8, TD2.10, TD2.11
	2.7.2 Standardized interfaces	6																														

Contracted activities
planned activities

Estimated budget of the TD: 8.03 M€.

2.8. TD2.8 - Virtually Coupled Train Sets (VCTS)

2.8.1. Concept

Many European railway lines are very busy today and have a problem to handle the requested capacity. New lines are built and tracks added to existing lines, but this is slow, 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 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 improve headway, optimise the use of station platforms, optimise timetables and solve traffic conflicting situations through smarter and more flexible functionality and behaviour.

TD2.8 will explore the innovative concept of 'virtual trains' 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 introduction of the Railways.

The proposal of the study is to start from the current interoperable signalling system that is UNISIG BL3 ETCS/ERTMS. It is deemed essential because:

- ERTMS is the common signalling system already applied and in service for many years.
- The common knowledge of ERTMS facilitates the understanding of what is necessary to upgrade in order to get the required behaviour.
- Simplify the interface with the signalling system avoiding to study the impact of TD2.8 on the legacy applications so making work more effective and really 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.: 1st part of the convoy going to platform x; 2nd 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 the headway, the distance between two trains, when the 2nd (i.e. the following) train has to change direction / route or when traffic needs dynamically require to improve capacity.
- The impact of VCTS on operational rules – i.e. what combinations of trains are allowed / forbidden (e.g. dangerous goods and passenger trains)
- Suitable train-control support tools for efficient operations of VCTS – e.g. what combinations of trains and services to avoid (e.g. commuter train ahead of long-distance high-speed train)

VCTS basically performs the objective to dynamically manage the 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 to underline that 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 impact on the main trackside signalling and supervision systems.

2.8.2. Technical Objectives

The technical ambition of the VCTS system is to allow overcoming of Fixed Block principle, taking advantage from Moving Block concept and relative braking distance, permitting more than one train into each block (of sufficient length) and by 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 with more than 100%, possibly 300%. The solution is to link the preceding train with the following train by data radio to create a so called "virtual coupling", running the trains together.

Virtually-Coupled Train Sets (VCTS) main technical objectives are:

- Manage dynamic train convoy joining/splitting also 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 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 ATP/ATO systems, the safety and the automatic driving according to the new physical constraints and scenario. ATPs/ATOs of different trains would cooperate through a common network in order to achieve the full Convoy Control. That is a new concept which enlarges the current Train Control features.
- Overcome the limitation of communication dealing with a new frontier of train-to-train data exchange (new standard interface necessary)

It is trivial to reiterate that all the above technical points must be achieved without reducing, but improving the current level of safety in all working scenarios (normal and degraded). That 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 foresees trains to follow 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 the 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 EoA located in the best case to the rear end of the previous train according to the absolute braking distance.	With VCTS, trains will be allowed to break this principle, by applying a new protection concept which is actually inside and not at the end of the absolute braking curve.
No train-to-train 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 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 its best achievable.
Train separation carried out of separate blocks	New Train separation concept which allows achieving much less than a block
Train separation on fixed blocks defined by block sizes and by their Absolute Braking Distance	As close as communication and controls delays and braking distance variations /uncertainties permit
Train separation on Moving Block based on Absolute Braking Distance	As close as communications and controls delays and braking distance variations /uncertainties permit

Figure 22: 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 controls delays and braking distance variations /uncertainties permit
Train separation	Moving Block based on Absolute Braking Distance	As close as communications and controls delays and braking distance variations /uncertainties permit
Following train driven by	Driver	Virtual Coupling OB 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 (of the same IP and/or of the other IPs)

The VCTS maximises its performances in a moving block system, so that synergies with TD2.3 are expected 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 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 the relevant information.

The table below shows the expected relationships with other TDs not only belonging to IP2.

Other TD	Main Outputs from TD2.8	Main Inputs to TD2.8
IP1 TD1.2 Train Control and Monitoring System (TCMS)	Provide requirements and system behaviour in order to define the needs for a convoy of trains.	Understanding of how TCMS could be applied to integrate solutions for train-to-train communication and within a convoy of trains.
TD2.1 Adaptable communication for all railways	Provide requirements and system behaviour in order to define the Train-to-Train communication needs.	Cooperate to understand how new technologies can facilitate and suggest solutions for train-to-train communication. Provide solutions in terms of communication between trains which can comply with the needs.
TD2.2 Railway network capacity increase (ATO up to GoA4 – UTO)	Provide requirements and system behaviour in order to identify impacts on ATO (on board and trackside).	
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 of 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.	Understanding the use possible improvements to odometry data for train location establishment / distance between trains in Convoy.
TD2.5 On-Board Train Integrity	Provide requirements and system behaviour in order to define the needs to provide the Convoy Integrity for a convoy of trains.	Cooperate to understand how Train Integrity information can be used inside a train consist virtually coupled (convoy of trains).
TD2.6 Zero on-site testing	Provide requirements and system behaviour in order to identify the needs for a simulation	Understanding 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 from TD2.7 outcomes.	Cooperate to follow common methodology in writing documents (FRS, SRS).
TD2.11 Cyber Security	Provide requirements and system behaviour in order to identify security needs.	Cooperate to verify the need to encrypt data for train to train communications.
TD3.2 Next generation switch and crossing	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 the so called Flexible Signalling will allow dynamic approach of 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 not only the possibility of trains communicating each other but also new horizons in which the traditional signalling logic, for instance of the classic interlocking, could be shared and activated by on board subsystems when needed in terms of controlled area in time.
Virtually Coupled Train Sets is seen as the first attempt to overcome the limit of train control taking also insights from automotive whereas the idea of automatically driven car, inside a full integrated road environment, is a subject of studies and research.

Strategic Aspect	Key Contribution from the TD
Network Capacity Maximisation	The VCTS offers the possibility to reach the best line exploitation without the need to improve railway infrastructure.
Train-to-train communication	The VTCS identifies the main safety-related constraints for train-to-train exchange of information, especially for addressing safety related functionalities. This can foster the research of telecommunication for on board purposes, not only dedicated to VCTS.
Simplified traffic management	VCTS allows to treat different consists as a single logical unit within the overall traffic management system, without necessarily the need to have physical coupling of the associated consists.

Most of the competencies and sub-capabilities are addressed by TD2.8 because it impacts the entire signalling, supervision and telecommunication system as well as trains and control systems.

The main impacted Innovation Capabilities have been listed in the table hereafter:

Innovation Capability	**TD2.8 “Virtual Coupling Train Sets” enablers - (TRL3)**
1- Automated Train Operation	• 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 Specifically the building blocks contribute to improve self-automated, autonomous, single units 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.

Innovation Capability	**TD2.8 "Virtual Coupling Train Sets" enablers - (TRL3)**
3- Logistics and Demands	• 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 Automatic Virtual Coupling and de-Coupling can significantly increase flexibility of freight transportation improving planning, tracking and shipment according to the real time customer demand. VCTS actually offers a solution to increase capacity of the line by allowing to break current limitations of the standard train separation principles and thus maximising the line capacity to the possible extent.
6- Service operation timed to the second	• 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 Enhanced automated trains contributes to improve flexibility and facilitate recovery from perturbation. TD2.8 building blocks contribute to achieve a more robust, resilient service by means of new and more efficient line exploitation in terms of capacity and systems (signalling and supervision) reaction to dynamic traffic change and demand. Specifically VCTS allows to tune the line capacity depending on current demand with minimal effort by the Operator, as allows longer consists to be dynamically and virtually composed along the mission.
7- Low Cost Railway	• 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 Virtual Coupling building blocks contribute to achieving a simplified and customised control-command system reducing man intervention and therefore impacting operational expenditure. Specifically, the flexibility introduced by the VCTS allows to tune the line capacity depending on current traffic demand and thus optimising usage of assets.

Innovation Capability	TD2.8 "Virtual Coupling Train Sets" enablers - (TRL3)
9- Intelligent Trains	• 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 TD2.8 building blocks contribute to significantly improve the so called train-centric system where many of the signalling and automation functions might be moved to on board system. Autonomous driving and Train-to-Train communication is also fostered by Virtual Coupling building blocks. VCTS can be also seen as an initial step towards further evolutions of the train-based railway signalling functionality, especially because it introduces the concept of the safe train-to-train interaction, that can become the basis of additional evolutions of the overall signalling functionalities.

2.8.5. Demonstration activities and deployment

TD2.8 does not address any deployment of the system, but mostly addresses an overall feasibility analysis that goes across technology, safety and business aspects of the VCTS deployment. No prototypes of the VCTS are foreseen being produced.

Planning and budget:

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022				input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.8	**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												■	■	◆															TD1.2; TD2.1; TD2.3; TD2.4; TD2.5; TD2.6; TD2.7; TD2.10; TD2.11; TD3.2	TD1.2; TD2.1; TD2.2; TD2.3; TD2.4; TD2.5; TD2.6; TD2.7; TD2.11;
	2.8.2 Safety and Performance Analysis	2														■	■	◆														
	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 34: TD2.8 milestones

When	What
Q2 2019	Conceptual analysis and boundaries definition for the VCTS
Q4 2019	System Hazard & 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: 4.8 million Euro.

2.9. TD2.9 - Traffic Management Evolution

2.9.1. Concept

The Integration Layer is a new communication platform which 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 the communication with external clients and services
Freight application integration is scope of CCA WA4.2 and is executed under IMPACT-2 program.
In a possible next step, the status data of extra services e. g. all vehicle constituents linked with the TCMS (IP1. TD2) are envisaged to be integrated into the data model and a structure for a centralized Track2Train 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 program.
A standardized Operator Workstation will enable the allocation of tasks inside a Control centre to different workstations benefitting from the availability of the different data on an integrated network.
The real time availability of data for "Multiple Clients" supported is the base of new Business Service Applications for TMS and Traffic Control.

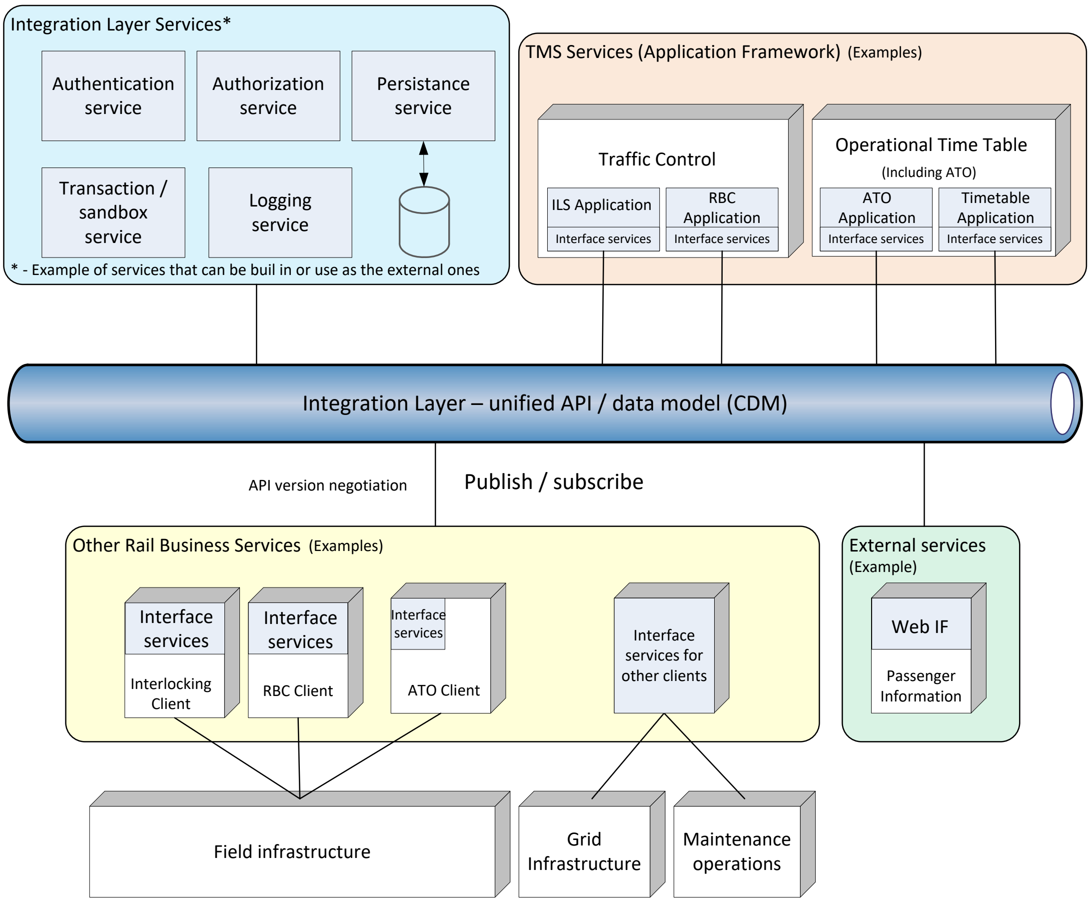


Figure 1: System Architecture

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 these information in one common layer are one 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 Traffic Control and the integration and enabling of new S2R functionalities into the Rail Operation Processes
  New business software using the new communication environment will enable advanced processes for Traffic Control and Traffic Management to optimize the flow of traffic and the decision making to deliver the production timetable with less delays.
- Integration of new technologies/functionalities
  The new System shall integrate of new technologies developed under the S2R program such as ATO, Moving Block (IP2), Data provision/exchange for new advanced Maintenance Strategies (IP3), Freight Transport (IP5) and Passenger Information services (IP4).

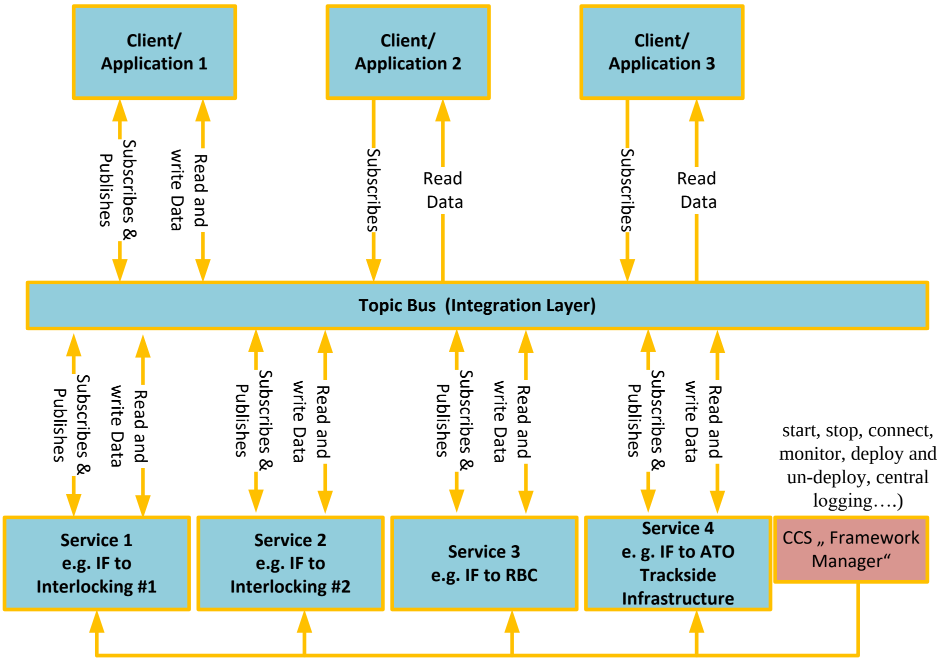


Figure 2: Integration of different Rail Operation Services

- Standardizing of Constituents and workflows inside a Control Centre
  p Standardized Operators Workstation and the framework with "Plug & Play" features will allow to increase the efficiency and reduced the cost of control centers and a Framework will enable easy (Plug & Play) installation and operation of Applications. API will be developed from the integration layer to different type of services, incl. ATO, RBC, IXL.
- Canonical Data Model (CDM)
  A scalable and flexible Canonical Data Model (CDM) is developed to secure the integration of legacy and future applications into one communication structure will be developed to a "Shift2Rail" Data Model

2.9.3. Technical Vision

- The proposed architecture, interfaces and the data model allow the integration of legacy installations through APIs (Application Programming Interfaces) into one network.
- The communication principle changes from a Point2Point principle to "Publish & Subscribe" methodology. This allows to apply new possible scenarios to substitute and simplify traditional operational processes.
- It can be envisaged, that the Integration Layer will be linked in the 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 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 track-side-based services in a Control Centre	One integrated system with automated data exchange, standardized frameworks to host applications and flexible Operators workstations
	Integrated Vehicle-Trackside Communication network
	Integration Layer supports « Zero on-site Testing" and other programs of S2R
Competing Data Models ETCS, EULYNX, railML, others	One Shift2Rail Canonical Data Model
Point2Point Communication	Subscribe & Publish Methodology

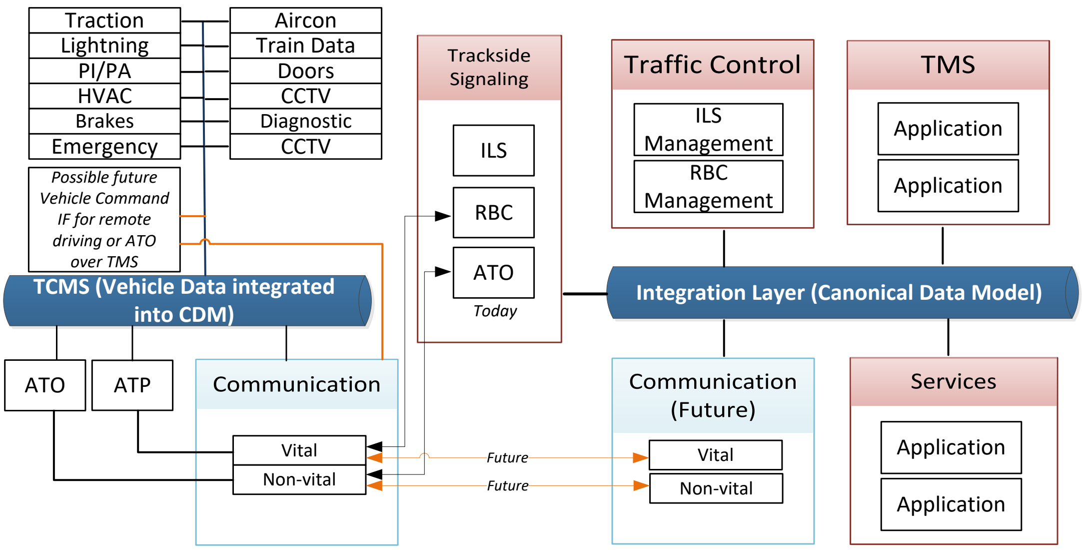


Figure 3: Future View: Integration TCMS with Integration Layer

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

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:

- IP1 – TD1.2 "TCMS" Providing data elements to be integrated into Canonical Data Model of Integration layer

- IP2 – TD2.1 “Adaptable Communications”: providing concept to utilize the different technologies for a new T2T interface
- IP2 – TD2.2 “ATO” agreement where to allocate the different functionalities (TMS, ATO-TS, OBU) and which data the different constituents need to secure targeted operation
- IP2 – TD2.3 “Moving Block” agreement on operational processes needed to provide Traffic regulation under Moving Block operation
- IP2 – TD2.11 “Cybersecurity”: Follow up of the results of this TD to secure security of the communication network proposed
- IP3 – Inputs required for Data elements to be integrated into Canonical Data Model
- CCA: WA4.2 “Integrated Mobility” – 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 the TD 2.9
Line capacity increase	New ATO and Moving Block traffic regulation applications in the TMS together with the related vehicle-based functionalities secure better utilization of line capacity.
Operational reliability increase	Seamless updated status information of all the rail infrastructure assets and vehicles will allow automated and optimized decision processes for traffic regulation applications to deliver the production time table with less delays. The distribution of traffic status forecast to asset management services will allow much better scheduling of preventive service & maintenance activities and increase the overall availability and reliability of Infrastructure assets.
Railway system life cycle cost reduction	Standardization 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 Standardized Operators Workstation will further reduce cost for investments into workstations operations, training efforts and HW and SW maintenance cost for workstations. New features such as a Traffic Optimization application on sector or corridor level will create an overall system energy reduction of up to 10% with better average distribution of Energy consumption in a sector or corridor and support allow to reduce Carbon emissions and air pollution.

TD2.9 addresses the following Innovation Capabilities:

Innovation Capability	TD 2.9 "Traffic Management Evolution" enablers - (TRL6)
1- Automated Train Operation	• 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 Services, processes and building blocks of TD2.9 organize the flow of traffic enabling Automated Train Operations.
2- Mobility as a Service	• 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 Building blocks of TD2.9 provide to all subscribed clients or service real time updated status information of the Traffic and information and all related information improving mobility
3- Logistics and Demands	• 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 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 received optimized proposal to increase the efficiency of their logistics
4- More Value from data	• 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 Building Blocks (Integration Layer) of TD2.9 applies a standardized data structure (Canonical Data Model) for all information carried on the network hence allowing to integrate information presented in different Data Formats to the communication network
5- Optimum Energy Use	• 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 Services, processes and building blocks of TD2.9 optimize the flow of traffic in terms of reducing delays, braking and accelerating manoeuvres of trains to contribute to a more efficient use of energy

6- Service operation timed to the second	• 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 Services, processes and building blocks of TD2.9 optimize the flow of traffic by including status information of assets, energy (grid) system, vehicle, staff and external information e. g. weather in the decision processes to secure the delivery of the production time table
7- Low Cost Railway	• 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 Services, processes and building blocks of TD2.9 organize the flow of traffic and integrates 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
8- Guaranteed asset health and availability	• 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 Services, processes and building blocks of TD2.9 integrate asset status information in 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
9- Intelligent Trains	• 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 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 Track2Train communication network

2.9.5. Demonstration activities and deployment

The following table summarises the contribution of TD 2.9 to the different ITDs of Shift2Rail:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	TRL	Focus of activity
Evolution of Traffic Management	Data exchange between the various Rail Services	SRS for Integration Layer, Specification of Canonical Data Model according scope of TD2.9	Mainline	6	Specification and development of Prototypes of constituents of the Integration Layer
			Regional	6	Specification and development of the CDM
	Business Applications for Traffic Management and Traffic Control	SRS for applications according scope of TD2.9	Mainline	6	Specification and development of new applications for Traffic management and Traffic Contro
			Regional	6	
	Integration of new technologies/functionalities which are developed under S2R IP2 program	SRS for Traffic Regulation for Moving Block and ATO (GOA2) operation	Mainline	6	Specification and development of new applications for Traffic management and Traffic Control
			Regional	6	
	Operator 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 Traffic Management System addressing both Regional and Mainline is foreseen. This installation shall become the “Reference” and “Promotor” for all future implementations which follows the new technology.

The partners of TD2.9 which have proposed prototypes for constituents of the system or business application develop 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 within X2RAIL 4.
Prototypes are proposed for TRL3 in the first step and will reach TRL 6 at the end of the project.

The overall guidance for the Canonical Data Model shall be allocated to a group of experts representing all IPs in S2R to secure that all TDs are able to set their data according to a standardized rule book to use the new communication Infrastructure for their best benefit. This coordination group will further set the strategy how to manage the CDM beyond the end of S2R program.

It can be expected that between three and five years after Shift2Rail 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				input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
			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		
TD2.9	**Traffic Management System**																															
	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																														
	2.9.4 Applications	6/7																													TD2.2, TD2.3, TD2.11, TD1.2, TD3.6, IN2RAIL	TD1.2, TD2.2, TD2.3, TD2.11, TD4.4, CCA WA4.2
	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

IN2RAIL (Lighthouse project)
Contracted activities
planned activities

Table 35: TD 2.9 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 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 are 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 are validated

The estimated total budget for TD2.9 is around 24,4 M€.

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 realizing a decentralized 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, and other necessary interfaces, depending on the specific project requirements.

Today's field-element controller 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 Train Management Systems follows rules and requirements given by railway authorities.

Currently trackside objects are interfaced to control systems in one of two ways:

a) Where trackside objects are fairly near signalling equipment, tail cables to individual objects are used;

b) 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 featured by poor 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 demands additional signalling equipment (object controller).

An avoidance of all cabling in the field will reduce lifecycle costs of future railway projects significantly, including: Material costs, Installation costs, Maintenance costs, Energy costs and Cost occurring because of cable thefts

2.10.2.Technical Objectives

A solution where locally derived power and radio communications (or any wireless network communication) together with maximum de-centralisation (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. Beside 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 project is to provide fully de-centralized control of remote trackside objects such as points, level crossings, etc., using standardised interfaces without requiring the use of trackside cabling, and associated cable routes, ducting etc. Additionally the higher band widths will be used for transmission of status reports / maintenance information and further required data.

A cable free connection between objects / machines gets more and more state of the art. Existing devices mostly deal with less safety relevant information / applications. For TD 2.10 we have to assure on the one hand safety and security of data and on the other hand we have to implement energy harvesting systems – which have to be that reliable as it is requested 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 of power consumptions
- Reduction of required cabling
- Data Exchange with existing and/ or new TMS
- Availability of Maintenance Data

2.10.3.Technical Vision

The innovation of TD2.10 project is to provide fully de-centralized control of remote trackside objects such as points, level crossings, etc., without requiring the use of trackside cabling, and associated cable routes, ducting etc. Additionally the higher band widths will be used for transmission of status reports / maintenance information and further required data.

The basic idea of a wireless connection between technical devices is known within several industrial areas. Even some singular, specific but non-standardized signalling solutions do 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 about the derivation of safety and security concepts.

It might be possible to use experiences from ETCS projects where a successful standard for the air-gap interface between trackside equipment and trains exists or other solutions available on the market, including Internet of Things.

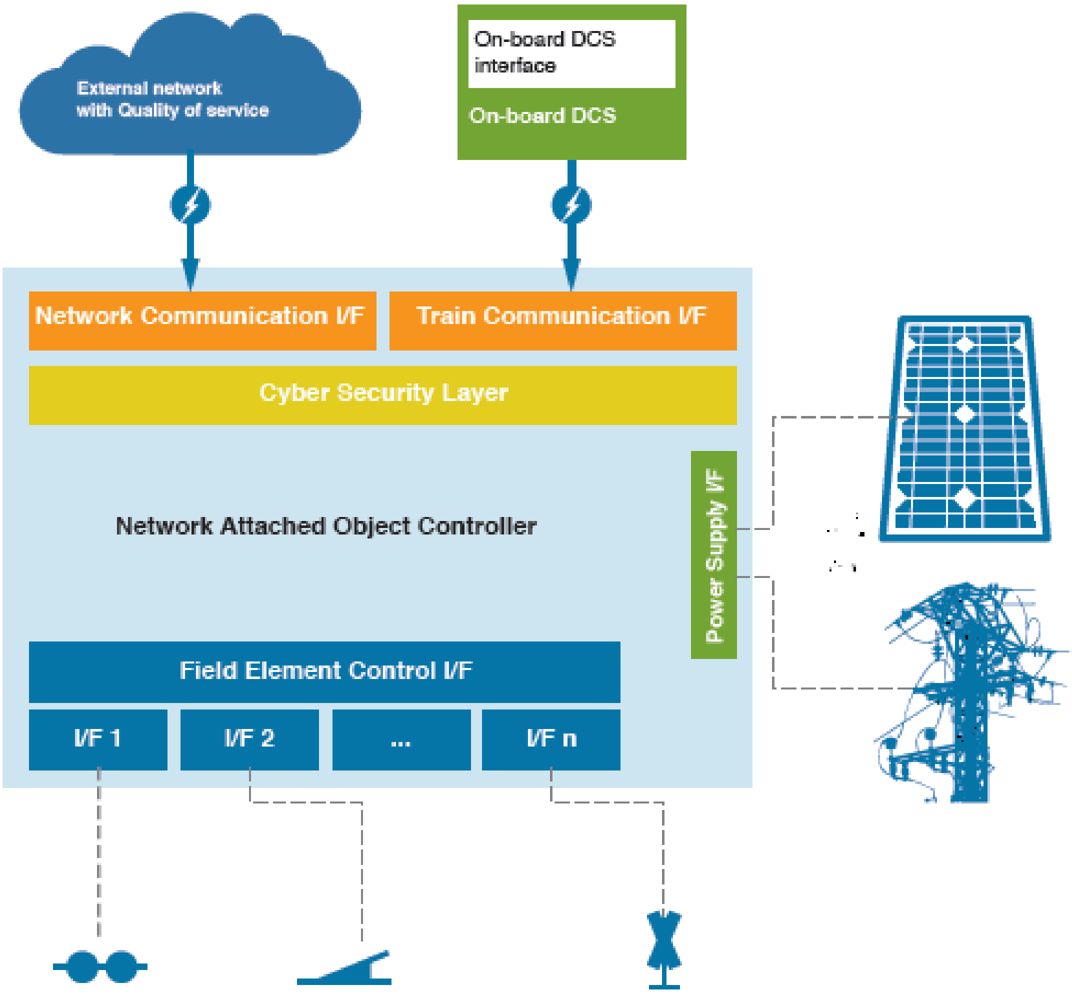
The introduction of network connected object controllers will permit the possibility of a direct connection between train carried equipment and the trackside object controllers, for example to report status of the trackside objects to the train. This would, for example, permit the train to react to failure 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 would impact existing ones.

Existing standards (especially safety and security aspect) 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 de-centralisation (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 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 23: Future architecture



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

Beside before mentioned interactions with other TDs/ IPs the following ones are taken into account:

Other TD	Main Outputs from TD2.10	Main Inputs to TD2.10
IP2 TD 2.1 Adaptable communication	Provide to the TD2.1 the communication QOS requirements and architecture for the Smart radio-connected wayside objects.	As input for TD2.10 it is expected the smart radio connection over the common communication network.
IP 2, TD 2.6 Zero on-site Testing	TD 2.10 resulting architecture and interfaces will provide requirements for Zero on site Testing, as basis for test definitions.	TD 2.6 may derive testability requirements as input for the object controller.
IP 2, TD 2.7, Formal methods		Will provide inputs to apply Formal Methods to the development.
IP 2, TD 2.11 Cybersecurity	Provide to the TD2.11 the communication QOS requirements and architecture for the Smart radio-connected wayside objects.	Provide a Cyber Security System solution able to secure the communication needs of the smart radio-connected wayside objects.
IP3 with regards to cost effective infrastructure and maintainability, interactions with TD3.1&3.2 (for Switch&Crossing) and TD3.6, 3.7, 3.8 (for diagnostic data)	The Use of "Smart" Object Controllers will help to reduce the initial cost of infrastructure, and to reduce the maintenance costs of infrastructure.	Provide structure for integrating diagnostic data from signalling devices.
CCA WA5.1 Energy	Power supply and energy saving conclusion.	To get help and support all energy saving related works.
FP7 NGTC WP6 Radio Based Communication		As input for the state of the art of communication techniques.

Figure 24: Interaction with other TDs and IPs

2.10.4.Impact and enabling Innovation Capabilities

Business Benefits as 1st step in Europe as 2nd step worldwide and Key Contribution from the TD2.10:

- significantly lowering the effort for project specific engineering, installation and commissioning;
- minimizing deployment of dedicated data communication cables and instead exploiting existing radio communication systems, public IP 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 “green up” the transport;
- overall objective is 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;
- the maturity of the communication systems as such should be very high: TRL 5-7 (The degree of maturity is strongly dependent on the outcomes of other TD, which will be implemented inside the Object Controller which are e.g. the communication solutions, cyber security, and of the advances made in the locally derived power supply technologies).

Measurable quantities are life cycle costs:

- basic invest – costs of cabling and material;
- installation costs – complexity, expenditure of time, required man power;
- maintenance cost (taking into account new hardware configuration as well as new functional possibilities with data exchange with TMS), MTBR, MTBF;
- 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 cabling reduction and then theft risk. Also higher availability thanks to redundancy and high dependability of wireless connections - *Reduced system Life Cycle Costs:* Reduced Life Cycle Cost 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) minimizing deployment of dedicated data communication cables and instead exploiting existing radio communication systems, public IP 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 IXL or either train can be easily stardardized in terms of physical and functional link. Open network will produce interchangeability of OC and IXL.
Compliance with EU objectives	- Promotion of modal shift: A big impact brought by the implementation of these new technologies towards automated train operation, 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 objects handling and less 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 optimization and the integration of local and green energy harvesting solutions.
Degree of maturity of the envisaged solutions	The different wireless communications technologies are on different stages of maturity and they are in constant evolution. Actions taken in this TD are required to apply such technologies to the railways domain guaranteeing the safety and security requirements. In the case of the energy harvesting it is envisaged the evolution from new proposed technologies starting in TRL 1,2 (Principles observed and the possibility of using them formulated). At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 6 or 7.

This TD will contribute to enable five **Innovation Capabilities** as follow:

Innovation Capability	***TD2.10 Smart radio-connected all-in-all wayside objects enablers TRL 5-7***
1.-Automated train operation	*'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.* By means of fostering new communication channels within a wide and new automated system.

6.-Service timed to the sec	*'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.* By means of improving reliability of the system.
7.-Low cost railway	*'BB2.10_1 Use of radio means for commanding/controlling Object Controllers* *BB2.10_4 Define a suitable energy generation and harvesting system.* By means of reducing the CAPEX thanks to cables deployment reduction.
8.-Guaranteed asset health and availability	*'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.* By means of improving the capability of remote diagnostic and maintenance.
9.- Intelligent trains	*'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* By means of fostering the introduction of new shared functionalities within the signalling and automation system.

2.10.5.Demonstration activities and deployment

The following table summarises the contribution of TD 2.10 Smart radio-connected all-in-all wayside objects to the different ITDs of Shift2Rail are shown in the following table:

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	TRL	Focus of activity
Smart radio-connected all-in-all wayside objects	Wireless Object Controller	Radio techn., 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 local derived Energy Harvesting Solutions including power consumptions optimizations. Including the outcomes of Energy experts OC and considering safety relevant aspects.
			Regional/Freight	5	
			Main Line	6/7	

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
	Functional distributed architecture	Specification, architecture and procedures	Regional/Freight	6/7	New architectural concept based on de-centralised architecture up to the level of one Object Controller for every individual trackside object. 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	Advance communication means and maintenance interface standardization 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				input from other TD (same IP or different IP)	Output to other TD (same IP or different IP)
TD2.10	**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	TD2.1; TD2.6; TD2.7; TD2.11; TD3.1;TD3.2;TD3.7;TD3.8; FP7 NGTC WP6; CCA WA5.1;	TD2.1; TD2.6; TD2.11, TD3.7;TD3.8;
	2.10.1 Analyses of existing lines and economic models	2																														
	2.10.2 Analyses of railway requirements / standards	2																														
	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

quick win

Contracted activities

planned activities

Table 36: TD2.10 milestones

When	What
Q3 2019	Functional architecture & Interfaces definition.
Q2 2022	Prototypes validation tests executed in laboratory and real environment. Validation Test results

The estimated total budget for Smart radio-connected all-in-all wayside objects TD is around 12.5 M€

2.11. TD2.11 - Cybersecurity

2.11.1.Concept

Nowadays the wired and wireless networks used by railways operators are usually heterogeneous, not protected well enough and they do not fulfil the minimum cybersecurity requirements in term of attack surface reduction, sustainability, protection and attack detection.

The Shift2Rail cybersecurity technical demonstrator aims at defining 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 level that it can be understood and applied by all key stakeholders: product suppliers when delivering products into 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 railway sector, since on the one hand a common understanding of security requirements allows reducing time and cost for introduction of secure systems, sub-systems and components supplied into the railway infrastructure, and on the other hand asset owners understand the risk and appropriate measures required to protect the assets from cyber exploitation.

2.11.2.Technical Objectives

The main goals of the cybersecurity railway system as framework of IP2-TD2.11 are the following:

- Security and safety improvement
  Applied to the railways 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 highly relates to security. Safety cannot be ensured in case of lack of security.
  As most of the railways devices are computer-based, this security mostly focuses on computer and network security, called ‘cybersecurity’.
  The cybersecurity addresses:
  - the protection of data against unauthorized disclosure, modification, or destruction;

- the protection of the computers against unauthorized use, modification, or denial of service;
- the protection of the railway IT network against attacks and malicious acts;
- the development of railway/urban sub-systems secure by design.

But, more widely, the security applied to railways also addresses the buildings, the infrastructure and the trains. Improving the security in the European railways also implies a more controlled and restricted physical access.

- Cost reduction and standardisation

  The second goal is reducing the infrastructure and maintenance costs of railways operators through the definition of common references for cybersecurity implementation in railway and improving compatibility and interoperability by standardizing the security approach at European level. This will apply to all new ICT used in railway (e.g.: traffic management, interlocking, urban signalling communication …).

Technical output to be delivered by this TD:

1. Objective 1: Definition of a cyber-security system dedicated to railways:

   This cyber-security system is intended to be comprehensive, easily sustainable and integrated. It has, among others, to provide:

- a common approach for security assessment, including the definition of the common threat-landscape, common assessment processes and risk matrixes;
- definition of the process, organisational and technical requirements in term of threat detection, prevention and response.

2. Objective 2: Definition of a security-by-design process dedicated to railway:

   Definition the requirement for the security by design approach. This guideline will fulfil the following objective:

- define a framework of requirements and processes for development, deployment, verification & validation and maintenance of railway components;
- ensure that railway components follow the defence-in-depth principle;
- ensure a systematic approach to develop and validate security requirements; and to assess the quality assurance level of security requirements implementation;
- ensure clear requirements and responsibilities among stakeholders.

3. Output 3: Develop a network of Railway Cybersecurity Experts (CSIRT):

   Besides the two main objectives presented here above, this third one concerns the development of a network of security experts in the railways community.

   This network of expert will analyse the feasibility of the deployment of a railway dedicated CSIRT (Computer Security Incident Response Team)/ISAC (Information Sharing and Analysis Center).

   In case of positive answer, this network would 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 which are interconnected through wired or wireless networks, making the railway transport vulnerable to cyber-attacks.

But Railway, as most of the critical infrastructures, was considered as being isolated from any external influence and therefore immune to security threats and attacks, no specific protection against cyber threat has been implemented.
Moreover, comparing to other critical infrastructure railway has to face some specificities that could make it more prone to cyber risks:

- distributed aspect: electronic components scattered along track or train leading to access protection issue;
- heterogeneous aspect of railway network and high level of certification leading to integration, defence in depth and patch management issues;
- very long life cycle (>>25 years) leading to legacy management issue;
- long design life cycle for railway specific components leading to time to market issue if no common reference.

These evidences of potential high cybersecurity risks and the observation that a cost and time effective solution could be provided only if all the stakeholders share the same cybersecurity framework led to the specification of the TD2.11.
The building of this common cybersecurity framework will be done through the pursuit of our 3 objectives:

1. Definition of a cyber-security system dedicated to railways
2. Definition of a security-by-design process dedicated to railway
3. Develop a network of Railway Cybersecurity Experts

Field	State-of-the-art of railway network	Cybersecurity System
Standardisation	No standardisation at European level except for ETCS protocols	Standardised CSS that could be applied to railway and urban sub-systems. Standardised "security-by-design" method that could be applied to the design of railway and urban sub-systems. Provide common approach for security assessment. Define generic protection profile for railway components/sub-systems.
CSS integration	No integration	Rules for integrated network at European level.
Security	The protection of most of the network is weak (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 for "security-by-design" and of generic protection profiles.
Deployment cost	High due to the diversity of networks and protection means	Low due to the use of standardised CSS, protection profiles, "security-by-design" processes and protections means.
Maintenance cost	High due to the diversity of network and to the significant level of manual operation to be performed on-site	Low due to the standardisation of the CSS, of the use of common approach for the security assessment and of the definition of generic profile for service providers
Sustainability in degraded situation	Very low due to the diversity of the network and the lack of coordinated incident or disaster recovery management plan	Very high due to the development of the CSIRT/ISAC, the implementation of the CSIRT/ISAC environment, the specification of the disaster recovery management plan and of the related workflows.

Table 25: Comparison between state-of-the-art and future of railway cybersecurity framework

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

IP1 TD	Contribution to TD2.11	Contribution from TD2.11
TD1.2: "Train Control and Monitoring System Demonstrator"	Provide the cyber security 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 cyber security requirements for the signalling system and the specification of Cyber Security 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 Cyber Security System specification. Make sure that the specified Cyber Security System is compliant with the specified "adaptable communications".
TD2.2: "ATO up to GoA4"		The proposed Cyber Security 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.
IP2 – TD2.6: "Zero on-site testing"		Services provided by the TD2.11 will facilitate and secure the remote testing between labs through the use of a common Cyber Security System.
IP2 – TD2.8: "Virtual Coupling"	Provide to the TD2.11 the communication QOS requirements for virtual train coupling.	Assess if the defined Cyber Security System is able to cover short or medium range communications needed for virtual train coupling.
IP2- TD2.9: "TMS evolution"	Provide to the TD2.11 the communication QOS requirements and architecture for next generation TMS.	Make sure that the specified Cyber Security System is able to secure the TMS communication needs.
IP2 – 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 Cyber Security 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
IP3-TD3.6: "Dyn. Railway Inform. Management Sys."		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
IP4-TD4.1: "Interoperability Framework."		Provide to the TD4.1 the cyber security framework specified for the traffic management and control systems.Provide to the TD4.1 the security assessment.

Figure 26: Interaction with other TDs and IPs

2.11.4.Impact and enabling Innovation Capabilities

The railway has been considered up to now to be immune to any external cyber threat due to this isolation. This is definitively no more the case and protection of the critical infrastructure, among which the transport, is a strategic challenge for our societies.

In this context, the TD2.11 will play a leading rule by proposing a concerted and shared approach by all the railway stakeholders for implementing railway devoted cybersecurity solution.

Strategic Aspect	Key Contribution from the TD
Support the competitive-ness 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 implied in the elaboration of this common security system will add a significant feature to the solutions they currently propose and the implied European companies specialized in information security will find new applications and new markets for their products.
Compliance with EU objectives	The European objectives are met since IP2-TD2.11 contributes in a significant way to the availability and safety of the European railway traffic by protecting against the substantial rise of the cyber-attacks against critical infrastructures and since the development of a common and standardized solutions and processes are two of the main objectives of IP2-TD2.11.
Degree of maturity of the envisaged solutions	Cyber-security technologies are considered as mature even if in constant evolution. Actions taken to apply them to railways networks are quite recent and defining the way to do it has still at the beginning. The target of the TD2.11 is definitively to play the rule 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 in TRL 1/2 , the target of the technical demonstrator is to raise this level up to TRL 4 to 6.

This TD will contribute to enable the following Innovation Capabilities:

Innovation Capability (IC)	***TD2.11 Cybersecurity enablers TRL 5-7***
1 - Automated train operation	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 Automation of train preparation processes could 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.
4 - More value from data	BB2.11_1 Definition of a security system dedicated to railway The 4th IC includes the following objectives: a. Definition of secure, robust, scalable and resilient open architectures and protocols allowing full interoperability b. Use of the Internet of Things (IoT) and Artificial Intelligent (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. The TD2.11 will participate to these objectives through the specification and application to railway generic architecture of security risk assessment processes allowing identifying the significant threats on the railway sector and the needed countermeasures. This process will use as framework the most up-to-date industrial cybersecurity framework and consider the railway specificities.

	Specific study will tackle the analysis of the security impact of the IoT integration in railway.
7 - Low cost railway	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 The time consuming certification process and the very long life cycle of the railway components lead to major patch management issues for security related update. Moreover, the small size of the railway sector will prevent him to impose 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 the cybersecurity certification potential cross compliance schemes.
8 - Guaranteed asset health and availability	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 BB2.11_3 Railway Cyber Security Experts (CSIRT) network The use of remote sensors and of industrial IoT (Internet of Things) will increase in a significant way the railway exposure to cybersecurity threats with potential impacts on the system availability, integrity and confidentiality. The integration of IoT and of remote sensors in the system will be part of a devoted security risk assessment that will provide security recommendation for such components.
9 - Intelligent trains	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 One of the objectives of the 9th IC 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. The TD2.11 will provide the processes to evaluate the level of risk of such connections and to identify the needed controls in order to reduce this risk to an acceptable level.
10 - Stations and "smart" city mobility	One of the objectives of the 9th IC is to provide seamless connection and data 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 BB2.11_3 Railway Cyber Security Experts (CSIRT) network Transfer between railway and smart city mobility platforms. This exchange of information will be achievable only if it is done in a secure way. The TD2.11 will provide the processes to evaluate the level of risk of such connections and to identify the needed controls in order to reduce this risk to an acceptable level.

2.11.5. Demonstration activities and deployment

The following table summarises the contribution of TD 2.11 cybersecurity to the different ITDs of Shift2Rail:

Research Area	Specific Techn. objective	Specification Activities?	Demonstrator Market	Demonstrator TRL	Focus of activity
Cyber Security	Secure Network and Systems	Security assessment, architecture and protocols	High Speed, mixed traffic lines, urban/ suburban	5/7	After having agreed, specified and applied 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 has to be demonstrated through a technical demonstrator (demonstrators 1). A specific attention will be paid to some railway specificities and demonstrated through a technical demonstrator (demonstrator 2).
	Secure railway application	Cyber secure design standard and security profiles	High speed, mixed traffic lines, urban/ suburban	5/6	After having identified protection profiles dedicated to railway component and security-by-design standard applicable to railway development, demonstrate their applicability through railway applications (demonstrators 1).
	Develop a network of Railway Cyber Security Experts (CSIRT/ISAC)	Define holistic knowledge database. Specify CSIRT model for railway	High speed, mixed traffic lines, urban/ suburban	4	After having defined a common understanding of cyber security matter for railway, 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 Shift2Rail 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 Cyber Security approach for railway network and application, including common security assessment, security-by-design and patch management guidelines;
- monitoring and protection tools dedicated to the railway Cyber Security 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:

- The first demonstrator should focus on the implementation of the cybersecurity guidelines in railway: it will demonstrate the use of protection profile among specific type of assets as one important aspect of the overall secure by design approach. During this task a protection profile is being specified for a selected demonstrator of TD2.1. "Adaptable communications for all railways". The provided demonstrator from the other work package will be verified and validated onto systemic effectiveness and completeness of the used protection profile. By conducting security tests and evaluation of the results the benefit of protection protect profiles will be demonstrated
- 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 railway business.
- The third demonstrator will propose a model for a railway devoted CSIRT/ISAC

Planning and budget:

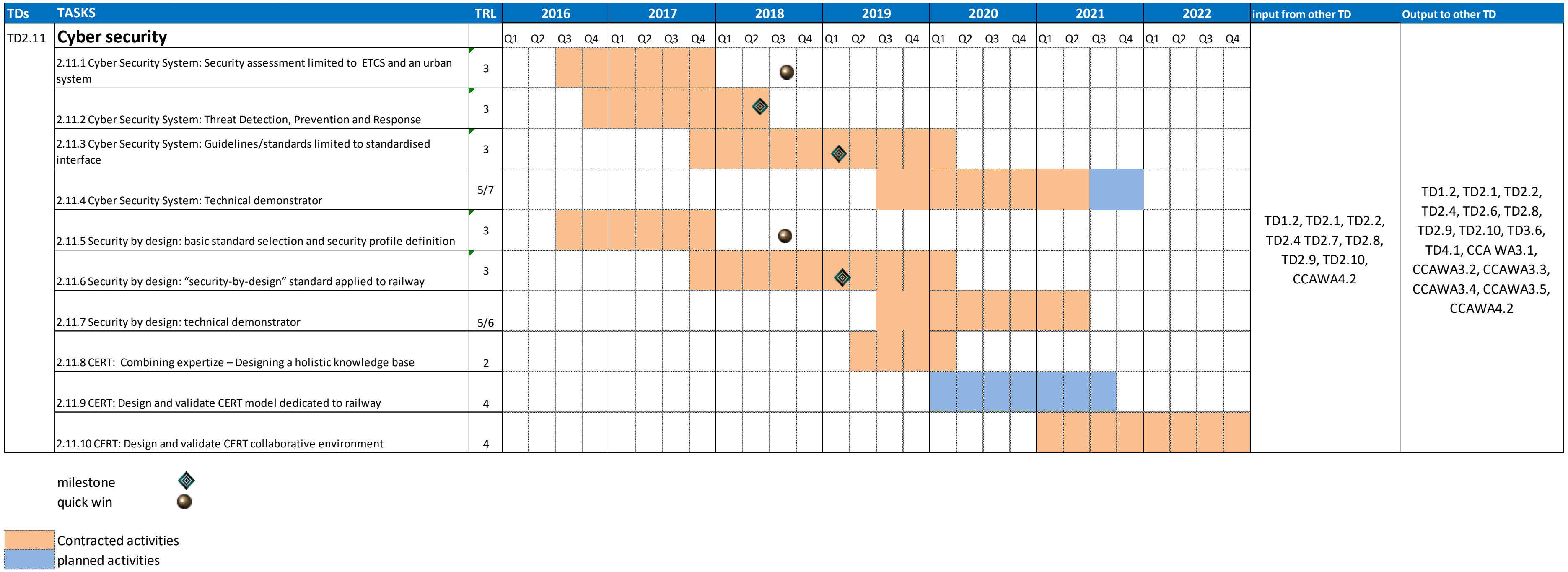


Table 37: TD2.11 quick wins

When	What	Contribution to MAAP
Q4 2018	Detailed security assessment of railway generic architecture	Main outcome of task 2.11.1
Q1 2019	Definition of generic protection profile for railway sub-systems/compo-nents	Main outcome of task 2.11.5

Table 38: 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 TCMS TD is around 12.5 M€

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 by 80% and 50% respectively by 2050. The Shift2Rail Innovation Programme 3 (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, sub-systems 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 design 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 have in general not been designed following a whole system approach.
- Rather than adopting risk and condition-based LEAN approaches to optimise Reliability, Availability, Maintainability, Safety (RAMS) and lifecycle 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 have 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 overall Shift2Rail objectives:

- enhancing the existing **CAPACITY** fulfilling user demand of the European rail system;
- increasing the **RELIABILITY** delivering better and consistent quality of service of the European rail system;
- reducing the **LIFE CYCLE COST** (LCC) increasing competitiveness of the European rail system and European rail supply industry

Specific technical impacts are listed for each Technical Demonstrator (TD) in the following sections.

IP3 will deliver outcomes which 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, and
- Environmental performance.

Corresponding societal benefits include:

- Capacity,
- Operational reliability, and
- Competitiveness – share of transports.

These objectives are all geared to achieve 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, and
- Improved standardisation.

More specific objectives are listed under the respective TDs.

To obtain the 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 inclusions of all affected parties in IP3,
- to ensure the identification of high-importance issues and the generation of relevant solutions and
- to ensure a working cooperation between partners – also this is partly addressed by having many of the partners involved in In2Rail.

Structure and set-up of IP3

Structure

The IP3 is organised around eleven Technical Demonstrators (TDs), which are briefly presented below and described in detail in later subsections. Figure provides an overview of the interrelations between all of the TDs of IP3 and also shows how the TDs are clustered together into 3 Integrated Technology

Demonstrators (ITDs). ITDs combine TD prototypes at system level (lab and on-site) and opportunity for testing optimisation and validation.

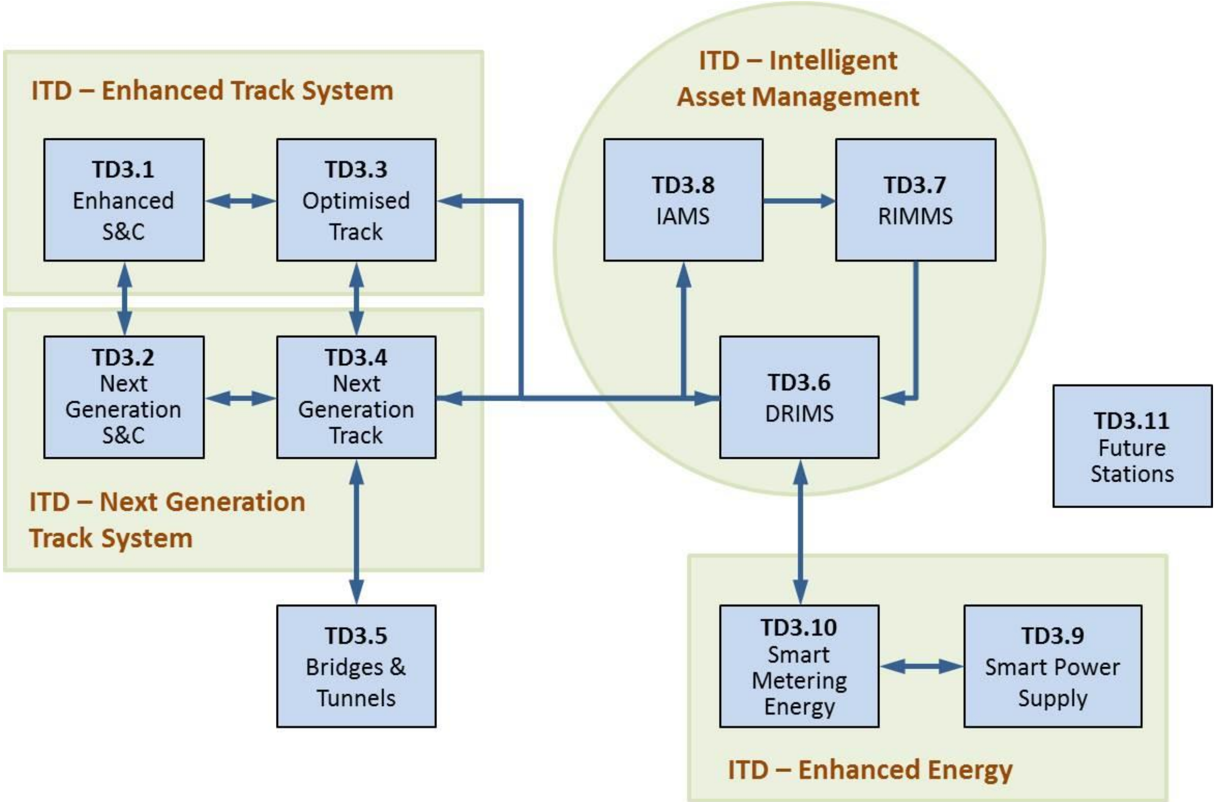


Figure 1: TDs and ITDs in IP3

TD3.1 Enhanced Switch & Crossing System Demonstrator

The main objective of this TD is to improve the operational performance of existing S&C designs through the delivery of new S&C sub-systems 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 & Crossing System Demonstrator

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 harmonized 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 present state-of-the art. This implies that step changes in performance are highly prioritized. 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 design/evaluation of solutions.

TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade Demonstrator

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. Also the reduction of noise and vibrations are prioritised objectives. The TD is organized around the different technical challenges to reach this end.

TD3.6: Dynamic Railway Information Management System (DRIMS) Demonstrator

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 (RIMMS) Demonstrator

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 (IAMS)

The vision is a holistic, whole-system approach of 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 the maintenance and other maintenance activities.

TD3.9: Smart Power Supply Demonstrator

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 design to obtain this target.

TD3.10: Smart Metering for Railway Distributed Energy Resource Management System Demonstrator

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 Demonstrator

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 switches and crossings interact with the operating vehicles (IP1 and IP5). In addition there is also an interface to 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 below.

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.

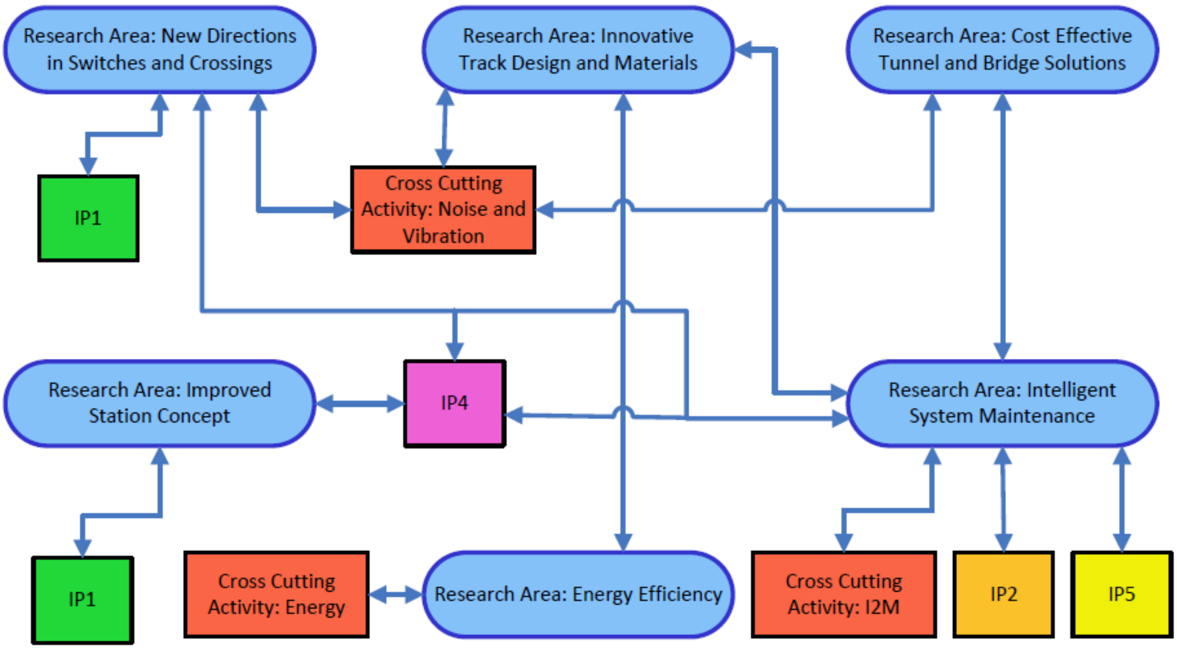


Figure 2: Relationship of IP3 with other IPs and CCA

In addition, the existing interactions with other IPs and within relevant TD´s of IP3 take into account the work on 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 lifecycle 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 59 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 lifecycle 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 lifecycle. For example, radically different options will be considered in the concept and design phase. It will also be necessary to consider the maintenance strategy and the timing of renewal and whether 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 rollout of new technologies and therefore the timescales over which the benefits are realised.

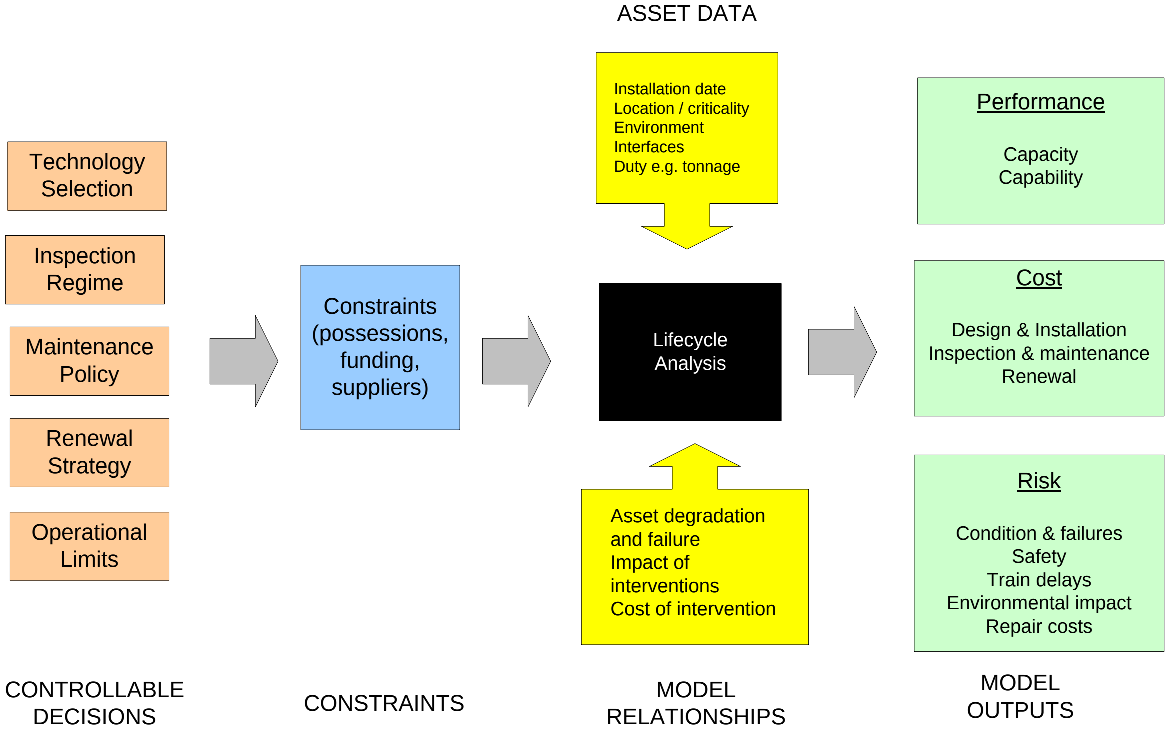


Figure 27: Appraisal framework for Whole Life Value and Cost analysis

Model relationships

These are the key relationships that support the calculation of performance, cost and risk at each stage of the lifecycle 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 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 a continuous evaluation of the performance, cost and risk of an option or combination of options.

3.1. TD3.1 Enhanced Switch & Crossing System Demonstrator

3.1.1. Concept

Switches and crossings (S&C) are a critical sub-system of the railway infrastructure, in terms of safety and performance. Service affecting failures associated with S&C account for some 25-30% of all infra-structure failures on European railways. Furthermore, a significant proportion of the life cycle cost (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 sub-systems whilst 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 has low LCC. Emphasis will be placed on sustainability and environmental issues with the objective of ensuring that a holistic strategy to minimize environmental footprint and whole life energy consumption.

The innovative approach is to adopt the growing trend of blending mechanical, electro-mechanics, 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 sub-systems with enhanced Reliability, Availability, Maintainability and Safety (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 demonstrator 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 sub-system level but not with a whole system perspective and thus potential improvements w.r.t. RAMS still exists.	**Design** An integrated whole system approach will be used to achieve multi-disciplinary optimisation. This results in fewer and more reliable components, more elasticity and flexibility, inter-changeability, and easier integration and commissioning procedures.
Assessment Individual time-consuming assessment processes for new S&C systems for individual railway operators.	**Assessment** Guidelines and procedures for hybrid assessment (virtual + experimental) and cross acceptance for new materials, components and systems.
Installation Installation and replacement of S&C requires 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 Existing S&Cs partly don't 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 (of the same IP and/or of the other IPs)
This TD will interact with:

- IP1 – TD1.4 Running Gear: Curve negotiation behaviour is influenced by S&C and running gear design (lightweight running gear, actuator and control technology).
- IP2 – TD2.10 Smart Radio-Connected all-in-all Wayside Objects: Security definitions influence the transmission of data from sensor equipped S&Cs.
- IP3 – TD3.2 Next Generation Switch & Crossing Systems: TD3.2 takes TD3.1 to the next generation by radically getting rid of system limitations while building upon TD3.1s experience. Outcomes may direct TD3.1s further enhancement even beyond S2R.
- IP3 – TD3.3 Optimised Track Systems: Innovative track solutions can be applied in both S&C and track, e.g. under sleeper pads, sleeper design.
- IP3 – TD3.4 Next Generation Track Systems: Outcomes may direct TD3.1s further enhancement even beyond S2R.

- IP3 – 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.
- IP5 – TD5.3 Smart Freight Wagon Concepts: Curve negotiation behaviour is influenced by S&C and wagon design.
- CCA – WA 3.2 Standardization (Standards relating to the areas of S&C, Track, Ballast, installation, inspection and maintenance.
- CCA – WA 3.1 Safety.

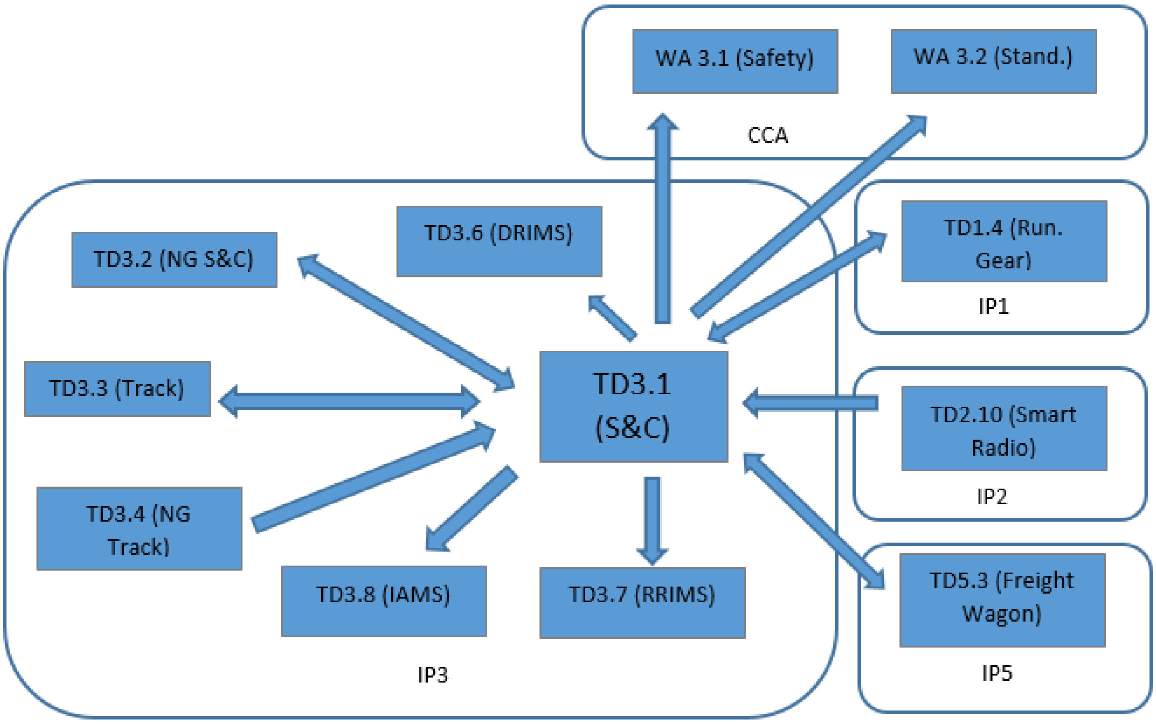


Figure 28: Interaction with other TDs within IP3

3.1.4. Impact and enabling Innovation Capabilities

The specific benefits of TD3.1 have a major impact in the Shift2Rail system-level KPIs.

Strategic Aspect	Key Contribution from the TD	
Support the competitiveness of the EU industry	Whole system modelling to reduce existing S&C failure modes through design	**Global technological leadership** supported by a combination of innovation and technical standards, setting an effective advantage for the European industry
	Integrated S&C RCM with automated self-correction and adjustment	
	Enhanced wheel to S&C interface conditions	
	Improved redundancy of safety critical systems for enhanced system reliability	
	Increase of operational reliability through more robust systems thanks to fewer components, enhanced assessment and debugging concepts, and more flexible information processing.	**Increase attractiveness and competitiveness**
	Asset LCC reduction through virtual assessment, lower physical complexity of systems and increased RAMS performance.	
	Capacity increase through reduced service affecting failures.	
	Automation of S&C inspection (via RCM) reduces manual surveillance (improving safety and maintenance efficiency) and reduces the reliance on subjective views of asset condition.	
	Improved customer ride quality through improved wheel-rail interface conditions	**Enhanced customer experience**
Compliance with EU objectives	Improved avoiding of service disruptions and adding new capabilities.	**Promotion of modal shift**
	Improving 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.	
	Supporting fair and efficient supplier competition and enhanced interoperability through inter-changeable solutions. This will support achieving a Single European Rail Area (SERA).	
	Support to capacity increase by introducing additional levels of redundancy and hence reliability to existing S&C systems. This will reduce service affecting failures.	
Degree of maturity of the envisaged solutions	Currently, most of the proposed technologies are at low Technology Readiness Levels (TRL) of between 1 and 2. At the end of Shift2Rail, it is expected that the successful concepts are brought to TRL 6 or 7.	

This TD will contribute to enable the below Innovation Capabilities as follow:

Innovation Capability	***TD3.1 Enhanced S&C enablers & 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' onto 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 incl. 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 regards to both construction and repair. Relevant Building Block: • BB3.1.2 Enhanced S&C design incl. 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
11 – Environmental and social sustainability	The use of Computer Aided Engineering (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 material, sustainable choice of material and easy reparability, eg. enhanced welding processes. Relevant Building Block: • BB3.1.2 Enhanced S&C design incl. materials and components, TRL 6/7 S&C deterioration data, obtained through embedded and integrated sensors, will deliver the possibility for online status monitoring and enables by that innovative asset management procedures and strategies. Relevant Building Block: • BB3.1.3 Enhanced control, monitoring and sensors systems, TRL 6/7

12 – Rapid and reliable R&D delivery	Virtual prototyping includes the virtual testing of the planned design and reduces by that the necessary physical in-situ testing while increasing the rate of design to need. Relevant Building Block: • BB3.1.1 Enhanced S&C whole system modelling, simulation and design, TRL 5

3.1.5. Demonstration activities and deployment

The following table summarises the contribution of TD 3.1 Enhanced S&C to the different System Platform Demonstrators (SPDs) of Shift2Rail:

Research Area	Specific Techn. objective	Specific Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Enhanced Switch & Crossing System	RAMS optimised S&C	Enhanced design & material properties, concrete bearers with USP, optimized 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 a S&C and the deterioration of its 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 of stresses and wear conditions		4/5	Design, development, testing and implementation 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 ADV, sharing information with operators capable of perceiving, analysing and acting according to the contexts and the environment.

Planning and budget:

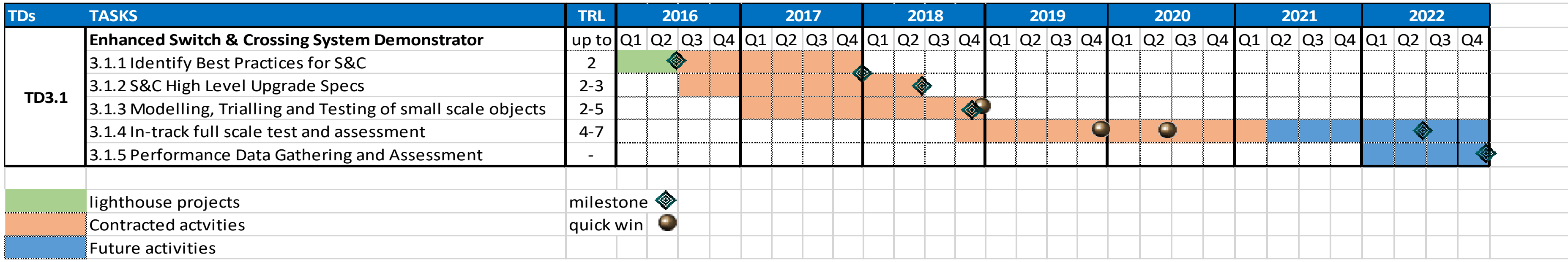


Table 39: TD3.1 quick wins

When	What	Contribution to MAAP
Q4 2019	first full-scale HS/ 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 40: TD3.1 milestones

When	What
Q2 2016	Start of In2Track project
Q4 2017	Collection, analysis of existing S&C components incl. 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
Q4202 2	Analysis of tests, performance, LCC in place End of In2Track Project

The estimated budget for the TD is around 15.5M€.

3.2. TD3.2 Next Generation Switches & Crossings

3.2.1. Concept

The competitive nature of today's world markets places even more emphasis on the rail industry to become more efficient and have a stronger presence in a trans-European and global context. 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 are profound to the overall performance and safety of the railway infrastructure. One such element is Switch and Crossing (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 are arduous and complex and advances in rail steel technology needs to be developed to resist abrasive wear and rolling contact fatigue.

This Technology Demonstrator (TD 3.2) aims to provide radical new system solutions that deliver completely new methods for directing trains to change tracks. TD 3.2 will adopt a structured R&D process to achieve technology demonstration through component, sub-system 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 methodologies of switching trains between tracks in a manner that drastically improves capacity, performance and reduces costs whilst maintaining safety as an over-riding consideration. Advances in materials, enhanced elastomeric components, optimised sensor technologies, adaptive control with active closed-loop feedback, 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 are not constrained by the principles imposed by todays 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 & Components

S&C rely on standard profiles that are machined to the specific shapes as required by the S&C configuration. Traditionally, the design application engineering is different across 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 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 that the S&C is 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 for 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 the TD3.2 – Next Generation S&C System Technology Demonstrator is to seek, by trialling, the radical redesign of S&C. Long-term, whole system developments will also build on the improvements achieved in the TD3.1 – Enhanced S&C System Demonstrator.

State-of-the-art	New Generation Switches & Crossings
Installation Installation of S&C requires many steps and manual actions to locate the unit in its position.	**Installation** A switch unit designed for automated installation and maintenance.
Maintainability Current design is labour intensive and requires maintenance staff to tend to the assets at regular intervals to survey its state as well as to make adjustments and refill consumables.	**Maintainability** Embedded remote sensors 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 one of the highest loaded components within the S&C system and are therefore significantly affected by wear, fatigue fracture and Rolling Contact Fatigue (RCF).	**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 (POE) may incorporate sensors that work independently to the whole system. For example, the relationships between drive forces, system lubrication and switch position cannot be automatically assessed and hence whole system condition is not known until a comprehensive manual inspection is complete.	**Operational** The next generation S&C design will include 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 solution of making the vehicles change direction is solved as part of the infrastructure causing wear and tear and failure modes to be associated with these locations.	**System Degradation** The proposed S&C system will consider alternative vehicle guidance techniques 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 has been designed by considering existing materials, computers, electronics and mechanics in mind but not from a whole system perspective. As a result, the existing state-of-the-art solutions have, in many ways, not been optimised with regards 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.

Figure 29: Next Generation S&C

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

- IP1 – TD1.2 Train Control and Monitoring System (TCMS)
- IP1 – TD1.4 Running Gear
- IP2 – TD2.1 Adaptable communications for all railways (quality of service, interfaces to signal-ling)
- IP2 – TD2.9 Traffic management evolution
- IP2 – TD2.10 Smart radio-connected all-in-all wayside objects
- IP3 – TD3.1 Enhanced Switch & Crossing System
- IP3 – TD3.3 Optimised Track Systems
- IP3 – TD3.4 Next Generation Track Solutions
- IP3 – TD3.6, TD3.7 and TD3.8 Intelligence Asset Management
- IP5 – TD5.3 Smart Freight Wagon Concept
- CCA Work Area 2 – KPI method development and integrated assessment
- CCA Work Area 3 – Safety, Standardisation, Smart Maintenance, Smart Materials & Virtual Authorisation

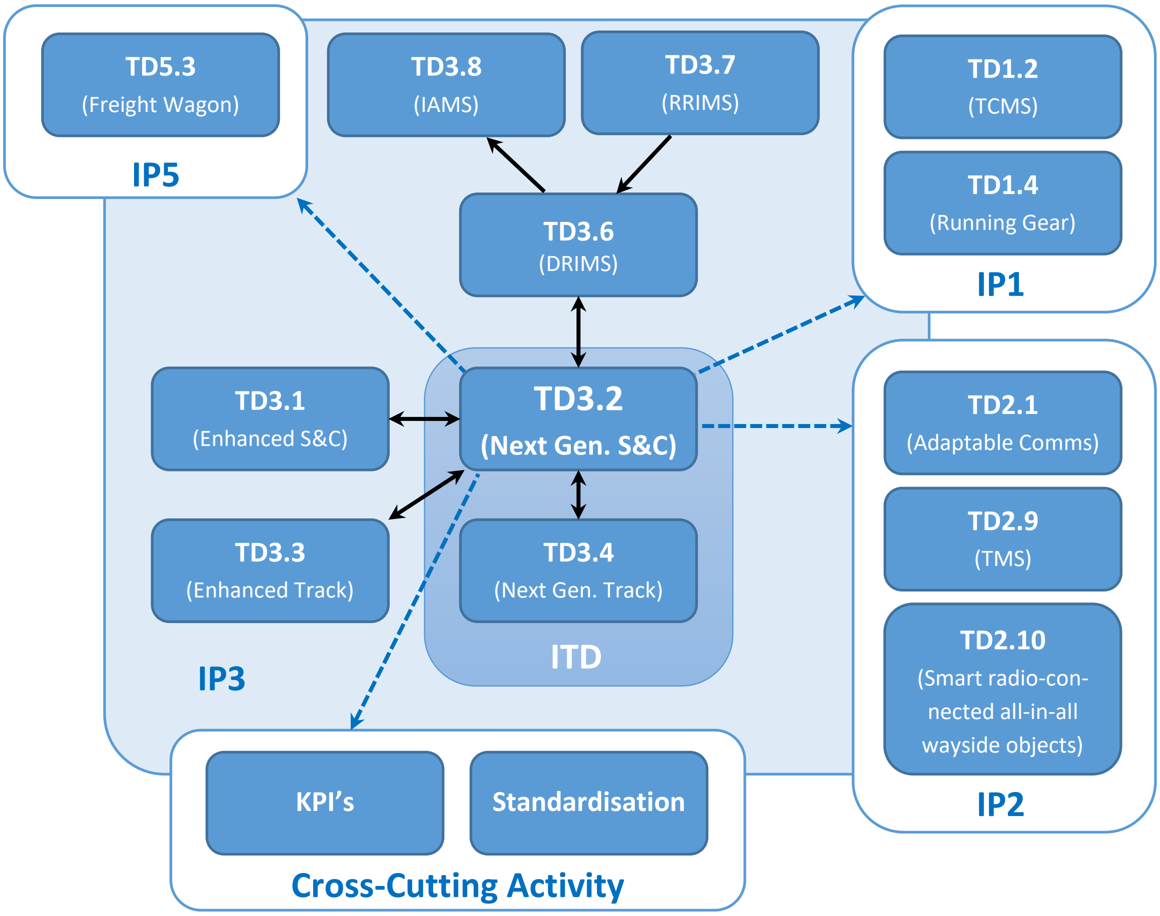


Figure 30: Interaction with other TDs and IPs

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	○ Improved RAMS performance (Reliability, Availability, Maintainability and Safety) of S&C 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 train 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 for 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 include reduction in the number of components embodied in a compact system design.
50% Increase in Reliability & Punctuality	○ Rolling stock components will have a reduced duty cycle exposure due to reduced dynamic track forces and hence alternative materials 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 able the system to 'self-manage' with respect to system setup, 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 sub-systems.

This TD will contribute to enable European rail industry innovation capabilities as follow:

Innovation Capability	***TD3.2 Next Generation S&C enablers & 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 / sub-system 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 Blocks: • BB3.2_2 Intelligent self-diagnostics systems with embedded RCM

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. • BB3.2_1 Enhanced materials for optimised asset lifecycle costs • BB3.2_2 Intelligent self-diagnostics systems with embedded RCM
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. • 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 Infrastructure Managers system and design resources and targets with suppliers will increase both the effort and funding available to generate the radical solutions. S&C system designed with aligned component life cycles to promote a reduction in Infrastructure Managers maintenance & renewals costs. • BB3.2_1 Enhanced materials for optimised asset lifecycle costs • BB3.2_2 Intelligent self-diagnostics systems with embedded RCM
8 – Guaranteed asset health and availability	New designs and materials will be explored capable of self-healing and self-maintaining whilst reducing asset failures and noise and vibration through optimised design and track support conditions through tailored stiffness transition zones. RCM solutions that enabling predictive asset health monitoring and inform traffic management of medium to long term asset remaining operational life (*i.e.* to inform optimised maintenance and renewals strategies) • 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
9 – Intelligent trains	Next generation S&C systems will be compatible with intelligent train systems, enabling train to infrastructure communication and to inform advanced traffic management. • BB3.2_2 Intelligent self-diagnostics systems with embedded RCM
10 – Stations and “smart” city mobility	S&C are critical nodes that enable railway network flexibility and unlock the maximum potential for optimised system capacity. Next generation S&C systems with optimised RAMS performance will enable railways to be connected to smart cities and provide seamless end-to-end journeys and interchange between modes of transport. • 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
11 – Environmental and social sustainability	New materials will be assessed for improved S&C RAMS performance and whole asset LCC with reduced carbon footprint. System resilience against climate change will be embedded within next generation system designs whilst ensuring low levels of noise and vibration. • BB3.2_1 Enhanced materials for optimised asset lifecycle 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:

D3.2_1 Small Scale Prototypes and Virtual Testing (TRL 4 – 5)

Design and build 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.

D3.2_2 Full-Scale Prototypes and Virtual testing (TRL 5 – 6)

The full-scale test phase will confirm safety and performance of the proposed design. Once 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 main line railways.

Due to the advanced nature of the next generation S&C solution, it is anticipated that there will be a heavy reliance on both virtual and laboratory testing within both stages of technology demonstration.

The full-scale test will form part of an Integrated Technology Demonstrator (IDT) alongside TD 3.4 – Next Generation Track Systems and will link to TD3.6, TD3.7 and TD3.8 – Intelligence System Maintenance. It is anticipate 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 Techn. objective	Specific Activities	System Platform Demonstrator Market	 TRL	Focus of activity
Next Generation Switches and Crossings	Next Generation S&C System Demonstrator	Next generation S&C prototype with optimised RAMS performance and LCC. Whole system demonstrator may also form an Integrated Technology Demonstrator (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		Generic	4/5	Fault tolerant switch control systems are being developed and seek to achieve virtual validation to TRL3-4 by 2019. ASTS will further develop the most feasible concepts in order to embed advanced switch control within the integrated next generation S&C system demonstrator. Initial laboratory demonstrations will be made prior to integration within the Next Generation S&C System Demonstrator.
	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 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 decisions 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.
	Next Generation S&C Materials and Components	Design, manufacture and demonstrate 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 will 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 be demonstrated within the operational railway or live test track environment (*i.e.* self-healing concretes).

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	TRL	Focus of activity
	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 will be defined in collaboration with WP4 for next generation track application. This will include instrumentation and monitoring to support future assessment of asphalt performance.
	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 occurs, are usually subjected 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 S&C life cycle with that of plain line track whilst aiming to reduce the impact of N&V.
	Optimised S&C Support Conditions	Modular Continuous Support (MCS) track is a ballast-less beam track offering an efficient, lower cost rail technology for all track configurations (including turnouts).	Generic	5/7	VCSA will further develop this concept by completing detail 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 a S&C Digital Twin (DT), which will form part of the overall strategy for validation and demonstration of next generation S&C system concepts. The DT is the representation of a system which 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.
	Automated Inspection & 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

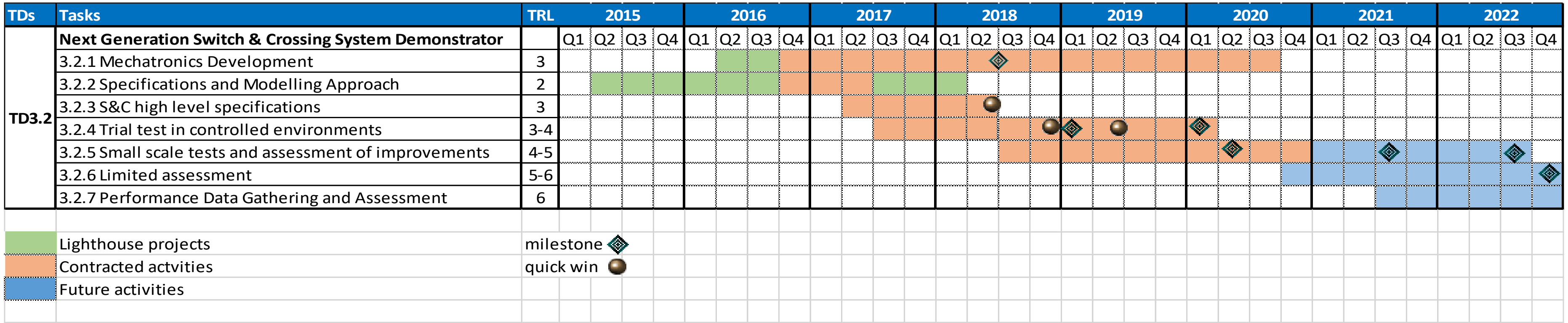


Table 41: TD3.2 quick wins

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 materi-als	Next generation S&C materials

Table 42: TD3.2 milestones

When	What
Q2 2018	Early designs for next generation S&C systems and sub-systems (up to TRL 3)
Q1 2019	Component and sub-system experimental proof of concept in controlled environment (up to TRL 4)
Q1 2020	Technologies (components and sub-systems) validated in a controlled environment (up to TRL 4)
Q2 2020	Integrated next generation S&C system concept established for demonstration (up to TRL 4)
Q3 2021	Sub-system prototypes validated in a 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 16.7m€ (Including 0.87m€ 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 high levels of sustainability, loading capability and LCC savings relative to existing construction types. Sustainable track and track component is a core issue for this TD. Also the digitalisation by inbuilt and integrate sensor system in the track system and components which will contribute to reach the objectives.

Therefore innovative solutions in the form of products, processes (e.g. plan and carry 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 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 with the aspect of interaction 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 other will emerge as the project commences.

3.3.2. Technical Objectives

The main technical objective of TD3.3 is to improve the operational performance of existing track system that includes the track designs. The solutions resulting in 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

Improved materials designs and processes.	~10% RP
Decreased the rail deterioration through lubrication, grinding, and rail grade optimization.	~5% RP ~10% LCC
Develop the welding technologies 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 in terms of reduce the degradation of wheel/rail system.	~5% CI ~5% LCC ~5% RP
Enhance the knowledge on track support and settlement conditions.	-
Reduction of high 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 of track and track components.	~5% CI ~5% LCC ~5% RP
Improve the performance on 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% IRP

Capacity Increase (CI), Reduction of LCC (LCC), Increase in Reliability and Punctuality (RP), Environmental aspects (EA)

3.3.3. Technical Vision

The vision for the optimised track system demonstrator is to improve the track performing by better components that built up the track system. The benefits in each component adds together at the track system level.

State-of-the-art	Optimized 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 for increased performance, reducing LCC and enhanced RAMS of the entire track system.
Damage epidemics on rail like squats and other RCF occur and cause high costs and operational disturbances.	With a deeper understanding of squats, RCF and also wear, a significant extension of life is feasible. Predictive models to foresee potential complications including contrasting to 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 on what to monitor/measure, how to measure, and how to interpret gathered data and translate these to maintenance / re-investment plans. Enhance the knowledge measurement performance.
The use of material derived from limited material resources is widespread, but becoming more and more unsustainable.	Increase the use of re-used/recycled materials into the design and construction process. Look for more environmentally friendly material choices.
Maintenance procedures are becoming more and more unsustainable as time in track decreases whereas maintenance demands increases.	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. Increase the knowledge of the phenomena and combat the noise and vibration issues at the source.
The track system deteriorates severely in specific track sections.	Knowledge on influencing parameters for the local deficiency, collection and analysis of relevant data, 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 larger wear and higher cost for the infrastructure manager and the rolling stock operator.	More knowledge needs to deal with deficiencies in the interaction of the wheel and rail. This should also be connected to stability as the comfort issue.
The friction management is in use but the knowledge of the topic is limited in the railway application.	The friction management need to be more investigated in terms of the phenomena and how to deal with that out in field to gain the operation in a LCC perspective. Also look in to more environmental friendly lubrications and the performance of them.
The current track has 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 regards to RAMS and LCC.	New materials, technologies and other solutions to reduce cost during engineering, integration and commissioning phases. More reliable components, that are developed to fit the system. Maintainability and availability aspects needs do be considered in the whole development process. Safety have to be a core aspect.

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

TD3.3 interact in this IP (IP3) by exchanging information and data between TD 3.1, 3.2, 3.4. 3.6, 3.7 and 3.8. A deeper interaction have to be done in between TD3.4 and also between TD3.1 and TD3.2 to verify responsibilities and limits. Also the technical aspects need to be interacted between the TDs. Figure 1 show the interactions between the TD3.3 and other TDs in IP3, also interactions to other IPs.

Other interaction between IPs should be performed between the IPs. IP1 with TD1.4 Running Gear in curve negotiation behaviour and running gear design and IP5 in TD2.10 Smart Radio-Connected all-in-all Wayside Objects and TD5.3 Smart Freight Wagon Concept.

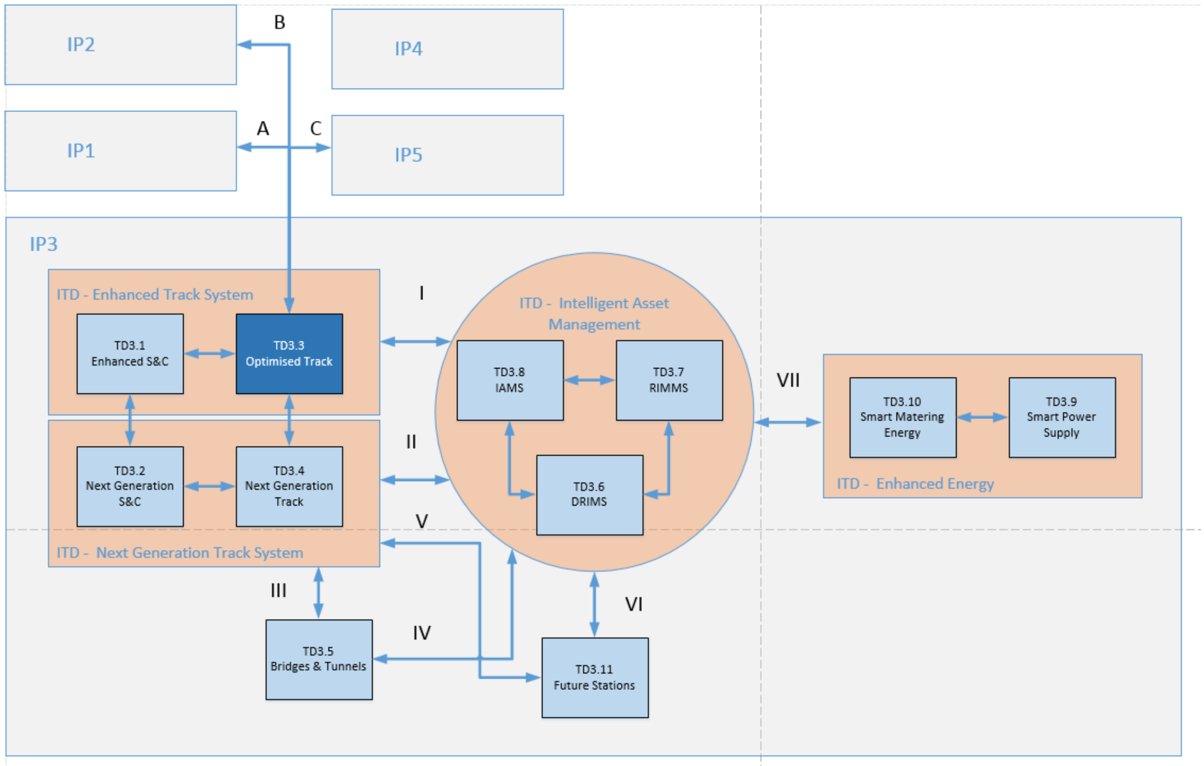


Figure 1: Interaction with other TDs and IPs

3.3.4. Impact and enabling Innovation Capabilities

The following technical impacts are envisaged by the implementation of TD3.3.

Strategic Aspect	Key Contribution from the TD
Support the competitive-ness **of the EU industry**	Increase of operational reliability through more robust systems with lower failure rate on components and sub-systems. Higher punctuality for the railway I general.
	Increased passenger comfort by better maintained track geometry. Higher satisfac-tion from the passengers.
	Improved wheel/rail interaction enhanced the punctuality.
	Lower LCC of the asset gives reduction on cost of railway transportations.
Compliance with EU **objectives**	Promotion of modal shift to more environmental transports: A big impact brought by the implementation of these improved and new technologies towards avoiding ser-vice disruptions and enhancing capacity.
	Support to capacity on track by less capacity consumptions: By enhanced condition monitoring and improved reliability of component the track can be more utilised.
	Better utilisation of track and more environmental friendly components will reduce emission harmful for environment

Strategic Aspect	Key Contribution from the TD
	Achieve single European Rail Area (SERA) due to a common understanding making long term decisions based on an ISO 55000 framework, monitoring the effect European wide 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 enable European rail industry innovation capabilities as follow

Innovation Capability	***TD3.3 Optimised Track Solutions enablers & technological building blocks***
4 - More value from data	○ Improve the condition monitoring by investigate the deterioration processes of components and systems. ○ Enhanced understanding of system performance and impact of components / subsystem degradation. ○ Find the right indicators for efficient condition monitoring. ○ Ensure high R&R 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 transports and enhanced capacity by improved 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
8 - Guaranteed asset health and availability	○ Improved and develop new solutions that require less maintenance, improved precision in identifying exact maintenance targets and improved 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	○ More reliable condition monitoring of track and track component. ○ Enable online connection/monitoring of track components for the remaining useful life estimation. ○ 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	○ More reliable condition monitoring of track and track component. ○ Enable online connection/monitoring of track components for the remaining useful life estimation. *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	○ Less environmental footprints from components by using more sustainably material chooses. ○ Less noise and vibration pollutions 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
12 - Rapid and reliable R&D delivery	○ Develop hybrid testing approach for faster and more precise component and system development. ○ Simplify the cetification process by performing the hybrid test approach ○ Contribute to improve the interactions between companies and infrastructure managers in Europa. ○ Global technological leadership through highly innovative solutions 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 Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Optimized Track System	Optimised track performance	Perform small scale tests and detailed instructions of maintenance procedures.	High-speed passenger rail, Regional passenger rail	6	Ballast less track: define the maintenance of slab track system.
		Demo out 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
		Demo out in field with monitoring, data analysis.		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.
		Built parts that verify the product and shows the performance. Small scale test on field.		6	Novel geometry defect repair techniques to establish optimised asset management.
	Friction management	Demo in field with monitoring, data analysis etc.		6	Lubrication and top of rail friction modifier, develop the optimal lubrication system for lubrication of track.
	Optimised track component performance	Demo in field with monitoring, data analysis etc.		6	Rail performance/Rail reliability management: improve the rail in term of wear and crack tendency also in combinations with machining of rails.
		Demo in field with monitoring, data analysis etc.		6	Improved fastening system: Develop more reliably fastenings system.
		Demo in field with monitoring, data analysis etc.		6	Rail repairs: Improve the rail repairs and rail welding.
		Demo in field with monitoring, data analysis etc.		6	Ballast recycling: Optimised ballast recycling, develop prototype of sorting machine based on advanced characterization techniques.
	Testing and certification process	Demo if 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 reliably.

Planning and budget:

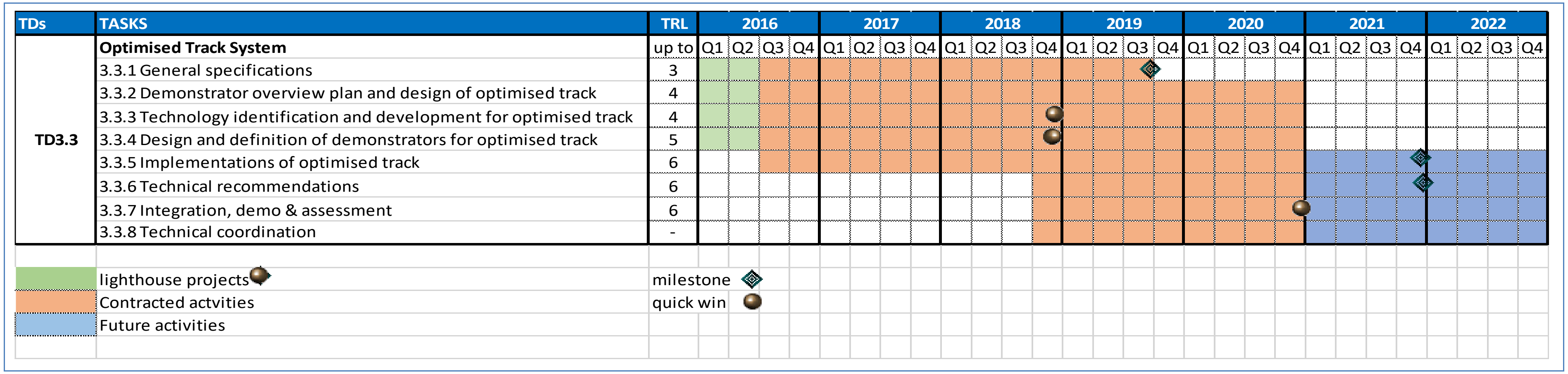


Table 43: TD3.3 quick wins

When	What	Contribution to MAAP
Q4 2018	Verify performance of Bituminous layer	Simulations and lab demonstration in smaller scale that built next step.
Q4 2018	Repair methods for slab track	In lab demonstration in smaller scale, important to future development.
Q4 2018	Material samples that represent rail formation	In lab demonstration in smaller scale, important to future development.
Q3 2020	Novel lubrication system for on-board use	Demonstration in field environmental, important to future development.

Table 44: TD3.3 milestones

When	What
Q3 2019	Finished the report, Requirements for track design and maintenance that defines in T3.1. This will be considered in other tasks (T3.3-T3.6).
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 18 M€.

3.4. TD3.4 Next Generation Track

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, harmonization toward today's railway system is less important, whereas step changes in performance are highly prioritized. 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 functionality 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 the aspect of interaction with vehicles.

3.4.2. Technical Objectives

The work in this TD aims at a substantial leverage of the track system 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, focus is given to providing the basic functional demands of the track system, including:

- Running surface that provides low running resistance, maintains gauge, provides steering, has very low deterioration
- Support for the running surface that keeps it fixed in vertical, lateral and rotational direction that also provides sufficient stiffness.
- Track foundation that provides a sufficient and continuous stiffness in the lateral and vertical direction 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).
- Eliminate 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 standardized and modularized track components with a 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 evolution over the track 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. 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 a 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;
- Optimized running surface damage prevention and mitigation;
- Detailed measurement of 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;
- Optimized management of friction, running surface geometry, material selection with a zero maintenance aim; and
- High-precision and very detailed geometry and stiffness measurements and the adoption of these in a zero maintenance vision / self-adjustment.

These solutions also demand radically increased knowledge on how different material and interfacial 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) that 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;
- Re-use and recycling materials in fastenings and pads. Specifically, an analysis of the influence of these new materials in the reduction of noise and vibrations;
- New materials (re-use, recycling materials) in the design of rail supports;
- New design for the reduction of loads and increased durability. This includes integration of elastomeric elements to vibration mitigation, decreasing variations in track stiffness especially in transition zones, and increase of 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 & 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 stabilization treatments for each single situation and showing the optimized dimensions of the support layers into design charts, and support component integration. Potential solutions include:

- Harmonized 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 in existing and new track. This includes optimised drainage systems that can adapt to altered climate conditions.
- Improved new materials and combinations;
- Optimized 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; and
- 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 (*c.f.* Recytrack – Life Program, Rivas – FP7). Solutions to be considered in the reduction of noise include:

- 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 will be evaluated. 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, new materials to increase efficiency, durability and allow easy installation and low maintenance ;
- Development of innovative methods for reducing the generation and growth of roughness and corrugation;
- Specific effort to model and mitigate curve squeal, especially for light rail.

Integrated maintenance procedures

Maintenance is focused on the track structure. The solutions will provide:

- Optimized methods to provide suitable track geometry;
- Optimized methods to provide suitable running surface geometry;
- Optimized methods to provide suitable friction between running surfaces; and
- 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 a reset of 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 make consequence analyses of different maintenance scenarios. In contrast, the focus in TD3.6, TD3.7 and TD3.8 is overall data management, prioritization and planning of maintenance actions.

Optimised condition monitoring

Technologies for early, high-precision track deterioration will be required in the long-term rail structures. Further, 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, improper track stiffness, etc.

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 namely:

1. Clearly and well defined and physically transparent and justified demands is a natural demand on vehicle characteristics. The next step with input from TD3.3.
2. The different damage phenomena are taken into account so the robustness clearly better. The knowledge has clearly increased of 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 the developed solutions.

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-standing solutions to address influences of climate change and assess the consequences for the track, and to assess re-use of waste generated by the railways.

Product identification and link to asset management

In the long-term perspective 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 prioritize 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 transport volume to road. Such a scenario would constitute a sub-optimization 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 the developed solutions will give the rail system.

The following table summarizes some examples of how this TD will progress the state-of-the-art and overcome existing limitations and difficulties:

State-of-the-art	New Generation Track
Although highly developed, current track structures are subjected to continuous increases in loads and demands on operational reliability.	Radically optimized design, and maintenance of track to allow for 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 on 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 re-used / recycled materials into the design and construction process
Maintenance procedures are becoming more and more unsustainable as time in track decreases whereas maintenance demands increases.	Improved precision in which maintenance to carry out when. Enhanced maintenance methods.

State-of-the-art	New Generation Track
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, on-line 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 as compared to 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.

Figure 31: Next Generation Track

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

- IP1 – TD1.2 Train Control and Monitoring System (TCMS)
- IP1 – TD1.4 Running Gear
- IP2 – TD2.1 Adaptable communications for all railways (quality of service, interfaces to signalling)
- IP2 – TD2.9 Traffic management evolution
- IP2 – TD2.10 Smart radio-connected all-in-all wayside objects
- IP3 – TD3.1 Enhanced Switch & Crossing System
- IP3 – TD3.2 Next Generation Switch & Crossing System
- IP3 – TD3.3 Optimised Track Systems
- IP3 – TD3.5 Bridges & Tunnels
- IP3 – TD3.6, TD3.7 and TD3.8 Intelligence Asset Management
- IP5 – TD5.3 Smart Feight Wagon Concept
- CCA Work Area 2 – KPI method development and integrated assessment
- CCA Work Area 3 – Safety, Standardisation, Smart Maintenance, Smart Materials & Virtual Authorisation

There is a tight integration with TD3.3, TD3.1 and TD3.2 and the transversal action on noise and vibration. Further, 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 towards IP1 and IP5, physically manifested in the wheel–rail interface. In is an addition indirect links to IP2 (and IP4 via IP2) in that any asset condition monitoring derived within TD3.4 feed decisions made within traffic management.

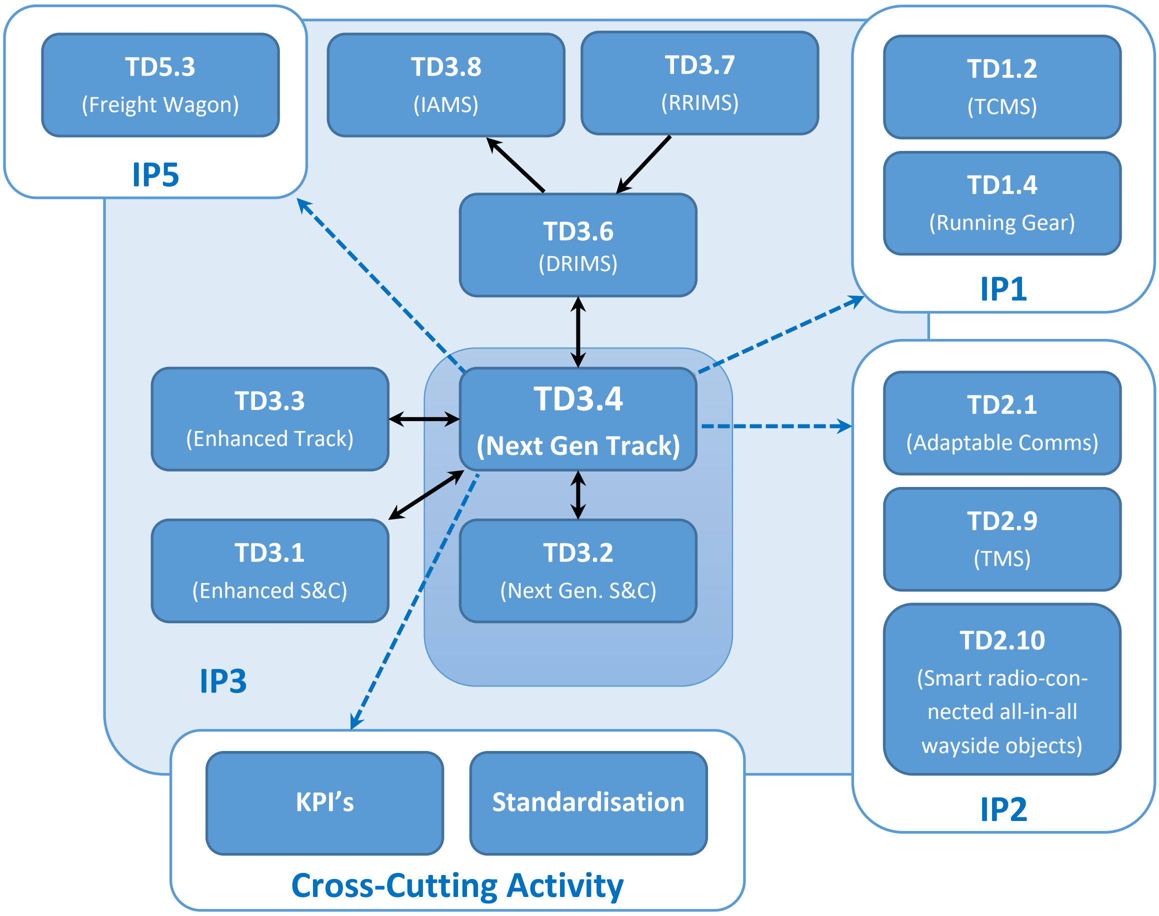


Figure 32: Interaction with other TDs and IPs

3.4.4. 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	○ 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. • Harmonized assessment of solutions to a larger degree based 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 & 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. ○ Optimized maintenance through intelligent monitoring and data analysis and prediction of deterioration rates.

This TD will contribute to enable European rail industry innovation capabilities as follow:

Innovation Capability	***TD3.4 Next Generation Track enablers & technological building blocks***
1 – Automated Train Operation	Eliminating or reducing ALARP existing failure modes that required maintenance intervention will enable automated train operation by optimising whole system RAMS performance. Reducing service affecting failures by introducing a more resilient, reliable and smart infrastructure will 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 will provide sustainable, whole system solutions to minimise environmental impact and carbon footprint whilst 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 transports. Relevant Building Blocks: • BB3.4.1 Predictive models integrated with measured operational data • BB3.4.2 Seamlessly integrated monitoring concepts

7 – Low cost railway	Achieve Single European Rail Area (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
8 – Guaranteed asset health and availability	Track forms with aligned component life cycles to promote a reduction in Infrastructure Managers maintenance & renewals costs. Promotion of modal shift through highly reliable an efficient rail travels. Solutions towards zero maintenance and 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 will 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 Technology, Integrated Technology and System Platform Demonstrations (TDs, ITDs and SPDs):

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	System Platform Demonstrator TRL	Focus of activity
Next Generation Track	Next Generation Track System Demonstrator	Next generation design and materials with optimised RAMS performance and LCC. Whole system demonstrator may also form an Integrated Technology Demonstrator (ITD) alongside TD3.2 for Next Generation S&C.	Generic	5/6	Next generation design, materials and manufacturing to 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 activites
	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 EMAT 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 SNCF faults difficult to detect with the system commonly used (Piezo ultrasonics).
	Rail Defect Repair	An innovative solution for the discrete defect repair of rail (DDR) 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 instrumented trials and will enable development of the process for different rail steel grades

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	TRL	Focus of activity
	Smart Geo-grids and Geotextiles	Innovative geotextile and smart fibre-based soil, ballast and concrete reinforcing solutions will be developed, based on innovative fibrous materials		4/5	Smart geo-grids and geotextile for layer, soil and ballast composites will be developed. The mechanical properties (strength, stiffness and ductility) of these innovative materials can be optimised based in laboratory tests, including small scale physical models. Also, ground improvement using alkaline activation and a new environmentally friendly process to apply a geotextile directly sprayed on the track, composed of cut fibre glass 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 where advanced numerical modelling of asphalt track solutions will be developed by RLM.
	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, where advanced numerical modelling of slab tracks and transition zones will be developed by RLM.
	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 realize cold spray coatings with good microstructure and properties, adapt the coating to the geometry of the rail, 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.

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	System Platform Demonstrator TRL	Focus of activity
	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 (DT), which will form part of the overall strategy for validation and demonstration of next generation track system concepts. The DT is the representation of a system which 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.
	Automated Inspection & 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:

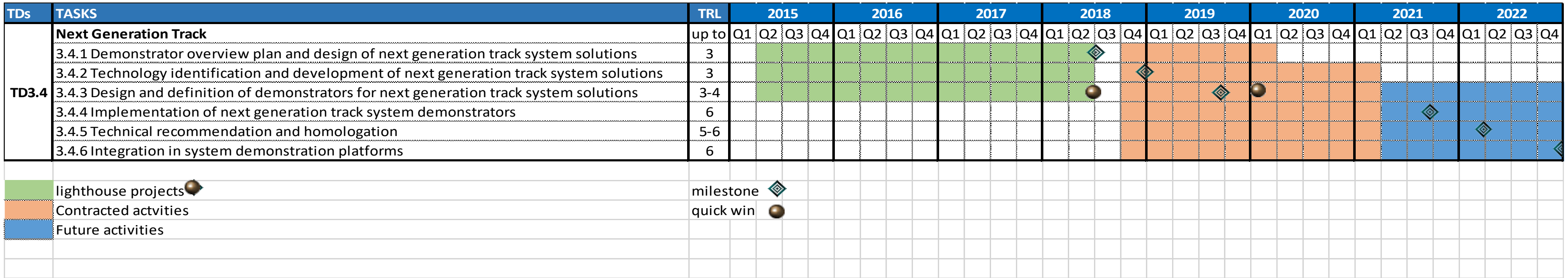


Table 45: TD3.4 quick wins

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 46: 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 13.5 m€

3.5. TD3.5 Proactive Bridge and Tunnel Assessment, Repair and Upgrade Demonstrator

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 and cost consuming repairs in the long run. This becomes critical and severely impacts track availability due to extended track closures. With enhanced inspection methods and techniques, reduction in inspection costs can be achieved whilst improving the quality of the inspection and rationalising the costs for corrective maintenance actions.

Even if many of the existing structures are close to or over 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 0.5-2M€ each. Similarly for the replacement of existing tunnels, apart from economic considerations, is not always a viable option due 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 likely 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 which did not take into account fatigue loading. The need for inspection and strengthening due to bigger traffic loads are increasing, whilst the ability to justify the pertinence 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 reinforce 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 reduce the implementation of non-standard and expensive solutions within the rail industry, leading to the optimisation of the future structure 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 reductions in costs and improving quality. With these methods and techniques, a proactive and more effective maintenance and upgrading of these structures to extend their service life is possible. A reduction of 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 for 10 % extension of service life.
- Develop new repairing, strengthening and upgrading methods which permit less traffic disturbance, fast installation with short track access time, and stepwise in nature to allow traffic movement between track operations allowing for 10 % extension of service life;
- Develop noise and vibration damping methods suitable for structures reducing sound pressure by 50%; and
- 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 progress the state-of-the-art and overcome today's limitations and difficulties:

State-of-the-art	Advance beyond State-of-the-art
Inspections of tunnels are today very time-consuming which includes 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 with enhanced quality. The inspections will be more objective, quantified and detect deterioration before defects arise and inspection results will have repeatability. With enhanced inspection, planning can be improved and actions can be planned well ahead to a lower cost with less traffic interruptions.
Inspections of bridges are subjective, 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 with enhanced quality. The inspections will be more objective, quantified and detect deterioration before defects arise. With enhanced inspection, planning can be improved and actions can be planned well ahead to a lower cost with less traffic interruptions.
Strengthening mostly covers improvement of ultimate limit state for semi static loading and is not fully working for a number of cases.	Strengthening methods can be used preventatively to reduce future problems. Strengthening methods will be enhanced on improving structural durability, structural ductility and bridge dynamic damping.
Tunnels are repaired made on small degraded sections with a limited impact on the tunnel life span and do not typically allow a wider tunnel gauge.	Concepts for tunnel improvement will be developed to undertake improvements of old tunnels including effectively used gauge and meanwhile allowing for traffic to continue operating.
Codes and standards are very prescriptive and reduce innovation and competition. Standards can also imply that best solution from life cycle analysis is not chosen.	Codes will be more descriptive, allow for innovation and for fair competition. Standards will promote best solutions from a life cycle analysis point of view.

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

Tunnel and bridge research need 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 pay loads, and to reduce vibrations. From TD3.7 viaTD3.6 data from on-board monitoring in useable format will be needed in order to monitor dynamic amplification of loads acting on bridges allowing for extended service life of bridges regarding fatigue. Outcome from research on tunnel and bridges can be integrated in 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 30 M€ (30 000 000€) every year. In addition, further savings are made by reduced 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 1.0 to 1.5 B€ (1 500 000 000 €). With societal costs for traffic disruption of 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 industrialised methods and refined codes and standards are estimated to have a potential of reducing 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 will allow for further innovation.
	Increase of operational reliability (less service disruptions) through more robust systems based on proactive maintenance. LCC reduction (through justified demands and longer use of structures)
	Increased passenger comfort from a 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 brought by the implementation of these new technologies towards 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 will significantly reduce emission harmful for environment
	Simplified business processes by setting functional well justified demands and reducing details 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 enable seven Innovation Capabilities as follow:

Innovation Capability	***TD3.5 Tunnel and bridge enablers* & technological building blocks**
4 - More value from data	Digitalization of tunnel and bridges includes models of individual assets and sensor data delivering real time status indications of assets themselves and also of 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 is the results by 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 in following be maintained and significantly reduced costs. Relevant Building Blocks: • BB3.5.4 Bridge dynamics.

8 - Guaranteed asset health and availability	Right decision at 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 for 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 of manual inspection, hence supporting the right preventive maintenance. Relevant Building Blocks: • BB3.5.1 Enhanced bridge and tunnel inspection.
10 - Stations and "smart" city mobility	Modernised railway and stations typically requires tunnels and bridges. Tunnel and bridge research on inspections, improvement and prolonged life indirectly contribute 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	Significant contribution to reduce the environmental impact will be ensured by postponing replacements. Relevant Building Blocks: • BB3.5.3 Prolonged bridge service life and to design and construct 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
12 - Rapid and reliable R&D delivery	The research in TD3.5 tunnel and bridges are design to reach implementation quickly and 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 are all based on needs, transparency and reality.

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 by quality requirements whilst not disturbing traffic and find deterioration early so measures can be taken in due time to eliminate long time closures for maintenance. Together with TD3.3 improved transition zones between embankment and bridge will be demonstrated by make existing bridges less harmful to track and vehicles at the same time as the traffic load being less harmful for the bridge. Method to reduce noise will be demonstrated. More profound code on dynamics will be developed and validated by demonstration activities.

<table>
<tr><th rowspan="2">Research Area</th><th rowspan="2">Specific Techn. 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="6">Proactive Bridge and Tunnel Assessment, Repair and Upgrade Demonstrator</td><td>Tunnel health monitoring</td><td>Digitalisation with high degree of objectivity and repeatability</td><td rowspan="4">High-speed passenger rail, Regional passenger rail, Urban/ suburban passenger rail, Rail freight</td><td>5/7</td><td>On-board health monitoring systems, tunnel drainage monitoring system, and tunnel integrity monitoring. Component testing of novel monitoring technology.</td></tr>
<tr><td>Tunnel improvement</td><td>Proactive maintenance and upgrading technologies</td><td>6/7</td><td>Improvement of tunnel drainage, replacement of damaged lining, and tunnel gauge enlargement. Reduce track and tunnel closure by offsite manufacturing and increase quality by factory environment.</td></tr>
<tr><td>Bridge health monitoring</td><td>Detection of early warnings and noise monitoring</td><td>7</td><td>Noise emission localization and monitoring, Optical monitoring methods for geometry and digitalization, and Fatigue capability utilization. Extend bridge service life and allow for more time for planning for contraction work.</td></tr>
<tr><td>Bridge service capability improvement</td><td>Technologies to efficiently classify bridges and real structural improvement</td><td>7</td><td>Noise reduction, Extend 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.</td></tr>
<tr><td rowspan="2">Bridge dynamics</td><td rowspan="2">Improved shear capacity of concrete bridges achieved with minimum of traffic disturbance installed</td><td>High-speed passenger rail</td><td rowspan="2">7</td><td rowspan="2">Damping and resonance under rapid cyclic loading, Passive dampers to improve bridge damping, and Proposal for improved design philosophy.</td></tr>
<tr><td>Regional passenger rail</td></tr>
</table>

Planning and budget:

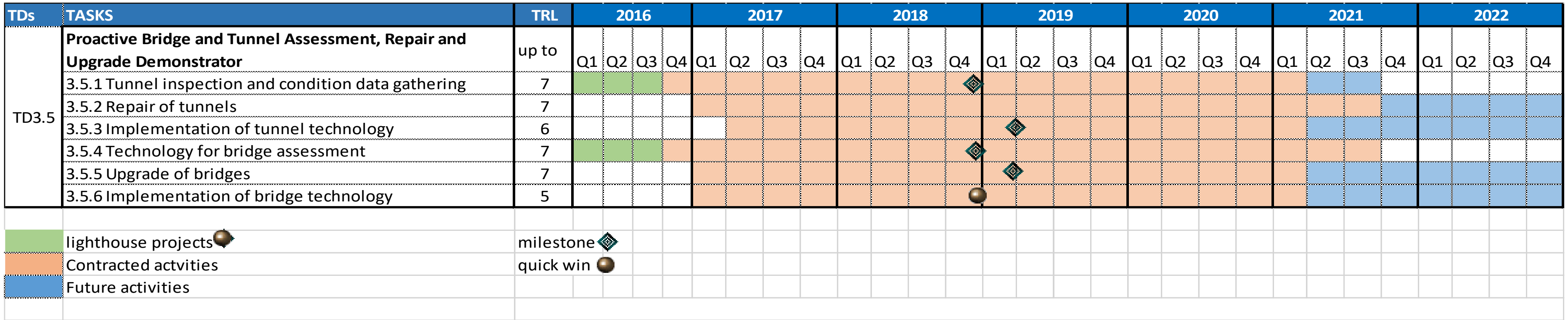


Table 47: TD3.5 quick wins

When	What	Contribution to MAAP
2018	Bridge exciter developed	Crucial equipment for research towards improving code on bridge dynamics.

Table 48: 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 Demonstrator is around M€ 15.

3.6. TD3.6: Dynamic Railway Information Management System (DRIMS) Demonstrator

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 isolated areas of the maintenance process, shows the need for a standardization, in order to seamlessly and securely access to and manage heterogeneous data and information.

The increasing amount of data provide the opportunity to apply data-mining and analytics tool 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;
- smart analytics framework for automatic detection of anomalies;
- smart analytics framework for discovering and describing the maintenance workflow processes;
- 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 of asset status monitoring capabilities by 45%: automatic anomaly detection algorithms will allow discovering issues in a faster way.
2. Increase of 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 by 30% based on condition based maintenance of railway assets and continuous improvement of components/maintenance schedules.

3.6.3. Technical Vision

The DRIMS TD3.6 aims to provide an **open, standardised, seamless and secure access** to railway heterogeneous data and information, covering aspects like transaction of IPR-protected B2B 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 IAMS module including:

- **automatic detection of anomalies** in the status of asset(s) based on the analysis of measured data and its evolution in time in order to predict in advance (nowcast and forecast) potential failures or drifts and to define the '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 according to prescriptive approaches and actual process executions;

- **implementation of predictive models** of decaying infrastructure assets based on data/information and relying on standard interfaces, eventually taking in account physical and statistical models, whenever available[2];
- **development of prescriptive analytics for maintenance** of railway assets based on the results of the analytic models;
- **contribute to the digitalisation of the railway system** to manage of maintenance activities.

DRIMS characteristics are extensive and complex, requiring a holistic approach and system-of-system thinking in order to develop and provide generic solutions, which can easily be adapted to a specific context.

State-of-the-art	New Generation DRIMS
A huge number of individual information systems is currently available in the EU railways, each of them dealing with individual and isolated areas of the maintenance process thus not exploiting the potentiality of big data analysis.	Achievement of a seamless interface with the existing information and the required characteristics on the different EU railways context
Data mining and analytics algorithms require considerable manual inspections and manual adaptions by experts	Correlation analysis ensures a credible detection of asset anomalies evaluating current infrastructure performance reflecting the whole system and interactions
Asset behaviour and degradation models 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 adjusted to perfectly match the monitoring data
Isolated applications managing a limited volume of homogenous data	Heterogeneous data formats are incorporated. Railway and non-railway information will be incorporated.
Applied maintenance is still periodic preventive maintenance based on good practices established a long time ago, simply integrated by targeted interventions when faults appear.	Prescriptive analytics for maintenance based on the results of the analytics framework

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

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and data and information flow for usage in asset management systems are:

[2] A lot of effort have been spent to find physical-based models of degradation phenomena (e.g. 6th FP INNOTRACK project targeting track infrastructure), which can be exploited in a synergic way with data-driven models.

- IP3 TD 3.7 RIMMS: using continuous monitoring information as an input for data analytic tools and platforms.
- IP3 TD 3.8 IAMS: providing high-quality input to the intelligent asset management system.
- IP3 TD 3.1 Enhanced S&C: processing switches and crossing data.
- IP3 TD 3.3 Enhanced Track: processing track data.
- IP3 TD 3.5 Bridges and Tunnels: processing bridges and tunnels data.
- IP3 TD 3.11 Smart Metering for a Railway Distributed Energy Resource Management System (RDERMS): manage high amount of data from different sources and analyze it to provide support to the energy resource management system.
- IP2 TD 2.9 Traffic Management System: 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.
- IP5 TD 5.2 Digital Transport Management : Improved Methods for time table planning, Real time yard management and Single-wagon load systems, Real-time Network Management , Intelligent Video Gate Terminals.
- CCA Impact1: KPIs and Reference Parameters definition.
- CCA Impact2: supporting CBM through analytics solutions.

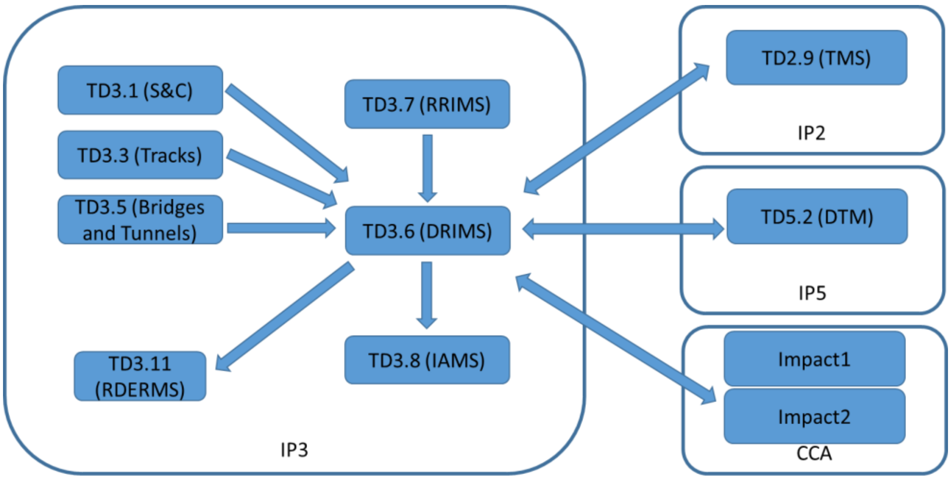


Figure 3: Interaction with other TDs

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 competitive-ness of the EU industry	• **Global technological leadership supported by a combination of innovation and technical standards, setting an effective advantage for the European industry:** TD3.6 DRIMS will contribute to the following TSIs and official or de facto standards: o the railML.org standardisation process to create railway-specific universally applicable XML-based data exchange format o the ERA ERA/REC/04-2011/INT Recommendation on specification of Register of Infrastructure (RINF) for what concerns the interfaces with asset registers o the ISO 55000 (Overview, principles and terminology), 55001 (Requirements) and 55002 (Guidelines for the application of ISO 55001) international standards for Asset Management o 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 to win situation. TD3.6 DRIMS will contribute to introduce the Internet of Things and the 'big data' advanced analytics which are considered among the IT-enabled business trends for the decade ahead. • **Increase of operational reliability** (less 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 sensibly reduce and better estimate the required occupation time and therefore heavily improve the overall operational reliability. • **Reduce cost:** predictive maintenance guarantee an optimisation in the maintenance activities, guaranteeing a cost reduction both in terms of spare parts and in terms of effort • **Increase capacity** more than increasing capacity, a modern and more cost-effective approach to maintenance can contribute to maintain the target capacity of the network and, in certain specific cases, also to slightly increase it.
Compliance with EU objectives	• **Achieve Single European Rail Area** (SERA): a standardized approach to the maintenance information and activities as the one developed within the TD3.6 will reduce the technical obstacles for a proper interconnection of technical solutions. • **Enhanced interoperability**: the usage of an open standard interface to access data will guarantee that information can be accessible in a standard way; algorithms, based on a canonical data model, should be able to be easily used by different organizations for performing the maintenance activities.
Degree of maturity of the envisaged solutions	In other sectors, with more mature ICT usage, like banking, aerospace and finance, analytics approaches are at TRL 7, 8 and, in some cases, 9 while in the railway sector 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 are brought to a TRL from 5 to 7.

This TD will contribute to enable five **Innovation Capabilities** as follow:

Innovation Capability	**TD3.6 DRIMS enablers & technological building blocks**

4 – More value from data	Management improvement of high amount 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 TRL5 to TRL7
7 – Low cost railway	Automatic anomaly detection, discovery of workflow processes and prescriptive analysis provide the means for an intelligent and more efficient asset management system. Relevant Building Blocks: • BB3.6.1 DRIMS IT architecture, from TRL5 to TRL7 • BB3.6.2 DRIMS data mining and analytics, from TRL5 to TRL7
8 – Guaranteed asset health and availability	Results of the analytics framework lead to condition based and predictive maintenance. Relevant Building Blocks: • BB3.6.2 DRIMS data mining and analytics, from TRL5 to TRL7
10 – Stations and "smart" city mobility	Management of high amount of data and analysis to provide support to the smart city mobility, with a particular attention to the human flow analysis. Relevant Building Blocks: • BB3.6.1 DRIMS IT architecture, from TRL5 to TRL7 • BB3.6.2 DRIMS data mining and analytics, from TRL5 to TRL7
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 railway sector. Relevant Building Blocks: • BB3.6.1 DRIMS IT architecture, from TRL5 to TRL7 • BB3.6.2 DRIMS data mining and analytics, from TRL5 to TRL7

3.6.5. Demonstration activities and deployment

The following table summarises the contribution of TD 3.6 DRIMS as part of Intelligent Asset Management Integrated Technology Demonstrator (IAM ITD) to the different System Platform Demonstrators (SPDs) of Shift2Rail:

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	TRL	Focus of activity
Dynamic Railway Information Management System (DRIMS)	Strategic long-term Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long term maintenance and operation decision needs.	High-speed passenger rail, Regional passenger rail, Urban/ suburban passenger rail, Rail freight	6	Design and implementation of a data analytics platform using already developed algorithms for track degradation models. Design and implementation of a strategical decision support tool based on the tactical planning tool (simulation-based approach) to support the assessment of the IM asset management strategic KPIs; Development of 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 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 Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short term and day by 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.

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	TRL	Focus of activity
	Metro/ Tram Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on 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	Definition of requirements for final demonstrator in strict collaboration with IM. Installation of monitoring systems and fine-tuning for obtaining quality measurements. Definition and implementation of data platform and HMI. Final demonstrator testing. The final goal will be minimising maintenance costs, optimising the use of resources while maximising network availability and reliability.

Three different demonstrators are foreseen for the Intelligent Asset Management ITD, composed of building blocks from the following TDs:

- TD 3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD 3.6 providing common interfaces and data modelling and analytics tools;
- TD 3.8 providing strategic and decision making tools.

The first two demonstrators focus on a railway market, while the third one on a urban scenario. At least an installation site or area will be defined for each demonstrator, to allow hosting of new developed technologies and building blocks.

The first demonstrator refers to a railway long term vision scenario, taking in consideration railway asset managements 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 initialization of their development in practice.

The second demonstrator refers to a short term vision scenario, taking in consideration railway asset management on an everyday bases up to a period of 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 by both existing monitoring systems and new developed ones.

The third demonstrator will take in consideration aspects from both previous ones, with the difference of focusing on an urban scenario, such as Metro or Tram line. Indeed urban scenarios represent different characteristics and challenges to the railway main line ones, such as: Infrastructure Manager's rolling stocks ownership and maintenance responsibility, higher requirements on service availability, punctuality and capacity (people/train/hour), different environmental requirements (e.g. noise emissions), etc.

Planning and Budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
	Dynamic Railway Information Management System (DRIMS) Demonstrator	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
TD3.6	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																												

lighthouse projects	milestone	
Contracted actvities	quick win	
Future activities		

Table 49: TD3.6 quick wins

When	What	Contribution to MAAP
Q3 2019	Analytic solution in lab test	In lab demonstration of an analytic solution to pave the road for IN2SMART follow up ITDs demonstrators
Q3 2020	Analytic solution test on real data	Preliminary demonstration of analytic results based on real data.

Table 50: TD3.6 milestones

When	What
Q1 2017	Asset management platform first definition in IN2SMART WP2, with an impact in IN2SMART WP7-8
Q2 2018	Canonical data model and communication protocols definition in IN2SMART WP7
Q3 2018	Test on canonical data model and communication protocols
Q2 2019	High level architecture in IN2SMART WP8
Q3 2021	Realization of an architecture for data exchange and final test canonical data model and communication protocols for ITDs
Q2 2022	Analytics uncertainty evaluation solution coming from IN2DREAMS open call will be integrated in 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 13M€.

3.7. TD3.7 Railway Integrated Measuring and Monitoring System (RIMMS) Demonstrator

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** sub-systems 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 actually clear from the several infrastructure inspection activities on an aged infrastructure which are done manually by maintenance staff. These inspections are time (money) consuming 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 maintenance infrastructure-related information; generating data/information to feed – using a standardized 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 of 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 sub-systems 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 the holistic railway system state, will take in consideration:

- Identification, within the most critical railway sub-systems, of parameters and items that represent the greatest potential to improve assets 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;
- Fill of 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 these data/information in an intelligent asset maintenance system, giving the possibility of their usage in novel ways;

Continuous, cost-effective, safe and automatic monitoring will be provided by low-cost, COTS components installed wayside, on in-service trains or on board of satellite/UAVs.State-of-the-art	New 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 line overall information to an asset management centre.
Maintenance activities scheduled on the basis of single components MTBF supplier declared values and best practices, not taking into account line utilization and operations impact.	Condition based maintenance for all railways assets, taking into account line utilization and operations (rolling stock) impact.
Signalling systems embedded monitoring not allowing agile modifications or upgrades due to integration 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 (of the same IP and/or of the other IPs)

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and data and information flow for usage in asset management systems are:

- IP3 TD 3.6 DRIMS: providing continuous monitoring information to data analytic tools and platforms via a common interface and canonical data model.
- IP3 TD 3.8 IAMS: providing the low level information necessary for an intelligent asset management approach.
- IP 3 TD 3.1 Enhances S&C: sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the S&C monitoring needs.
- IP 3 TD 3.3 Optimized Track: sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the track monitoring needs.
- IP3 TD 3.5 Proactive Bridge and Tunnels assessment: sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the bridge and tunnel monitoring needs.
- IP 5 TD 5.1 Fleet Digitalisation and Automation: sharing requirements on monitoring parameters, techniques and data models, in order to fully cover the monitoring of rolling stocks impact on the railway infrastructure.
- CCA WA3 Smart maintenance: providing a comprehensive list of the infrastructure assets and parameters to be monitored for an overall railway Condition Based Maintenance system.

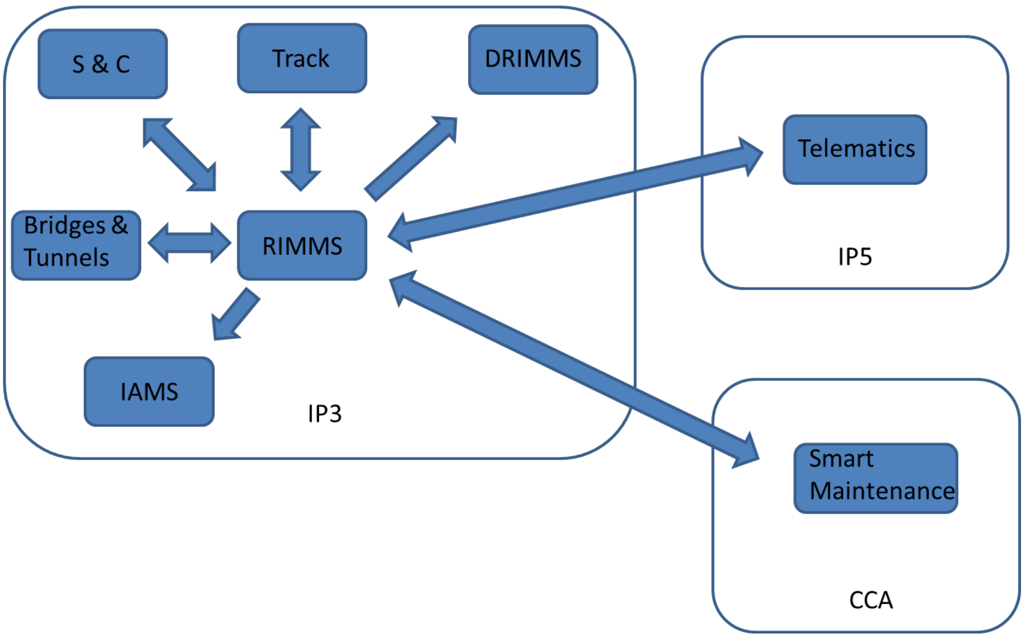


Figure 33: Interaction with other TDs and IPs

3.7.4. Impact and enabling Innovation Capabilities

The RIMMS specific objectives have a major impact in 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 an effective advantage for the European industry:** TD3.7 RIMMS is highly focused on innovative technologies, which must be cut off ones, more robust and easy to use and integrate. The Measuring and Monitoring tools must be integrated in the Intelligent Asset Management System, so they must send data through standard open interfaces (defined in the TD3.6). • **Increase of operational reliability** (less service disruptions) through continuous and precise condition monitoring of key components leading to a condition based monitoring and more in general an asset management effective approach. • **Reduce cost:** predictive maintenance via a condition based approach.
Compliance with EU objectives	• **Achieve Single European Rail Area** (SERA): a standardized approach to the maintenance information and activities like the one developed within the Intelligent Asset Management System, will reduce the technical obstacles for a proper interconnection of technical solutions developed within the TD3.7. • **Promotion of modal shift**: the impact brought by the implementation of these new technologies can enhance the attractiveness of the Railway System being more reliable, 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 the TD3.7 will have two main different degree of maturity: • A TRL 4/5 if the technology used is a very innovative in the railways context; • A TRL 6/7 if the solution is an improvement of existing tools

This TD will contribute to enable six Innovation Capabilities as follow:

Innovation Capability	**TD3.7 RIMMS enablers & technological building blocks**
1 – Automated Train Operation	Support efficient and safe ATO through continuous monitoring of rolling stocks assets and their impact on the infrastructure. Relevant Building Blocks: • BB3.7.4 RIMMS operations, TRL6/7
4 – More value from data	High amount 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 & 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 & 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 & 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 railway current and predicted asset status is always available to people and services. Relevant Building Blocks: • BB3.7.1 RIMMS tracks, TRL 6/7 • BB3.7.2 RIMMS switches & crossings, TRL 6/7 • BB3.7.3 RIMMS signalling 5/6 • BB3.7.4 RIMMS operations 6/7
12 - Rapid and reliable R&D delivery	Monitoring data collected from railway assets could be used for continuous products evolution 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 & crossings, TRL 6/7

3.7.5. Demonstration activities and deployment

The following table summarises the contribution of TD 3.7 RIMMS as part of Intelligent Asset Management Integrated Technology Demonstrator (IAM ITD) to the different System Platform Demonstrators (SPDs) of Shift2Rail:

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	 TRL	Focus of activity
Railway Integrated Measuring and Monitoring Systems (RIMMS)	Strategic long-term Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long term maintenance and operation 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 Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short term and day by 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 Management Integrated Technology Demonstrator IAM-ITD)	Full demo on 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 foreseen for the Intelligent Asset Management ITD, composed of building blocks from the following TDs:

- TD 3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD 3.6 providing common interfaces and data modelling and analytics tools;
- TD 3.8 providing strategic and decision making tools.

The first two demonstrators focus on a railway market, while the third one on a urban scenario. At least an installation site or area will be defined for each demonstrator, to allow hosting of new developed technologies and building blocks.

The first demonstrator refers to a railway long term vision scenario, taking in consideration railway asset managements 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 initialization of their development in practice.

The second demonstrator refers to a short term vision scenario, taking in consideration railway asset management on an everyday bases up to a period of 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 by both existing monitoring systems and new developed ones.

The third demonstrator will take in consideration aspects from both previous ones, with the difference of focusing on an urban scenario, such as Metro or Tram line. Indeed urban scenarios represent different characteristics and challenges to the railway main line ones, such as: Infrastructure Manager's rolling stocks ownership and maintenance responsibility, higher requirements on service availability, punctuality and capacity (people/train/hour), different environmental requirements (e.g. noise emissions), etc.

Planning and budget:

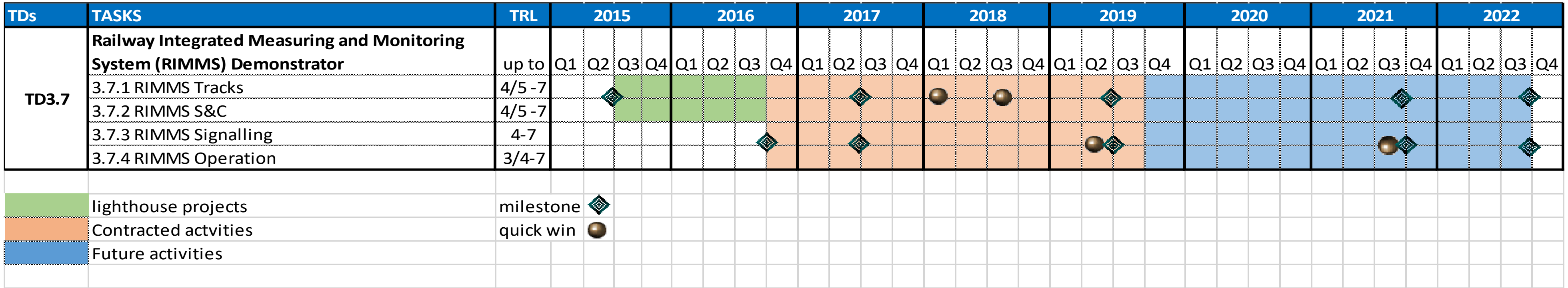


Table 51: TD3.7 quick wins

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.	Allow 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.	Definition of the general approach and validation of 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 52: TD3.7 milestones

When	What
Q2 2015	Start of the requirements definition and system specification activities for track and switch and crossing monitoring.
Q4 2016	Start of the requirements definition and system specification activities for signalling and operations monitoring.
Q3 2017	Start of the prototypes development activities for all demonstrators.
Q2 2019	End of TRL4 prototypes validation for all demonstrators.
Q3 2021	Installation end and first results from field prototypes of all demonstrators.
Q3 2022	Field demonstrators final validation and inclusion in a IAMS.

The estimated total budget for RIMMS TD is around 17.5 M€.

3.8. TD3.8: Intelligent Asset Management Strategies (IAMS) Demonstrator

3.8.1. Concept

IAMS (Intelligent Asset Management Strategies) focuses on the definition of concepts for maintenance planning and decision support; implementation of risk- and condition-based maintenance strategies; 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 for 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 focussed on the actual execution of maintenance activities. In this context also the safety precautions needed to execute maintenance is 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 and condition based), and
- 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 bridges theoretical processes about asset behaviour and degradation, asset management theories and individual maintenance strategies for specific sub-systems to the actual work outside in the operational process. The operational process is defined as the day to day maintenance and small and medium 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 sometimes is 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 focussing 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 Infrastructure Managers in fulfilling their tasks/activities in particular for capacity calculation, allocation and enhancement of the infrastructure. Decision making processes will become more transparent, controllable and their results will be directly accessible by railway service providers and customers.

Use of Artificial Intelligence algorithms (HPC), Blockchain for Smart Contracts and high performance computing (HPC) are part of the technologies used to reach the TD objectives.

3.8.2. Technical objectives

The following represent the main technical objectives of this TD:

1. Show a shift towards tailor made maintenance approach by using the necessary tools for information management and decision support. 15% of the assets can benefit from the new approach and are suitable for 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 lifecycle management, efficient maintenance strategies and adequate operations planning which includes logistic preparation, 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 time needed for maintenance and cost. Reduction per example should be 20% or more reduction of time.

3.8.3. Technical vision

The vision behind IAMS is to come to a **holistic**, system approach in combination with the **new methodologies**. In other words: make new maintenance approaches happen in a practical way. ISMES bridges the theoretical processes, asset management theories and individual maintenance strategies related to one specific sub system and based on its own behaviour and deterioration, to the actual work outside in the operational process. Day to day maintenance and small and medium 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.

By making long term strategies it will be put in the context the actual execution of the maintenance work in combination with other maintenance activities.

Instead of focussing on individual, simple systems (objects), IAMS will look at it as a "system of systems".

Therefore IAMS focuses on the implementation of:

- The support of 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, age of asset and root causes for maintenance – supported by DRIMS
- New and advanced working methods, tools and equipment and logistic solutions

The above mentioned equipment in the last bullet should be based on a **modular, reconfigurable, robotic platform** using sensing and perception to make its own decisions based on specific situations. 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 work site management systems.

State-of-the-art	Advance Beyond 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 fail to take full advantage of enhanced components built-in the network	Advantages of new components are identified and are 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

State-of-the-art	Advance Beyond state of the art
Maintenance decisions based mostly on static and pure geometric track quantities.	Reliable maintenance decisions based on asset assessment drawing from vehicle-track-environment interaction
'Preventive' 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
Immature predictive concepts using asset specific degradation models neglecting uncertainties	Data drive approach. Probabilistic information on condition and risk assessment as base 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 in 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 take 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 heavy to use leading to physical problems for staff using/operating the machines	work methods, express maintenance machines (short time to get in and out 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).

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

The main interaction envisaged with other TDs and/or IPs, both from the point of view of technologies employed and data and information flow for usage in asset management systems are:

- IP3 TD 3.6 DRIMS: providing continuous monitoring information to data analytic tools and platforms via a common interface and canonical data model
- IP3 TD 3.7 RIMS: railway data management, processing and analysis.
- IP 3 TD 3.1 Enhances S&C: sharing requirements on maintenance requirements and approach.
- IP 3 TD 3.3 Optimized Track: sharing requirements on maintenance requirements and approach.
- IP 3 TD 3.5 Proactive Bridge and Tunnels assessment: sharing requirements on maintenance requirements and approach.
- IP1, various TD's covering the maintenance aspect: sharing maintenance and asset management approach applicable towards rolling stock.
- IP 2, TCMS: providing maintenance related alerts and improvement of possession management
- CCA WA3 Smart maintenance: sharing maintenance and asset management approach applicable towards other types of assets (rolling stock).

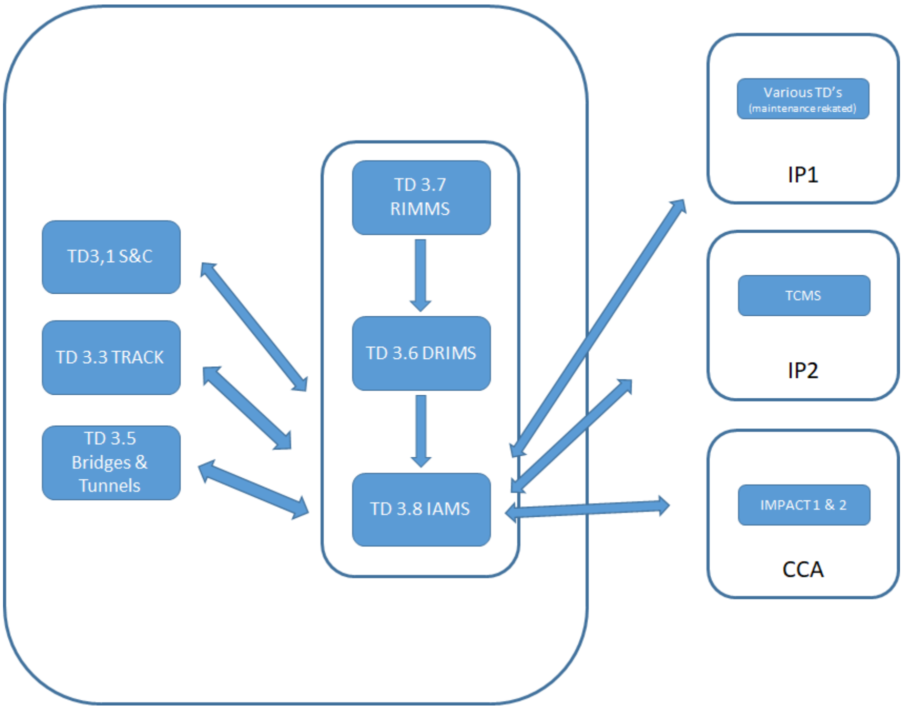


Figure 34: Interaction with other TDs and IPs

3.8.4. Impact and enabling Innovation Capabilities

The results of IAMS have a major impact in the Shift2Rail system-level KPIs. The relative weight of the benefits provided by the work are estimated (over a total of 100%) in the table below which provides an overview of the effects generated at larger scale by the application of the TD results:

<table>
<tr><th>Impact type</th><th>Key Contribution from the TD</th></tr>
<tr><td rowspan="2">Support the competitiveness of the EU industry</td><td>Global technological leadership supported by a combination of innovation and technical standards, setting 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.</td></tr>
<tr><td>Increase attractiveness and competitiveness:
Increase of operational reliability (less service disruptions) through a progressive migration from corrective maintenance to predictive maintenance, which is less resource and time consuming and has less impact in train operation.
Reduce system cost in the short term, by 40% 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 infrastructure capacity by at least 20% because of the reduction of downtimes due to unexpected failures and the optimisation of track possession for maintenance activities.</td></tr>
<tr><td>Compliance with EU objectives</td><td>Promotion of modal shift: A big impact brought by the implementation of these new technologies
Achieve single European Rail Area (SERA) due to a common understanding making long term decisions based on an ISO 55000 framework, monitoring the effect European wide 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 and contributing to existing standards across Europe.</td></tr>
<tr><td>Degree of maturity of the envisaged solutions</td><td>Currently most of the proposed technologies are in TRL 2-4 (Formulation and experimental proof of technology concepts). At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 6 or 7.</td></tr>
</table>

This TD will contribute to enable eight **Innovation Capabilities** as follows:

<table>
<tr><th>Innovation Capability</th><th>TD3.8 IAMS enablers & technological building blocks</th></tr>
<tr><td>1 - Automated Train Operation</td><td>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</td></tr>
</table>

Innovation Capability	*TD3.8 IAMS enablers & technological building blocks*
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 is used as an integral part of the maintenance activities: for assign risk, planning maintenance activities based on actual 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 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. 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 Traffic Managements Systems leads to balanced and controlled interventions in between service and maintenance. Optimised working methods reduce the required down-time for maintenance activities. Predictive maintenance planning reduces down-time required for inspection and due to unexpected failures. Combined maintenance activities in a LEAN approach to 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,
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" principals are the basis for decisions concerning renewals. The use of emission-free machinery with low noise and vibration levels are the objective. Relevant Building Blocks: • BB3.8.2 decision support tools

Innovation Capability	***TD3.8 IAMS enablers & technological building blocks***
12 - Rapid and reliable R&D delivery	The developed examples covering all building blocks will be a show case 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 TD 3.8 IAMS as part of Intelligent Asset Management Integrated Technology Demonstrator (IAM ITD) to the different System Platform Demonstrators (SPDs) of Shift2Rail:

Research Area	Specific Techn. objective	Specific Activities	System Platform Demonstrator Market	TRL	Focus of activity
Intelligent Asset Management Strategies (IAMS)	Strategic long-term Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on long term maintenance and operation 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 Intelligent Asset Management Integrated Technology Demonstrator IAM-ITD)	Full demo on infrastructure asset management including monitoring, data analysis and strategic planning with a focus on short term and day by 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 Management Integrated Technology Demonstrator IAM-ITD)	Full demo on 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 foreseen for the Intelligent Asset Management ITD, composed of building blocks from the following TDs:

- TD 3.7, providing measuring and monitoring systems for data collection and interpretation;
- TD 3.6 providing common interfaces and data modelling and analytics tools;
- TD 3.8 providing strategic and decision making tools.

The first two demonstrators focus on a railway market, while the third one on a urban scenario. At least an installation site or area will be defined for each demonstrator, to allow hosting of new developed technologies and building blocks.

The first demonstrator refers to a railway long term vision scenario, taking in consideration railway asset managements 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 initialization of their development in practice.

The second demonstrator refers to a short term vision scenario, taking in consideration railway asset management on an everyday bases up to a period of 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 by both existing monitoring systems and new developed ones.

The third demonstrator will take in consideration aspects from both previous ones, with the difference of focusing on an urban scenario, such as Metro or Tram line. Indeed urban scenarios represent different characteristics and challenges to the railway main line ones, such as: Infrastructure Manager's rolling stocks ownership and maintenance responsibility, higher requirements on service availability, punctuality and capacity (people/train/hour), different environmental requirements (e.g. noise emissions), etc.

Planning and budget

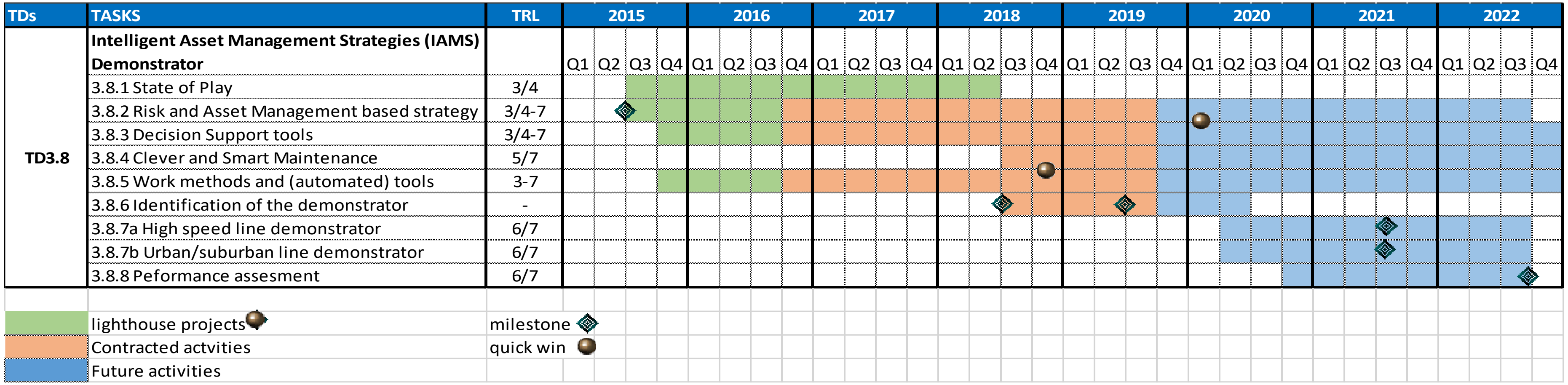


Table 53: TD3.8 quick wins

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 towards the building blocks: • BB3.8.1 Risk and asset management based strategy • BB3.8.2 decision support tools

Table 54: 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 prototypes development activities for all demonstrators.
Q2 2019	End of TRL4 prototypes validation for all demonstrators.
Q3 2021	Installation end and first results from field prototypes of all demonstrators.
Q3 2022	Field demonstrators final validation and inclusion in a IAMS.

The estimated budget for the TD is around 16M €.

3.9. TD3.9: Smart Power Supply Demonstrator

3.9.1. Concept

The railway traction power supply system [ETS] delivers the demanded electrical energy to the trains, with consideration of quality and availability. The special characteristic of electrical traction power supply systems, interacting with running trains resulting in special load characteristics, requires different solutions from standard power supply systems. By historical developments a variety of systems with alternating current (AC) and direct current (DC) have been developed and are in use in different regions in Europa.

The ETS is connected to the feeding public supply networks and will also act as supply system for other energy consumers outside the railway traction system. The development of new sources of electricity, like renewables or photovoltaic, requires different solutions for power infeed (e.g. small decentral systems).

The Railway traction power grid of the future needs important “SMART” functionalities.

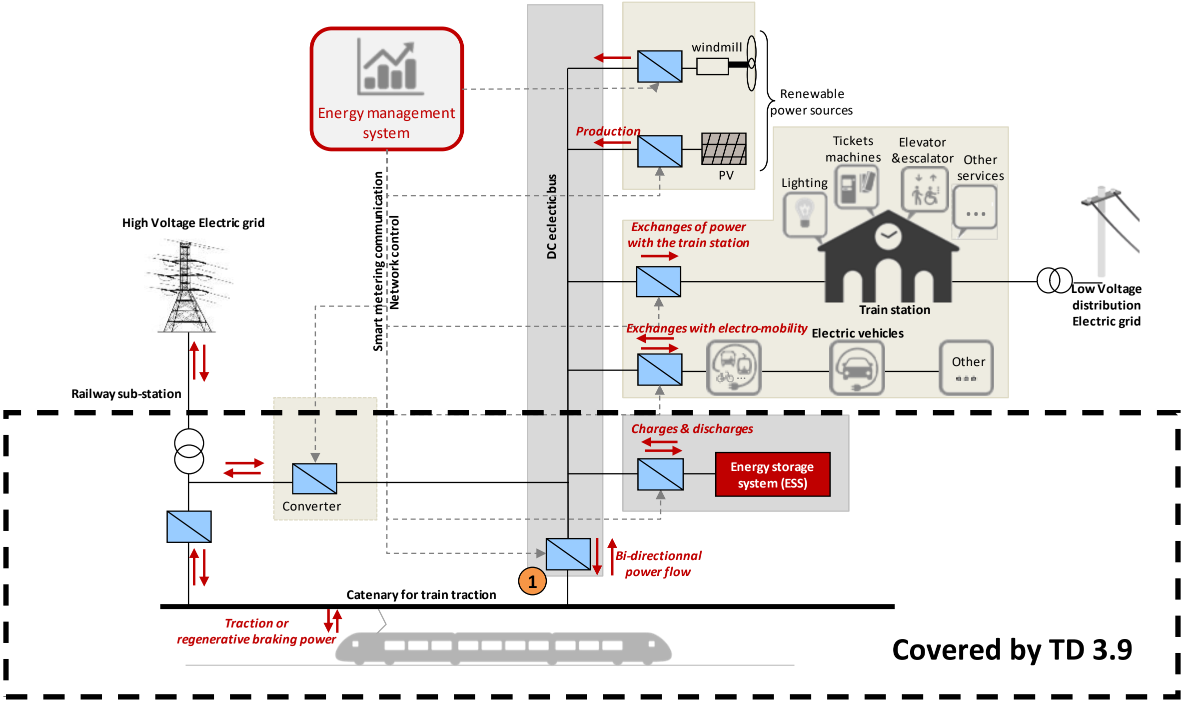


Figure 35: Schematic view of rail traction power supply in a smart power environment

Figure 35 shows the target railway traction power supply network. 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; imbedded in an overall network control concept.

TD 3.9 covers the traction power supply system itself. The interaction capabilities are different for the several traction power supply systems. E.g. for DC systems active elements can be controlled rectifiers and inverters, for AC systems with special frequency 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 Smart Railway Power Grid. 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 Smart Railway Power Grid enable improvements and optimizations 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. Minimize energy losses by means of double side feeding in traction power supply systems reducing the transmission losses up to 50%.
2. Optimal dimensioning of network equipment for minimizing 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 allows for elimination of phase separations on the line and will reduce restrictions to operation for better operability and reduced maintenance costs. No power-switch-off on trains every 20… 40 km in 50Hz 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 minimized investment. Allowing an efficient electrification of railways in regions without necessary improvements in the 3 AC grid.
5. Optimizing 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 optimized dimensioning.
6. Capability to offer services to the grid operator like frequency and voltage support, reactive power compensation, reduction of the phase unbalance, etc.
7. Increase of interoperability, availability and control and protection functions in substations station control systems by means of IEC 61850.
8. Reduction of costs by minimizing 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 a “Smart Railway Power Grid [SRPG]”. The SRPG allows bi-directional energy flow and the integration of other consumers and sources of electric energy. The control of 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 a minimum of the total LCC. The technical vision is based on following developments:

- Converters with semi-conductors as active elements connecting networks with different characteristics
- Digital control and protection equipement in substations allowing to manage complex networks
- Data acquisition and connectivity solutions to interact with the load control and energy measurement systems of adjacent network
- Integration of operational data for interactive load control

State-of-the-art	Smart Railway Power Supply
Passive elements in substations (transformer, rectifier).	Active elements in substations allowing for 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 50Hz systems requiring shut-down of traction power at trains.	Double side feeding of line sections for uninterrupted traction power supply with reduced transmission losses.
Unbalance in 3 AC grid created bysingle phase railway load.	Load balancing for symmetric load energy consumption of the 3 AC grid.
No control of reactive power.	Control of reactive power in both grids, traction power supply grid and pulic supplygrid.
No interaction with asset and maintenance management systems.	Condition monitoring and data support for maintenance management and traffic control.
Copper wiring between instrumented transformers and control and protection equipment	Decentralization by using merging units at the instrument transformers and introduce a process bus network between the control and protection equipment

<u>Interaction with other TDs (of the same IP and/or of the other IPs)</u>
The Smart AC Rail power supply system interfaces inside S2R project with:

- IP1: New Traction systems (TD1.1) will change harmonics in the load characteristic and give more freedom for 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 for using load/stress characteristics for scheduling maintenance for the elements. This will be interact with the DRIMMS planned in TD3.6.
- IP3: The results of ‘Smart Metering’ demonstrator will be used for the control and protection concepts in TD3.10.

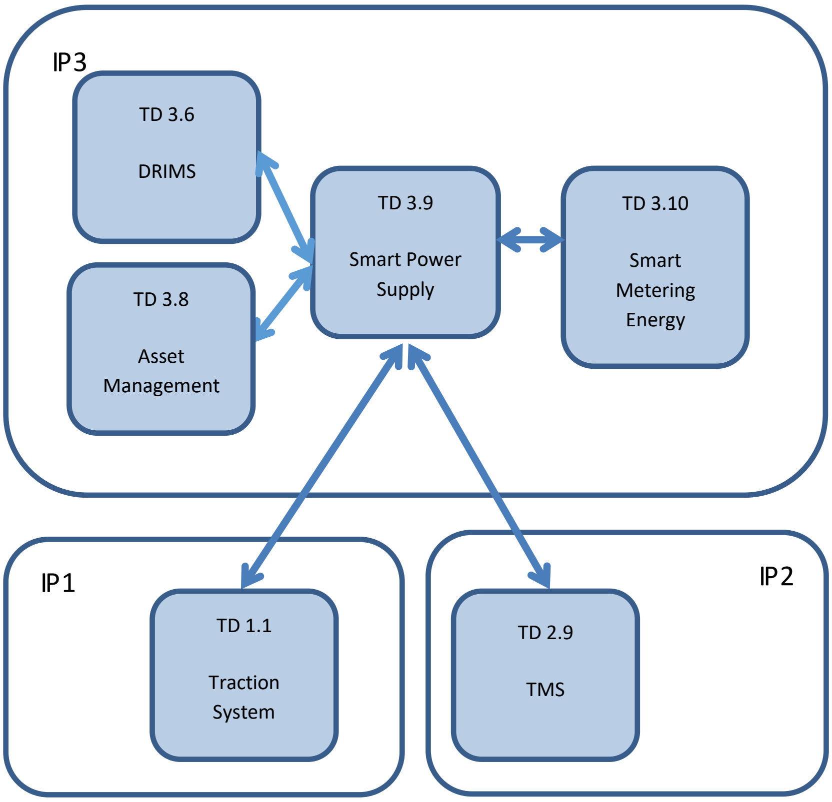


Figure 36: Relationship of TD3.9 with other TDs

3.9.4. Impact and enabling Innovation Capabilities

The Smart Railway Power System benefits will impact all the Shift2Rail system-level KPIs. Achieved TRL Levels are defined for demonstrated power supply system. The benefit differs depending from the used power supply system. The relative weights of the benefits provided by this work are estimated (over a total of 100%) in the table below which 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	• Technological leadership supported by a combination of innovative elements (FACTS equipment, digital control and protection) with a complete 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 allow for a better power distribution to the train. • Operational reliability: new protection concepts will improve 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 less 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 enable the six Innovation Capabilities as follow:

Innovation Capability	***TD3.9 Smart Power Supply enablers & 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 allow for 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 50Hz substation
7- Low Cost Railway	Control of energy flow with knowledge of energy demands gives the possibility to minimise investment for traction power supply systems. Control of energy flows to minimize losses and the use of stress based maintenance to minimize LCC. Relevant Building Blocks: • BB3.9.1 Smart control and protection system • BB3.9.2 virtual demonstration of smart 50Hz substation
10 - Stations and "smart" city mobility	This TD gives an important part for integration between the several electric networks as basis for integration of Railways in SMART-Energy-Grids. Relevant Building Blocks: • BB3.9.1 Smart control and protection system • BB3.9.2 virtual demonstration of smart 50Hz substation
11 - Environmental and social sustainability	Control of energy flow allow for 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 TD 3.9 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 50Hz substation

3.9.5. Demonstration activities and deployment

TD3.9 "Smart Railway Power System" will be demonstrated in parts in different systems to support the transfer of system solution 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 for a wider participation of existing experience in the fields of 16.7Hz and 50Hz 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 a technology demonstrators. Additionally the functionality in the 50 Hz demonstrator is split into two sequential steps to allow for results at an early stage, taking into consideration the risks from outer interface to public grid operators.

TD3.9 will implement the 2 demonstrators according to the following table.

Research Area	Specific Techn. objective	Specific Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
SMART Rail 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 sswitchgear station of DB Energy.	All electrified railways in all market segments	5	Check and demonstration of functionality, capacity, application and integration in the systems.
	FACTS demonstrator for 50Hz 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 investigate in a re-thinking of traction power supply system considering future demands from integration of other modes of electric transport and new challenges from energy supply and 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 LOC&PAS for implementation and authorisation of the new system.

Different standards specifying active components, protection principles and systems and for relevant interfaces as EN 50388; EN 50633 and others need to be improved.

Planning and budget:

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
TD3.9	**Smart Power Supply Demonstrator**		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
	3.9.1 Basic Design Specification	3																												
	3.9.2 Implementation of Demonstrator for improved control and protection system	5/6																												
	3.9.3 Technology Demonstrator for 50 Hz Rail power supply	4																												
	3.9.4 Demonstration of power grid interface capabilities	6/7																												
	3.9.5 Concept for future integration of Smart Rail Power System	6/7																												

	lighthouse projects	milestone
	Contracted actvities	quick win
	Future activities	

Table 55: 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 50Hz 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 Railway Power Supply System

Table 56: 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 5 M€.

3.10. TD3.10: Smart Metering for Railway Distributed Energy Resource Management System Demonstrator

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 prevision, 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 the figure below and the associated objectives are summarized as follows:

- To realize a non-intrusive Smart Metering sensor network at a Railway System level.
- To realize an open system and interface for data collection, aggregation and analysis in an open source ODM (Operational Data Management) Platform.
- To realize a set of User Applications design and specifications. The Applications will exploit the energy analysis process with the aim of enhancing the energy decision making and the line

operation patterns, as well as other possible Applications such as preventive maintenance plans, asset management and LCC dashboards, or energy market interfaces.

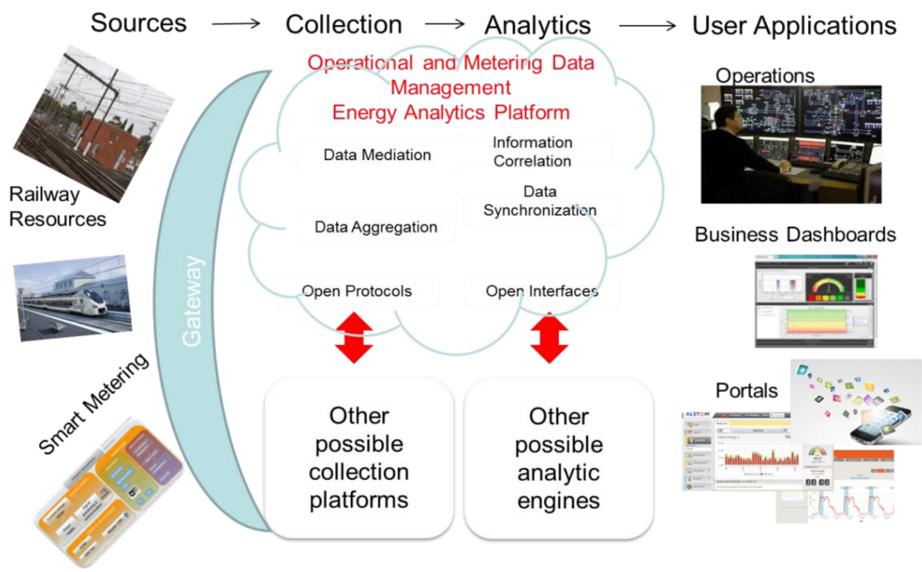


Figure 1: Demonstrator Concept

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:

Metro and sub-urban:

- 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 function of each region due to specific time-table constraints and climatic conditions).
- Allowing the optimisation of the energetic 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.
- 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.
- Optimized 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 stations 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 optimizing the line capacity.

3.10.3. Technical Vision

In the Railway Transportation 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 GPS/GSM based train tracking system can provide accurate, dependable and timely information to the controller. In addition, the train speed and dynamic status (accelerating, braking, maintain 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, GPS, gyroscopes, voltmeter, ampere meter) and combined to produce a comprehensive database with a common time and spatial reference. Once the database is ready, user customized applications will evaluate the current situation and finally enhance the decision-making process.

An important scientific work will be performed in order to implement intelligent algorithms for energy consumption evaluation using as less sensors as possible. The measurements must be as much 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 associate interface devices, which are costly and difficult to install on trains and substations already in commercial operation configuration.

The integration in the future Smart Grid allowing energy exchange between the railway and alternative generation modes such as renewables or local distributed generation is conditioned by 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 below:

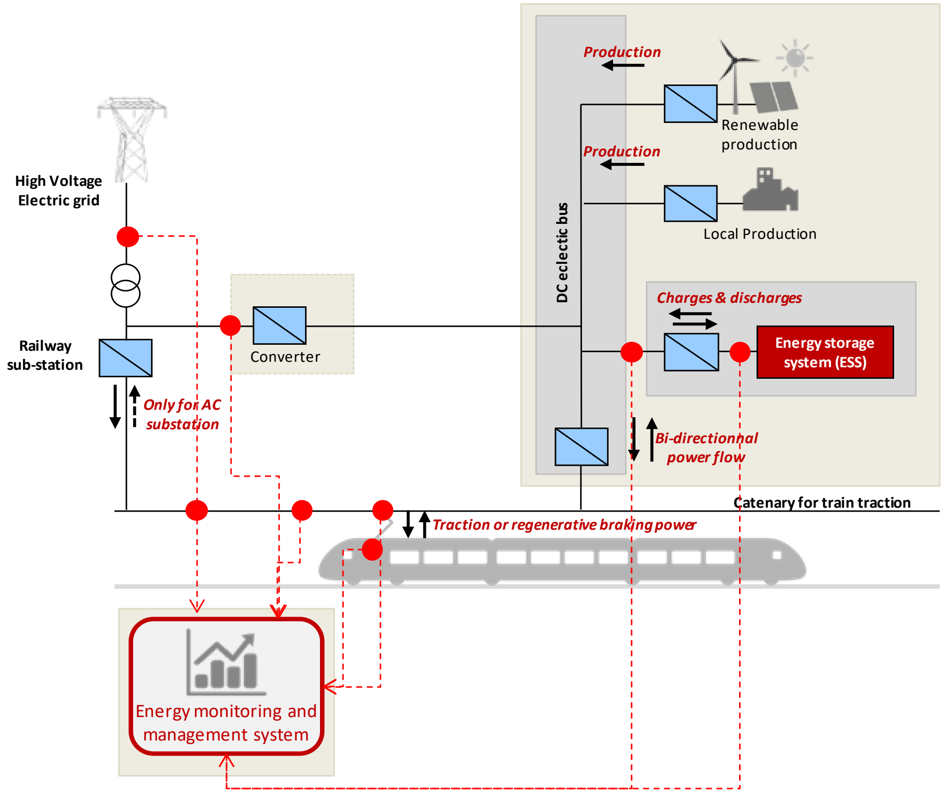


Figure 2: Sensor network functional architecture applied to Smart Grid integration

Nowadays, only customised on board system measurement devices are available. They are mainly focused on the rolling stock internal energy flow with the aim of measuring separately the energy used for the traction and the other auxiliary energy usages.

The concept novelty comes from the system level measurement integration which provides synchronized measurements on-board and at ground. The other main feature is the path provided by the RDERMS to the energy market with an enhanced prevision capability.

Last but not least, the today mobile information technology makes affordable quite sophisticated mobile terminals such as smartphones and Systems-On-Chip (SOC) mobile technologies to industrial applications such as sensor networks.

State-of-the-art	Advance beyond the state of the art
The state of the art today shows a focus on rolling stock on-board energy meters for energy billing purposes at pantograph. These measurements are not used in an integrated energy management process.	Railway System level measurement integration which provides synchronized measurements both on-board and trackside of traction and non-traction energy flows. These measurements allow new business models such as a digitalized access to decentralized energy market, along with an enhanced prevision capability and flexibility.
System energy consumption is usually measured at the substations only and averaged over a defined period of time, which does not allow for an exact energy analysis. This is actually done by simulation algorithms based on models that make simplified assumptions on real conditions. No correlation with trains operations is made after measurements.	Energy flows are mapped for the whole railway system, continuously and with refined granularity. The synchronization via a Network Time Protocol (NTP) server of train and ground energy measurements, both traction and non-traction, will allow data analytics on a larger scale by correlating the data such 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.	Solution based on the non-intrusive technology and quite sophisticated, but on-the-shelf and mass marketed, mobile terminals such as smartphones and Systems-On-Chip (SOC) mobile technologies dedicated to industrial applications such as sensor networks. Embedded applications, combining measurements and modelling, open a wide possibility of local processing data in order to enhance the sensor capabilities in non-intrusive measurement configurations.

Interaction with other TDs (of the same IP and/or of the other IPs)
This TD will interact with:

- IP2 – TD2.10 Smart Radio-Connected all-in-all Wayside Objects: Implementation of safe and reliable wireless connected object controllers developed in TD 2.10.
- IP3 - TD3.6: Dynamic Railway Information Management System (DRIMS) Demonstrator: Implementation of data management, processing and analysis for energy related data as an extension of the asset management data applications developed in TD 3.6.
- IP3 - TD3.9: Smart Power Supply Demonstrator: Development of common gateways and energy related data analytics.
- CCA Sub Work area 5.1 – Energy: Development of a standardized methodology for energy consumption estimation by measurements and simulations at railway system level.

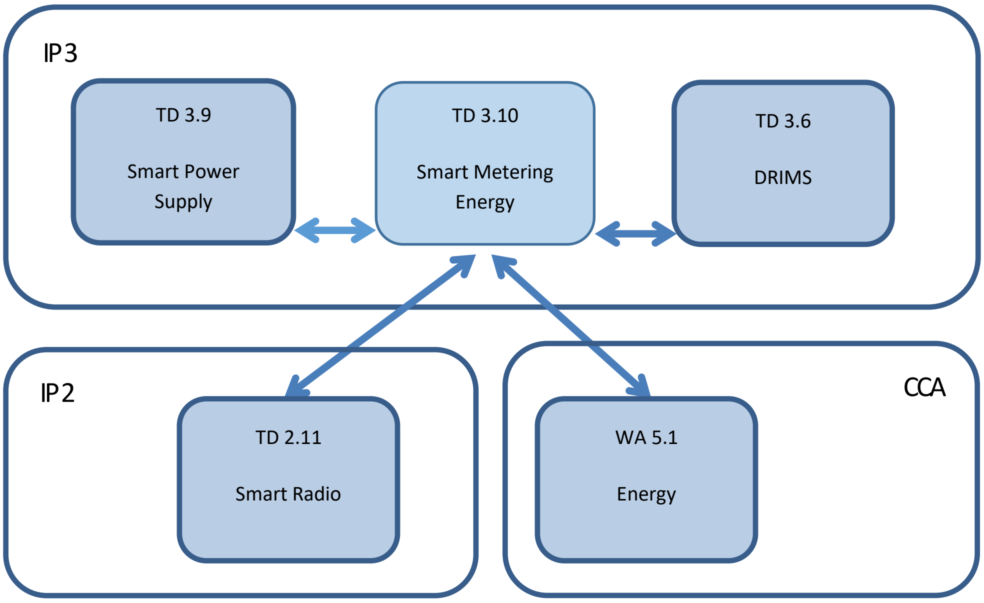


Figure 3: Relationship of TD3.10 with other TDs

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 an effective advantage for the European industry: o Enhance the Energy Management at the level of Railway System. o Application of Big Data concept to Railway energy data management and its extension to other data types such as maintenance and asset management ones.
	• Increase attractiveness and competitiveness: o Increase of operational reliability: less service disruptions through continuous monitoring of subsystems energy consumption. o Reduce cost: smart metering infrastructure cost reduction by using non-intrusive and standard components. Also, energy cost reduction by using measurement results for Energy Management applications. o Increase capacity: by a more rational energy usage, optimizing the asset management and the need of new energy infrastructure dedicated to capacity increase.
	• Enhanced customer experience: the final customer can access through dedicated portals the energy data related to his own trip and thus contribute to energy savings by changing travel habits.
Compliance with EU objectives	• Promotion of modal shift: throughout customer dedicated User Applications using geolocation data and real life measurements, and not only pre-defined 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 the transport greening.
	• Achieve single European Rail Area (SERA): by promoting data exchange formats and protocols.
	• Enhanced interoperability: facilitating the detailed energy consumption knowledge will promote operation costs reductions for all operators.
	• Simplified business processes: energy data detailed cost sharing will simplify the business cases elaboration.
Degree of maturity of the envisaged solutions	Currently most of the proposed technologies are in TRL 1, 2 (Principles observed and the possibility of using them formulated). At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 5.

This TD will contribute to enable six **Innovation Capabilities** as follow:

Innovation Capability	***TD3.10 Smart Metering for Railway Distributed Energy Recourse Management System Demonstrator* enablers & technological building blocks**
4- More value for Data	The 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 to enhance not only the energy efficiency of a given system, but also to design and optimize the future investments for the whole electrical infrastructure of the system. Relevant Building Blocks: • BB3.10.1 Smart Electrical Monitoring
9- Intelligent Trains	This TD contributes to the train to ground communication services with a particular focus on the data synchronization between on-board and track side energy measurements. Relevant Building Blocks: • 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 Blocks: • BB3.10.1 Smart Electrical Monitoring
11 – Environmental and social sustainability	This demonstrator will give the opportunity of using real operation energy related data for measuring the railway system specific energy and CO2 footprints at any time of the day, season and of weather condition. This data can be published via specific portals and have a real influence of choosing railway as an environmental social action. Relevant Building Blocks: • BB3.10.1 Smart Electrical Monitoring
12 – Rapid and reliable R&D delivery	Not only the demonstrator itself is based on a massive technology transfer between the IoT, Big Data and Smart Grid technologies towards the railway domain, but also the data generated by the field measurements is contributing to a fast and reliable decision making process both for the commercial and the technical management of a railway system. Relevant Building Blocks: • BB3.10.1 Smart Electrical Monitoring

3.10.5. Demonstration activities and deployment

Research Area	Specific Techn. objective	Specific Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Smart Metering for Railway Distributed Energy Resource Management System	Commercially operated line use case (CO-OP)	Demonstration of Smart Metering implementation with energy measurement on infrastructure and rolling stock in order to improve energy management on the commercial operation. Demonstration of energy measurements of both on board and trackside electrical equipment on a synchronized 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 on the CO-OP use case. Check and demonstration of functionality, capacity, application and integration of all field sensors.
	Stationing and maintenance facilities operation use case (STM-OP)	Demonstration of Smart Metering implementation in a tramway depot, in order to improve energy management in depot and maintenance facilitie. 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 on the STM-OP use case. Understanding the energy flows between trains and electrical infrastructure.

Research Area	Specific Techn. objective	Specific Activities	Demonstrator		Focus of activity
			Market	TRL	
	Electrical infrastructure monitoring use case (IN-OP)	Demonstration of Smart Metering implementation in order to improve electrical infrastructure monitoringDemonstration 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 the electrical monitoring, highlighting the benefits of Smart Metering on the IN-OP use case

Planning and budget:

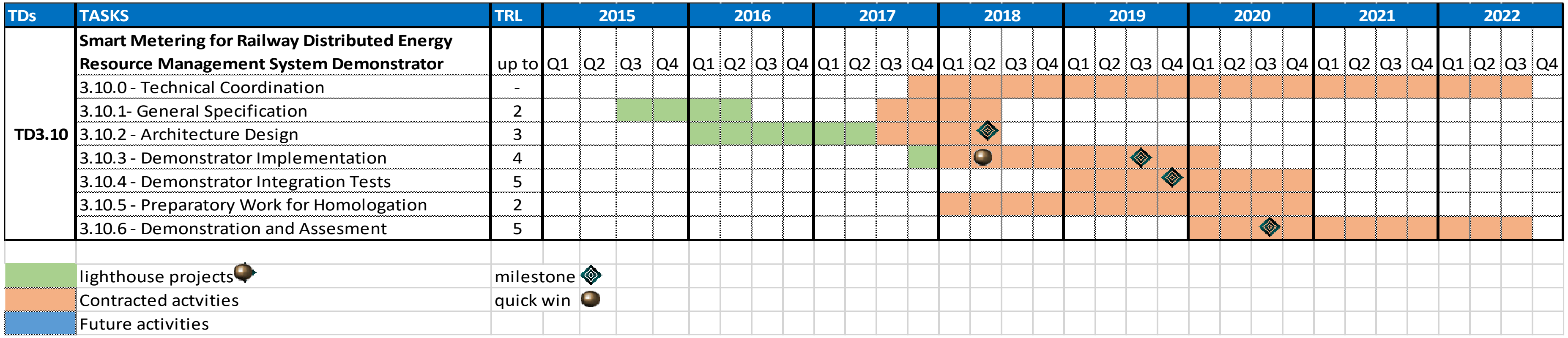


Table 57: TD3.10 quick wins

When	What	Contribution to MAAP
Q2 2018	Smart Metering PoC implemented in Reims tramway	Tested hardware and data collection software platform in a real life railway environment, as well as user application example.

Table 58: 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	CO-OP, STM-OP and IN-OP operational use case ready for operational test
Q3 2019	Sensors & Telecommunications and ODM ready for Integration into use cases
Q3 2020	User Applications & Decision ready for integration into use cases

The estimated budget for the TD is around 5.5 M€.

3.11. TD3.11 Future Stations Demonstrator

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 Demonstrator 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 details, TD3.11 addresses the primary objective of improved customer experience by improving efficiency, cost effectiveness and security via 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: Emergencies Risk Assessment of major Stations

3.11.2. Technical Objectives

The technical objective of work stream Crowd Management and Revenue Protection in large Stations is to improved flow between platforms and concourse. This 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 loose revenue. This shall 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 anticipating possible interface with IP4.

The technical objectives of work stream 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 shall 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 shall 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 Platform to Train Accessibility is improvement with focus on customer experience. The transition from the train to the platform is a major issue not only for wheelchair users but also 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 shall be undertaken that develop the optimum PTI configuration to achieve safe and consistent boarding and alighting. The study will then form the basis by which European countries can meet and address in a cost-effective manner their PRM interoperability objectives and commitments.

The technical objective of work stream Emergencies Risk Assessment of major Stations is improvement with focus capacity and security. Research activities shall 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. It shall seek to develop appropriate tools and procedures to assist large station operations.

3.11.3. Technical Vision

The following table summarises how TD3.11 will progress the state-of-the-art and overcome today's limitations and difficulties.

State-of-the-art	Advance Beyond State-of-the-art
Gated barriers for revenue control; Reliance on CCTV cameras to provide station staff visual information and surveillance of the station.	Increased capacity in busy stations by removing gate barriers currently used for revenue control. 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 communications 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 on real-time data.
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 to aid optimised selection and specification; Provision of accessible, step-free routes to platforms and train; Guarantee of independent mobility at station areas and platforms including way-finding solutions (apps) and visible, clear static signage; Creation of agreeable, accessible, safe space for passengers to wait for trains with real-time information about timetables, disturbances and also changes;
Majority of existing platforms cater for a variety of rolling stock with varying floor heights. Curvature of existing platforms creates gaps between train and platform. Reconstruction of existing platforms is very expensive and cannot be justified where rolling stock is variable.	Solutions that will allow safe and inclusive access to the train and will not be too demanding on maintenance and 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. Inconsistent security provisions and lack of best practice sharing.	Element of surprise and unpredictability during emergencies will be countered with strategies and procedures worked out in advance for major stations.

Figure 37: Technology for Future Stations

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

Research activities linked with TD3.11 need interaction and research results from other IPs to fully reach its potential. The Platform to Train Accessibility will not be solved only with new approaches on infrastructure side but need also innovative rolling stock solutions developed within IP1. In general IP4 and Future Stations have extremely tight connections regarding new and disruptive IT services with the only focus to improve customer experience, capacity and safety. Finally Future Stations cannot be developed without taking issues into account linked to Automated Train Operation (ATO) which handled in IP2.

	Crowd Management and Revenue Protection in large Stations	**Standardisation and Prototypes for small Stations**	**Platform to Train Accessibility**	**Emergencies Risk Assessment of major Stations**

Links to other work streams internally TD 3.11	Emergencies 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 Platform to Train Accessibility IP2 Automated Train Operation (ATO)	IP4 Customer focused IT-services

Figure 38: Interaction with other TDs and IPs

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 gate to enter the railway system as a passenger, it must be ensured that R&D activities within TD3.11 have also an impact on cutting-edge services for the customer and of course on customers directly. With this keeping in mind areas which nowadays need optimization and improvement are well addressed by the help of R&D:

- Consideration of the needs of passengers
- Crowd management as input for planning processes
- Equipment & quality standards including installation costs
- Subjectively perceived customer safety through published opinion
- Individualized services & customer information
- Individualized apps for intermodal access
- Sustainability & energy efficiency

To achieve all this, a wide variety of instruments, methods and technologies shall be used, for example:

- Sensors for measuring and controlling changes in technical systems
- Data Science, Analytics, Internet of Things & Artificial Intelligence
- Predictive Analytics & 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 & 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 service and for a future on-demand logistics	Results from work stream *Crowd Management and Revenue Protection in large Stations* will be used to optimize station design, improve the location and type of station asset to improve rail user experience and minimize 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 trouble free, punctual and a service fit for PRM rail users.
Identification and establishing of new technologies and innovations to strengthen efficiency at all levels	The deliverables from work stream *Standardisation and Prototypes for small Stations* will identify and validate new technologies in the rail environment. These will potentially include new fabric materials, energy efficient mechanical and electrical equipment, automated and intelligent building management systems to reduce carbon emissions and digitalisation of passenger information requirements through the use of phone apps and innovative tactile signage for PRM passengers. 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 whilst 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.
Optimizing costs and increasing of productivity and performance to improve rail's overall competitiveness by faster deployment of new system solutions and capabilities	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 size 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 work streams *Crowd Management and Revenue Protection in large Stations*, *Standardisation and Prototypes for small Stations* and *Platform to Train Accessibility*.
Provision of a sustainable mobility along the entire pathway chain	All work streams within *TD3.11 Future Stations Demonstrator* will consider the latest definition of sustainbable development and will include reference to environmental (decarbonisation/low pollution) economic and social sustainability – known as the three pillars of sustainability. Work stream *Standardisation and Prototypes for small Stations* in particular will provide detailed sustainability information in the station design both in terms of construction but also in how the station is used to ensure that design ambition is achieved when the station is in use by the rail operator and passengers.

This TD will contribute to enable the six **Innovation Capabilities** as follow:

Innovation Capability	*TD3.11 Future Stations Demonstrator enablers & technological building blocks*
2 - Mobility as a Service	Improve key elements of 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 flows management in operation conditions by 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 use 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 passengers groups, including needs of PRM's; • BB3.11.4 Safety management in public areas: Improve passenger flows management in standard operation conditions and in emergency situations; Technical and organisational safety improvement in all public areas for low capacity small and medium stations;
4 - More value from data	Better use of the gathering data in order to achieve better value from the collected data for 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: Rich simulation capabilities to build a realistic synthetic world calibrated with real data and behaviour modelling, depend on use case (standard operation, emergency management); • BB3.11.2 Improved station designs and components: Better use of the data relating to passenger traffic on railway stations (station building and public area); • BB3.11.4 Safety management in public areas: Improve using CCTV systems on passenger stations (station building and public area);
5 - Optimum energy use	Implementation of 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: Improvement of components, optimisation of the types of using materials and use new technologies in order to ensure low emission and energy demand in railway station area in whole life cycle (construction, operation, and demolition);
7 - Low cost railway	Improve standards for design solutions in a holistic approach to reduce operational cost passenger stations in whole life cycle with ensuring the expected level of service for the needs of passengers, including needs of PRM. Relevant Building Blocks: • BB3.11.2 Improved station designs and components: Technical (components and materials), technology (digitalisation, CCTV, service) and organisational (flexible service area) innovation solutions in order to optimisation life cycle cost; • BB3.11.3 Improved accessibility to train-platform interface: Improve organisational and technical methods to ensure accessibility from platform to trains in order to reduce costs passenger service process (including PRMs) with use universal, most common and available solutions;
10 - Stations and "smart" city mobility	Improve standards for design solutions in order to improve interoperability, accessibility, safety and security. Providing repeatable solutions to optimise the whole life cycle costs of stations (station building and public area) with keep the expected level of user experience in the door-to-door service in transport chain. Relevant Building Blocks: • BB3.11.2 Improved station designs and components: Improve standards in the scope of interoperability and accessibility for PRMs and safety in using new components, materials and digital solutions; Improve standards of passenger service in stations in order to improve user experience with using universal design and non-

	discrimination rule; Improve standards of distribution and validation ticketing systems with using new technologies in order to improve user experience; • BB3.11.3 Improved accessibility to train-platform interface: Improvement boarding and unboarding passengers process on stations in order to improve user experience with using universal design rules; Improvement of accessibility through implementation of universal technical and organisational solutions in scope of ensure accessibility from platform to train for all groups of passengers including PRMs needs ;
11 Environmental and social sustainability	Adapting the standards of the solutions to the requirements of sustainable development by reducing the demand for energy, 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 on sustainable development and reduce emissivity and energy consumption of railway stations ;

3.11.5. Demonstration activities and deployment

Research Area	Specific Techn. objective	Specific Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
Future Stations Demonstrator	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 3-D 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
	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 multiplicated at all types of railway station for improvement are expected to be delivered and demonstrated. Improved Stations designs and its components: Develop standards, designs for small stations that will enable low energy impact, use of sustainable solutions and addressing the needs of passengers (design for all inc. 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. Interoperability, accessibility, flexible in use, passenger safety, resistance to vandalism

Research Area	Specific Techn. objective	Specific Activities	Demonstrator Market	TRL	Focus of activity
	Platform to Train Accessibility	New approaches for platform-train interface design methods	Stations	5	Improve accessibility to trains for all travellers groups by addressing issues related to the platform-train-interface (PTI). Results will be an improvement in the ease-of-transfer as well as an improvement of the customer experience. On the basis current state description, the goal is to develop solutions that will allow safe and inclusive access to train, not be too demanding on maintenance and not increase the dwell time of the train significantly.Interoperability, accessibility, passenger safety, universal design
	Emergencies Risk Assessment of major Stations	Technical manual of options and associated benefits/ limitations for safety management	Stations	4	Simulation, development of basics to have decision support, passenger safety, resistance of design against terrorism

Planning and budget:

TD	TASKS	TRL	2015				2016				2017				2018				2019				2020				2021				2022			
	Future Stations Demonstrator	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
	3.11.1- Crowd Management and Revenue Protection in large	5/6														◆			◆			◆										◆	◆	
TD3.11	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 Stations	4																					◆								◆			

(green)	lighthouse projects	milestone	◆
(orange)	Contracted actvities	quick win	●
(blue)	Future activities		

Table 59: TD3.11 milestones

When	What
Q2/2018	Work stream 1: Reference use cases, scenarios & KPI for standard & 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 & KPI for standard & 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 passengers with reduced mobility 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, digitalization, 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 6M €

4. IP4 - IT Solutions for Attractive Railway Services

Context and motivation

A critical environmental challenge of the coming years is the reduction of the carbon footprint, and citizens will be asked to reduce their car usage as much as possible. One of the effective contributions of Shift2Rail 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 journey using multiple modes of transport, is a pre-requisite to foster the use of rail over private vehicles, enabling reduction in traffic congestion and associated greenhouse-gas emissions, amongst other benefits.

Currently travellers are faced with barriers when trying to engage a journey mixing rail transport with other modes: these range from needing to access multiple sources for timetables and planning information, the need to carry and purchase multiple tickets to demonstrate the validity of the different parts of the journey, to adjust to different fare media, interfaces, devices, conventions, procedures and tools developed over the years by many retailers, operators, and distributors.

Besides, different transport modes (air, main line rail, urban rail, buses…) have grown independently at diverse speeds and 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 travelling over different transport modes is confronted to the lack of interoperability.

This makes multimodality patchy and as a consequence travellers are unable to exploit the diversity of the market place easily and have little control in managing their travel. Without an end to end, one stop shop experience, travellers have to manage for themselves the context of their search and purchase for their itineraries, by interacting with very different systems and interfaces covering only partial elements of their trip. Current ticketing and validation systems across transport modes and operators have great variability in terms of concepts, architectures and equipment, further limiting the means by which they can integrate without conscious efforts. Level of services, capability description, booking, pre-paid product versus post-payment, validation media and profile of users vary greatly from a system to another. The consequences are that the citizens must often switch between sites, ticketing devices or offices in order to shop, book and pay the components of their intended journey – and must have multiple tickets to validate through the multimodal journey.

On top of this, there is little in-trip assistance for travellers when navigating transport nodes, confronting service disruption, or when 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) 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.

Access to heterogeneous data:

Amongst the challenges in the travel market place, an important one is the 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 find an interest to share their data, must have guarantees on the usage made by third parties, and the responsibility in front of the final user for the quality and reliability of provided information must be clarified. The market uptake will depend on the data available to support the market growth.

But the challenge is not only the access to data, it is also the heterogeneity of data format, which is critical in a multi-modal context. Data standards exist in the rail sector: TAP-TSI, SIRI (Service Interface for Real Time Information), amongst others. But different ones exist for other transport sectors (e.g. air).

Because the objective is to facilitate multi-modal transport for the benefit of the rail sector, bridges between these standards must be defined. The option which has been chosen in the Shift2Rail IP4 context is to develop an interoperability framework (based upon semantics-technology), which offers ways to automate at the framework level (and not at the application level) the translation between standards.

The first interest of an operator to use the interoperability framework is to become visible by an open-ended world of service resources on the market place, which is a condition for business increase. Moreover, the technologies used in IP4 are giving some guarantees which can ease the market uptake. The interoperability framework, using semantic technologies, is proposing a more controlled environment (data access, usage control) than a complete “Open Data” approach. Annotation contributes to protecting data, as it permits to fix commercial conditions, or to define 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 convince the operators to publish more easily their data. Although IP4 places the traveller at the centre and takes his comfort as main target, by increasing the attractiveness of the 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 insight from 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) are stored in the travel companion wallet, and also assets with significant financial value (long range airplane entitlements tokens for instance) for which protection and resilience towards cyber-attack must be guaranteed. The possibility offered to retailers and operators to access information in the wallet (e.g. to read preferences) must be carefully controlled, and profiling by the usages must be subject to explicit consent. The security challenge also exists in the booking and ticketing processes, where financial data are managed in order to support settlement payments and clearance.

Moreover, applicable from May 2018, the new General Data Protection Regulation (‘GDPR’, (EU)2016/679) is now regulating the processing of personal data relating to individuals in Europe. The relevant IP4 developments will have to comply with.

Objectives of the IP and expected results

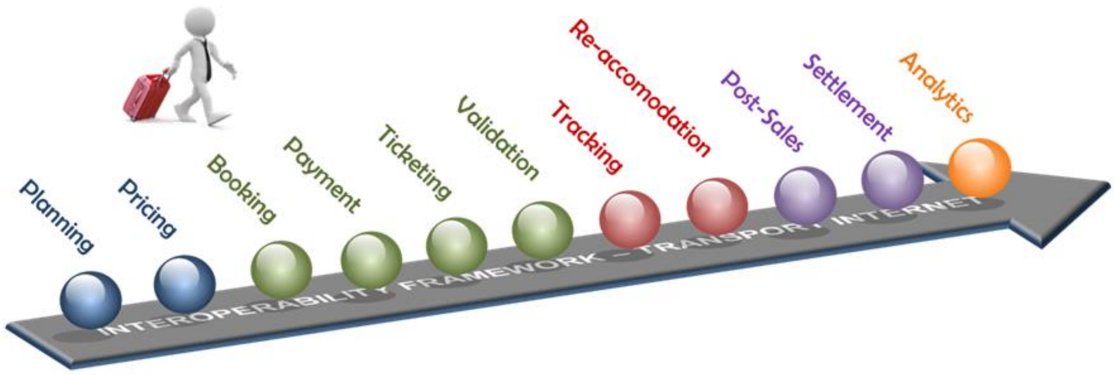
To support modal shift, rail must become more attractive for the end user; this will come with additional comfort and a better reliability of the rail system, but also by simplifying all the stages of the passenger journey and by ensuring a better connection with his daily life.

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 citizen work and leisure environments, across all transport modes, local and long-distance.

This transformation, or "Digitalization" of Transport Ecosystem, will also boost the expansion of new transport paradigms and concepts such as Mobility as a Service (MaaS), based on delivering to individuals access to a packaged offer of 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: offering a multimodal travel offer connecting the first and last mile to long distance journeys, by combining air, rail, coach and local modes of transport;
- A seamless access to all travel services, with the integration of all steps of a journey (from planning to after sales)



This core objective of extended seamlessness will be answered 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 whilst limiting impacts on existing systems, without prerequisites for further centralised standardisation. Transport industry incumbents and newcomers will discover wide opportunities to provide new services, products and new competitive business models, such as Mobility as a Service (MaaS).

The overall strategy for IP4 developments can be summarised as follows:

- IP4 will not develop a "one size fits all" solution (or set of solutions), but a 'Market Place', 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 if IP4 will encourage open data, it will accept any kind of data in any standards, interpreted by the "interoperability framework". IP4 provides the mechanisms to access and orchestrate data and processes wherever they happen to be located. IP4 is completely agnostic to whether data and processing is 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 to whether products and services are directly or indirectly distributed.
- IP4 will be completely distributed (no centralisation for data or processes, no imposed technology) and modular. IP4 does not mean a centralised data and/or processing centre, or centralised single platform for customers to get their multimodal travel plans and tickets. It's about facilitating these capabilities everywhere.

The following table 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 60: Objectives and challenges of IP4

Objective	Result	Practical (concrete) deliverable
Enhance the (capacity/) 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, all operators and supporting shopping over all types of distribution channel (direct, indirect, online, offline etc.)
	Provide a unified access to ticketing services for all transport modes, regardless of their location, access method or format, validation process.	"Booking & Ticketing" will provide specifications and reference implementation covering 100% "standard" entitlements (air, train, long-distance bus, daily/weekly/ passes, origin-destination/zonal, etc.)
	Provide a personal "guardian angel" which gives access to all information, additional services, and simplify the user travel experience taking into account the user preferences	Reference implementation of a "Travel companion" with innovative human machine interfaces.

Objective	Result	Practical (concrete) deliverable
	Better adaptation between supply and demand	Business Analytics will help operators adapt their services to the demands of the marketplace and deliver a more effective, optimized and satisfactory service
Consolidate the (reliability/) Quality of services	Increase the attractiveness and transparency of the rail system for the passengers	The "Trip tracker" will provide real-time information on the current trip legs, including access to alternative journey propositions and re-accommodation services if required.
Improve on Life Cycle Costs / 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. Amount and heterogeneity of data and improved "Business analytics" process allow more efficient operations and use of resources.

KPIs for IP4:

The Key Performance Indicators (KPIs) for IP4 are dissimilar to those used in other IPs (capacity, reliability, LCC). The increase of passengers, resulting from IP4 activities improving the attractiveness of the rail sector, is a pre-requisite to the other IPs - we will only need additional capacity if we are able to attract more passengers.

The Shift2Rail initiative seeks to increase the capacity for a given infrastructure, by increasing the number of trains (control command), while increasing the number of seats per train (rolling stock), and reducing the life cycle cost (of the rolling stock and infrastructure) all 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 with better integration of the rail into the overall mobility ecosystem.

An in-depth analysis about the best way to quantify the increased attractiveness that IP4 is bringing is developed by CCA, in charge of the KPIs for S2R. Starting with a list of obstacles (to take the train) coming from various inputs/projects, each IP4 TD is assessing how the activities developed in the TD are contributing to remove some of the obstacles, and this is used to derive KPIs for the 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' 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 co-exist 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:

- Passengers' services: the travel companion will give easy access to IT services adapted to passengers "profile" 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 the social life (culture, degree of mobility, aesthetic considerations, merchandising, etc.).
- The market of transport services (shopping, ticketing but also services related to guidance) will be opened 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 a new competitive market.

Past and ongoing European & 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 digestion of external innovations while promoting the key concepts of Shift2Rail IP4 towards other groups:

Major Projects	Valuable outputs for IP4
TAP-TSI	Telematics Applications for Passengers – Technical Specifications for Interoperability: a common denominator set of standards for the rail industry designed to establish base-line standards for cross-border rail services, including reference data for location codes and company codes. This legislation is legal binding in the EU.
Full Service Model (FSM)	Door-to-door rail products & services distribution across all distribution channels (domestic & 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	'EU-Spirit' is a cross-border and Internet-based travel information service for customers of public transport.
MOBIWALLET	Integrate different payment means for multiple transport modes, fostering a seamless travel and proving other added-value services to improve intermodal journeys.
IT2RAIL	IT2RAIL is the Shift2Rail light-house project initiating IP4 activities
Co-Active & AT-TRAcKTIVE	The 2 IP4 projects for members started in Sept 2016 are covering : TD4.2, TD4.3, TD4.4, TD4.5
GoF4R & ST4RT	The 2 IP4 open calls started in Sept 2016 are covering the governance and some technical activities for the Interoperability framework TD4.1
CONNECTIVE	This CFM project (2017) is continuing IT2RAIL activities for TD4.1
COHESIVE	This CFM project (2017) is the integration project (ITD) for IP4
MaaSive	This CFM project (2018) will cover : TD4.2, TD4.3, TD4.4, TD4.5
MOBiLus (EIT Urban Mobility)	EIT Urban Mobility will work on 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 with respect to Intra-Rail sector standardisation epitomised by TAP-TSI Regulation and implementation project together with the objectives of FSM project. With regards to inter-transport mode standardisation, apart from 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. As such IP4 draws from current or emerging sectorial standards.

IT2RAIL, the Shift2Rail light-house project initiating IP4 activities, is used as a ramp-up towards Shift2Rail IP4 full capabilities.

Set-up and structure of IP4

Structure of the IP

To achieve its objectives, IP4 will conduct work in three Research and Innovation areas listed in the Master Plan:

- Technical framework:

Enforcing multi-modal travels 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, 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: open-ended, non-centrally coordinated world of networked sensors, devices, social media, services and transactions. 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 actors of the ecosystem, and new intelligence for the benefit of operators and travellers.

- Customer experience applications:

It is a key objective to provide travellers a 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.

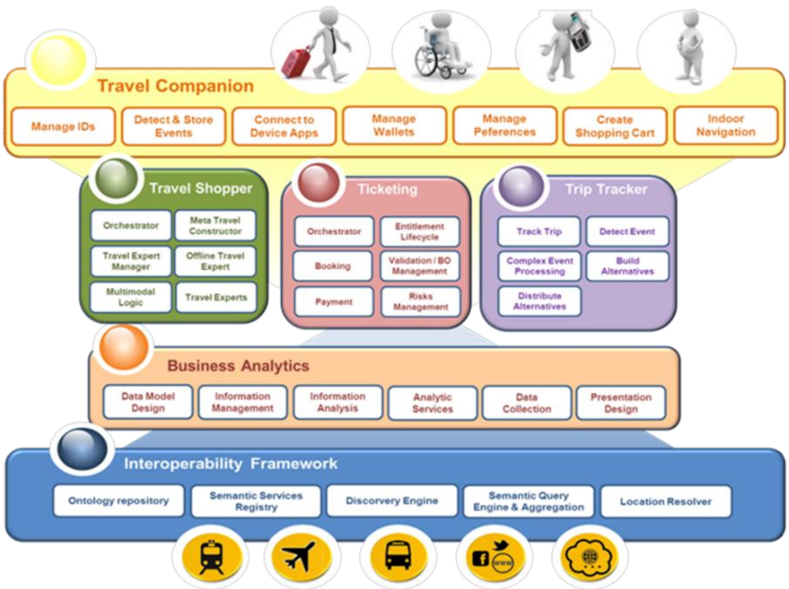
The traveller will have full control of the journey thanks to their own personal and secured “Travel Companion” (TD4.5), storing and sharing their personal preferences in a wallet. The Travel Companion gives access to all travel services needed for the journey, shopping and booking, allow the storage of the rights to travel, and provide guidance within stations. At the same time retailers and operators are able to identify and authorize 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 the “Trip-tracker” (TD4.4) giving continuous monitoring of the journey, personalized information (related to preferences stored in the Travel companion), up to date status on the subsequent legs of the journey, and supporting the Traveller in case of disruption, by proposing new travel alternatives with the possibility to book and acquire updated rights to travel.

- Multimodal travel services:

To engage on a multimodal journey, the traveller today must switch between several websites, retailer and ticket offices in order to shop, book, pay, and must have multiple fare media and tickets 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. The “Travel Shopping” (TD4.2) will provide a comprehensive shopping application enabler which 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.

The “Booking & 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. Sustained by the concept of a unique traveller identifier and the Travel Companion wallet – the traveller will have easy access to the complete and integral 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 lifecycle management will radically simplify the traveller’s life by abolishing constraints associated to 'behind-the-scenes' multiple booking, payment and ticket processes. Although downward compatibility to existing and legacy systems will be possible for operators joining the scheme without modification of 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 which have to be developed:



Although IP4 is organised around Technology Demonstrators (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 TDs developments, and which is providing the system approach to integrate the different TDs results.

Approach within the IP

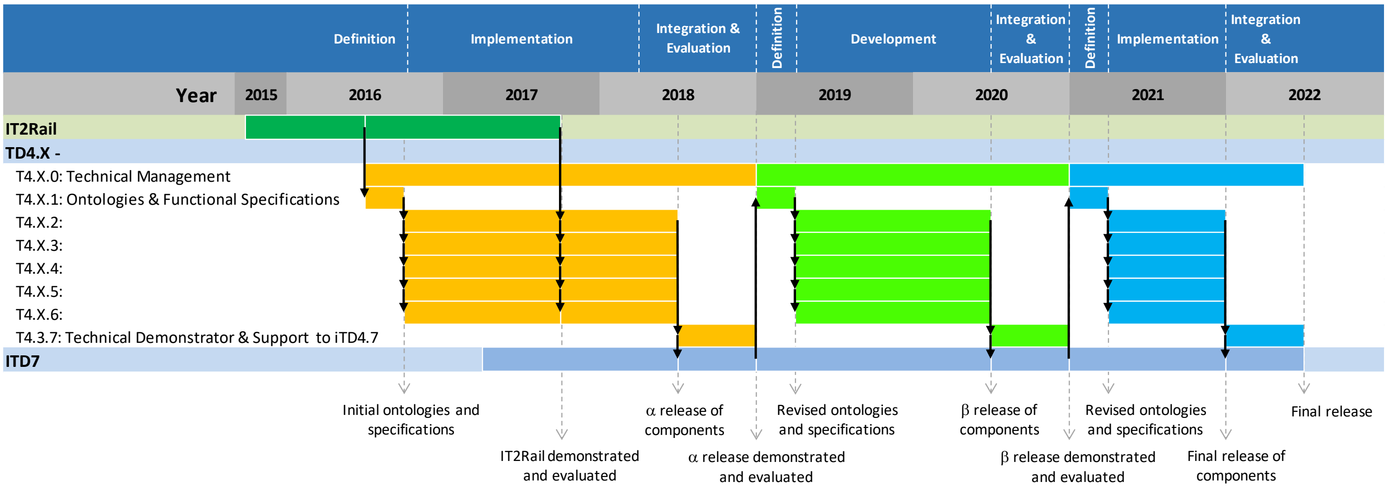
The overall method is to target a system level “complexity” and “maturity” (scope and TRL), defined through releases at ITD4.7 level, and to identify the functions (at TD level) to achieve this objective.

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 4 releases: the first one is the final deliverable from the IT2RAIL lighthouse H2020 project, which is starting all activities with a reduced complexity and a low TRL (TRL4-5). 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 the (I)TD7.

The objective is 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 TRL 6 minimum.

As a consequence, all IP4 developments will be regular and developed in parallel in the different TDs, following the 4 system releases as shown in the scheme below:



Links to Other IPs, and ITDs

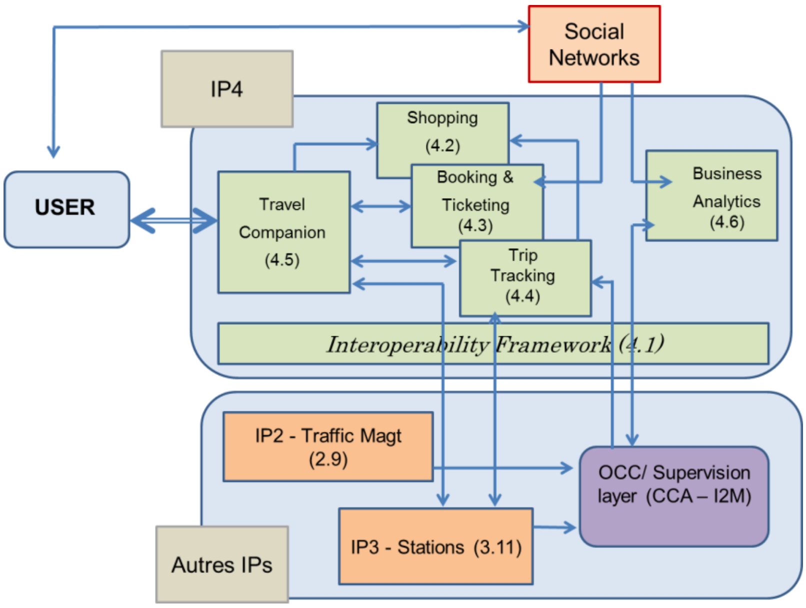
The adherence of IP4 with the other IPs comes mainly from one of its objectives, which is to give to the user real-time information about the traffic for the current and future legs of its journey. The status about operations is given through the trip-tracker, which monitors in real time the complete journey, and must be informed about any disruption, delay, cancellation, and alternatives. Conversely, business analytics is collecting traveller's flow 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 & Access					–>	<–>	
S2R IP2	TD2.1	Communications				–>	–>		
	TD2.9	TMS	<–			–>		<–>	
	TD2.11	Cyber-security	–>			X	X		X
S2R IP3	TD3.6-8	Maintenance				–>			
	TD3.11	Future Stations			<–>	<–>	<–>	<–>	
S2R IP5	TD5.2	Access & Oper.	<–						
CCA	WA 1	Social network				–>	–>	<–>	
	WA 2	KPI developt						<–>	
	WA 4.1	Smart Planning						<–>	
	WA 4.2	I2M	<–	–>	–>	–>		<–>	

The main inter-connections are therefore with IP2/ TMS, IP3/stations, and CCA/I2M (Integrated Mobility management) activities. 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 the Business Analytics 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 the traffic, and then gives back input to IP3 for the infrastructure management and IP2 for the traffic management.

In addition, the existing interactions with other IPs and within relevant TD´s of IP4 take into account the work on on the S2R system architecture performed in IPx.


Social Networks
IP4
Shopping (4.2)
USER
Travel Companion (4.5)
Booking & Ticketing (4.3)
Trip Tracking (4.4)
Business Analytics (4.6)
Interoperability Framework (4.1)
IP2 - Traffic Magt (2.9)
OCC/ Supervision layer (CCA – I2M)
IP3 - Stations (3.11)
Autres IPs

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 Transportation ecosystem into a global services and data market place, 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 ICT systems such as:

- The multitude of data formats across modes and services
- The absence of connectivity standards for ICT systems across modes and actors
- Low availability of good quality data, including real-time data
- High integration costs due to non-interoperable ICT systems
- Large number of specific solutions for different use cases
- Reluctance to sharing data and services from actors benefiting from the current fragmentation

The "Interoperability Framework" should provide technical interoperability making possible the digital transformation of rail and in general all the transport ecosystem, by enabling the creation of an open "Web of Transportation": a shared distributed database of transportation data built according to internet technologies. Linked data principles supported by semantic web will be considered, besides ultimate advances in architectures and big data technologies for the multi-formats 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 for adaptation from TSP systems to become part of a network of services available, minimizing the need for static exchange of data sets, and giving these applications the capacity to "interpret or understand" the different data representations and concepts used by the different TSP.

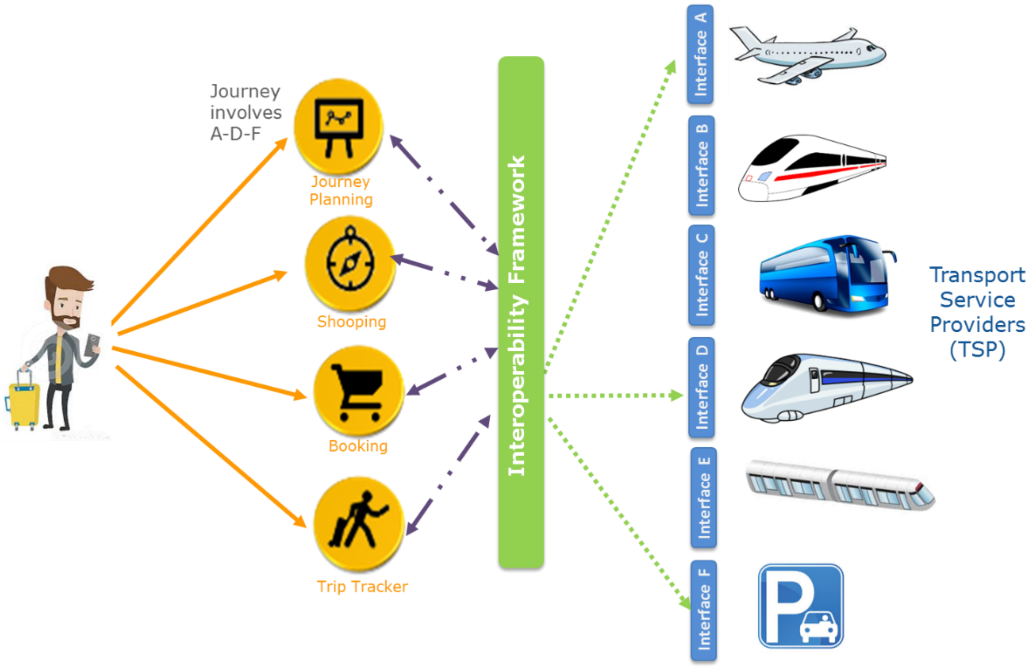


Figure: IF within the IP4 Transport Ecosystem

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 realized as the web of transportation things.

1. Share and distribute Travel and Transportation domain knowledge ("ontologies") to facilitate automation of interoperability
2. Harmonised 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 the 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 actors of the transport ecosystem, providing mechanisms to abstract data consumers from the complexity of varied data formats and non-integrated services, facilitating interoperability among systems and the creation of added value services for achieving 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 on a fragmented vision of the ecosystem.	Provision of the Framework, tools and technologies that will allow data exchange among different actors of the transport ecosystem, providing mechanisms to abstract data consumers from the complexity of varied data formats and non-integrated services, facilitating interoperability among systems and the creation of added value services for achieving a seamless multimodal door-to-door experience
Specifically within the rail domain, several projects have tackled the challenge to integrate ICT systems making them interoperable, resulting in the development of lots of interfaces and data format standards, and sometimes in the generation of additional ad-hoc solutions adopted through agreements by a small number of partners	Develops an open and extensible semantic web based standard encapsulating interoperability problems and removing them from the ICT assets business logic. IF will additionally constitute the 'reference' implementation of the specification, to be used as a compliance benchmark of alternate implementations. It plans to develop new concept-map where the integration and harmonization are mandatory for building a complete transport ecosystem covering all the stages of the value chain. Besides, mechanisms will be provided to ease and automate the publication of new service providers information, ambitioning levels of higher seamless and easiness in the introduction of new actors.
The essential limiting feature of the approach to interoperability adopted in the past has been approached as matter of describing common formats or codes to describe data items to be exchanged. Although this could be sufficient for an M2M (Machine-to-machine) exchange of data, the real meaning of this data is not understandable for 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 decentralization of management is defined by "unambiguous semantics", based on the definition of complete semantic model, using ontologies for the identification of the concepts representing the information. The "semantics" should support the underpinning legislation and European standards (such as TAP-TSI, NeTEx, but also on-going initiatives like FSM- full service model). 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 already experts in the domain, limiting market uptake and the base of possible solution suppliers, and creating significant barriers to entry	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 centralized components. The provision of a "Web of Transportation" guarantees decoupling among systems and eases to expand the model, allowing the fast Integration of systems.
Each stakeholder is an eager owner of its own information, having in mind the risk of sharing data beyond the potential benefits of new value chains.	The IF minimize the need for static exchange of data sets. 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 centralized data base that includes ticketing information of all the actors of the ecosystem.

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

The Interoperability Framework is the specification of generic capabilities to allow any compliant rail business application to interoperate. It provides other IP4 functionalities (such as Shopping (TD4.2), B&T (TD4.3)) the ability to interoperate with legacy systems, and this approach could also be applicable to other IPs. Within IP4, TD4.1 acts as an “horizontal” layer, and it is related to all other IP4 TDs.

At Shift2Rail level, for example TD2.9 TMS, CCA I2M or TD5.2 entail and 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 needed ontologies need to be defined to allow semantic interoperability of systems.

There is also a close connection with TD2.11 Cyber-security, as TD4.1 is related to information exchange among systems, where cyber-security 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 bring include:

- Enable a complete digital transformation of the European Transportation ecosystem into a global services and a market place for third parties, including SMEs. Digitalization will allow 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.
- Liberate from technological barriers where actors and business models will be able to emerge and prosper for the benefit of European Travellers.
- To promote the development of 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.
- To promote 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 submitting the cost of interoperability to downwards market pressure.

Besides, TD4.1 developments will contribute to the following strategic aspects:

Strategic Aspect	Key Contribution from the TD
On cost reduction	Enhanced interoperability will allow: decreasing the cost of interoperability of current systems and new ones; decreasing the costs of acquisition of Customer experience systems for Railways Operators (and other TSPs); decreasing the costs to Railways Operators of product distribution through Third Parties. Besides, it will foster reusability, and data harmonization.
Increase revenues	Creating new value chains: Generating additional revenue to Retailers and Railways Operators from richer product offerings and smart services to Customers.
More Agility	By flexibility of the framework: Decreasing 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 incomers in the ecosystem and easily 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. Besides, by aggregating suppliers' systems to the offering, market of specialists suppliers of products and services will be encouraged to be compliant with the Interoperability Framework specification, thus putting additional downwards pressure on the cost of interoperability for Customer experience system developers.

This TD will contribute to enable 2 Innovation Capabilities as follow:

Innovation Capability	***TD4.1 Interoperability Framework enablers & technological building blocks***
2- Mobility as a service	*TD4.1 aims to move a step forward towards the Digitalization of Transport Ecosystem and boost the expansion of new transport paradigms and concepts such as Mobility as a Service (MaaS), based on delivering complete sets of mobility to each individual and integrated access to a complete offer of 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 ensure connections between the different modes, including rail integrated with other modes, and assures the 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 for Data	*IF facilitates that relevant information is shared among systems, enabling the 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 across Technical Demonstrators within IP4 and across data assets provided by multiple organisations. As a complex technical foundation for all technical demonstrators, it is important that the strategy for its development is provided with 'built-in' capabilities accommodated to minimize risks to the successful completion of the entire IP4 programme, and for it to be coherent with the consistency and convergence mechanisms designed in the ITD4.7 technical demonstrator to guarantee overall integration of the IP4 products.

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
Interoperability Framework	Definition of the framework and ontologies	Specification, Ontologies	Generic	5	Identify, formalize and document requirements and global specifications for interoperability across IP4 TDs' applications, as well as integrate ontologies defined in other TDs.
	Integrate Travel Service Providers and resolvers	Specification, Architecture & interface, SW devlopt	Generic	6/7	Deploy components for the integration of legacy systems of travel experts, including the mechanisms to register, annotate, and discover the TSP and their data. Provision of resolvers based on semantic interoperability mechanisms.
	Architecture and interface with other IP4 components	Specification, Architecture & interface, SW devlopt	Generic	6/7	Integration with orchestrators and other IP4 components.

The first release was the result of the IT2Rail project. It proposed a reduced approach 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 Shift2Rail IP4. The use case presented for IT2Rail was a selection from all the possible use cases that will be addressed by the Shift2Rail 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 the IP4 evolves and extended functionalities, new approaches, and new transport modes are included in IP4 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. Besides, the platform will improve its performance through new tools, resolvers and higher automation of processes. This will be reflected in the different releases (ALPHA, BETA, FINAL), detailed in the Milestones Table below.

Planning and budget:

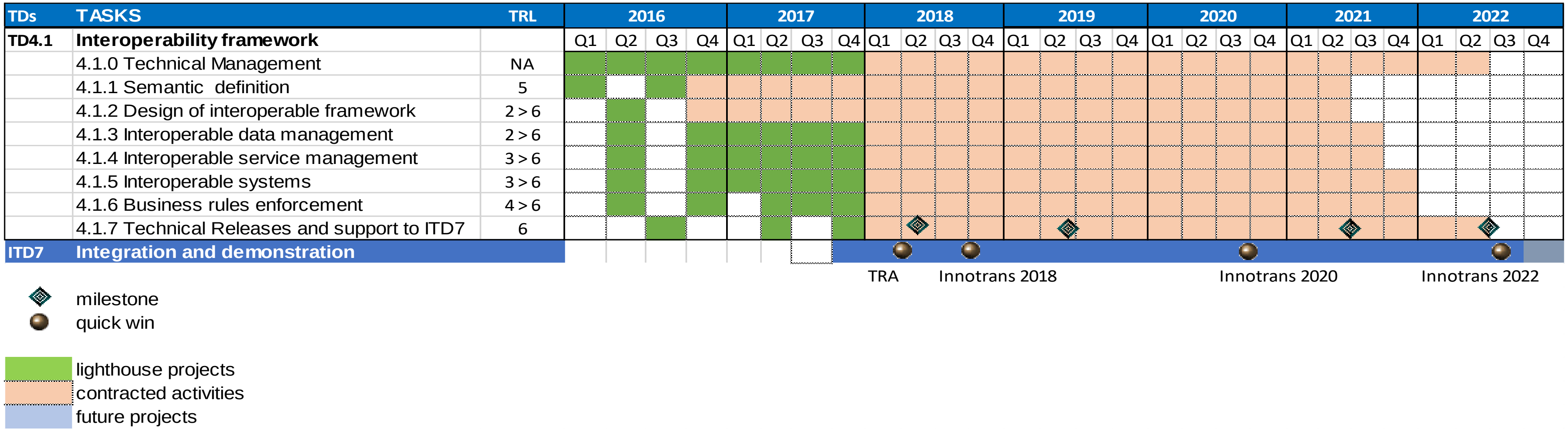


Table 61: TD4.1 quick wins

When	What	Contribution to MAAP
Q3 2018	Integration of existing relevant features to develop use-cases during Innotrans event : in "live" demonstration	Use of IF and its functionalities to support an end to end demonstration in a controlled environment. It will reflect the initial works within CONNECTIVE project, focused at 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 at the backbone of a demonstrator following a MaaS approach, complementing with CONNECTIVE developments in TD4.1 the works of MaaSive project. It will allow to demonstrate the performance of the IF 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 62: TD4.1 milestones

When	What
Q2 2018	Integration of all features developed in the IT2RAIL project - IT2RAIL : May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRAcKTIVE project - ATTRAcKTIVE: Sept 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 M€9.4

4.2. TD4.2 Train 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 market place within a Single European Transport Area (SETA) due to 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-2-door (D2D) travel solutions for customers' (European residents and visitors) mobility needs and preferences implicating any sort of travel within the SETA.

TD4.2's technical enablement of this capability is fundamentally 'distribution-channel agnostic', meaning that all retailer operations, whether belonging to 3rd 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 and risking the feasibility of their combination. Such products and services may be prepaid, purchased 'en route', or even post-paid (as in a number of urban, regional or national smart ticketing systems). As such there is no single travel shopping experience for customers today: each de facto multimodal travel is achieved via multiple shopping experiences before, during, or, indeed, after the trip has completed.

As such, the customer directly confronts the fragmentation of the European travel market. The overwhelming majority of attempts to plan and purchase an entire door-2-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' becomes a distorting factor influencing their travel choices; and, frequently, the customer defers travel purchase decision-making for most parts of their trip to the 'en route' shopping window, 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 underutilized by customers arriving from outside the city.

This TD looks at how to reduce, radically, the risk and effort of travel shopping, whilst simultaneously facilitating the supply and distribution of comprehensive and combinable transport services. It consequently allows for flexibility and increased choice of business model and distribution strategy for transport undertakings, leading to an optimisation of demand satisfaction, and increased take-up of greener forms of transport. Therefore multimodal door-2-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, which inhibit exploiting the business opportunities that commercial partnerships offering smart (intermodal) solutions for recognized 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 market place:

1. Provide multi modal 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 applications representing 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 which underscore intermodal products which 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 for which they might be relevant.

4.2.3. Technical Vision

State-of-the-art	New Generation Travel Shopping
Multiple mono modal services between stop points	Multi modal door-2-door travel planning capabilities while distributed journey planning functionalities
Closed system with high barriers for new business opportunities	Due to the integration of an Interoperability Framework an "unlimited" number of TSP can be taken into account
Dedicated closed modal schemas	Open multimodal schema
Trips are not according to 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

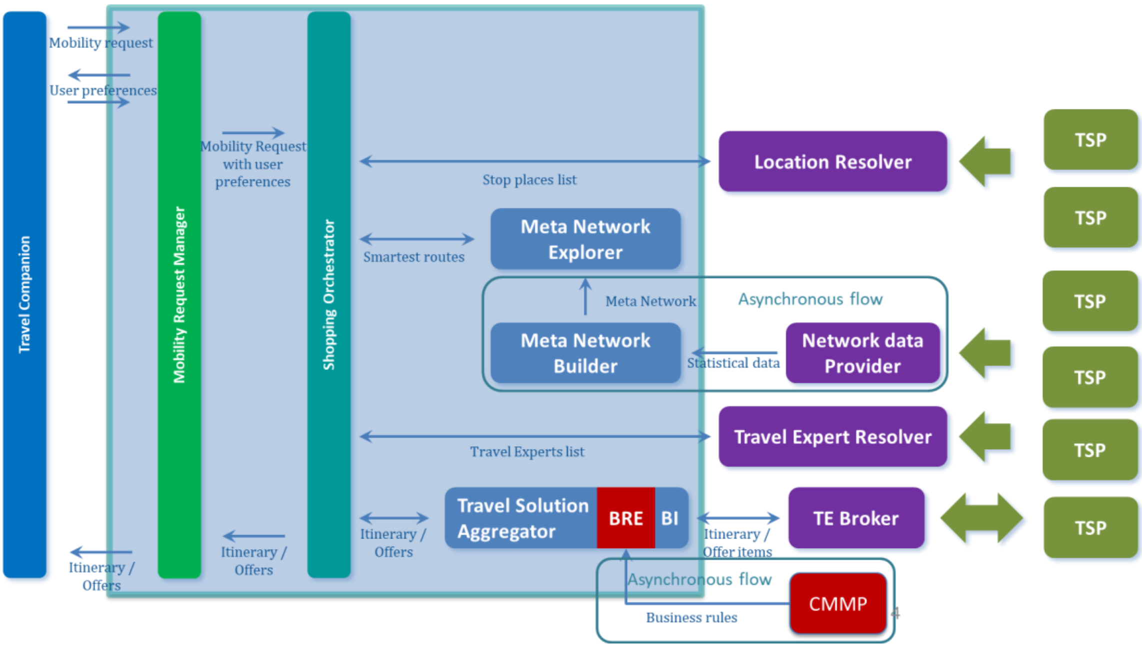


Figure 39: Future Travel Shopping architecture

Interaction with other IPs

- TD1.2 → Any train related data relevant for travellers
- TD1.6 → Occupancy rate of a train or waggon
- TD1.7 → Display the actual vehicle layout to the traveller
- TD2.9 → Usage of real time information
- TD3.6 → Train related information like utilization
- 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
  - Storing of all kind 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 Services 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 dialogue without having to invest in adaptations of interchange messaging between them. This should encourage a snow-ball 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) Single European Railway Area (SERA)	The comprehensively and combination power of the travel shopping framework will help ensure not only the emergence of a Single European Railway Area, 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 1st, mid 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 the 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 TAPTSI messaging meaningfully without demanding compliance outside of the Rail Sector. This in itself will encourage accelerated take up and implementation of TAPTSI due to the added value of this potential external connectivity.

This TD will contribute to enable **Innovation Capabilities** as follow:

Innovation Capability	***TD4.2 Train Travel Shopping enablers & technological building blocks***
2- MaaS	TD4.2 develops a technical enabler for one-stop-shop which allows Multimodal Planning for Itineraries and Offers. As travellers needs to been informed about all options for travelling (including all modes) these multimodal Travel Shopping capabilities are key for any 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 for Data	Spread over Europa a huge amount of date for travel services is available: • Time table information (network and schedule); • Real time information; • Information from travellers and provided through different internet channels. Travel Shopping will collect data about the travel demands. Analysing these data while Business Analysis while allow to adopt the offer to fir better to the real demand. This includes both long term planning as well as 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

4.2.5. Demonstration activities and deployment

Research Area	Objective	Nature of activities	Demonstrator		Focus of activity
			Market	TRL	
Train Travel Shopping	Define Travel Shopping	Specification, Ontologies	Generic	6/7	Develop exhaustive vocabulary of common terms for every transport mode, with key objects, roles and concepts, used in the Travel Shopping compatible with existing legal environment (e.g. TAP TSI).
	Multi-modal Travel Shopping	Specification, Architecture & interface, SW devlopt.	Urban (MaaS)	6/7	Develop and establish a system that allows Multimodal Travel Shopping European wide, but for demonstration purpose on given long distance corridors only. Therefore interaction with the TC PA, TC CW and the IF will be established.
			Co-modal long-distance journey	6/7	
	Co-modal agreements between TSPs	Specification, Architecture & interface, SW devlopt.	Generic	6/7	Develop a tool to manage co-modal agreements (contracts and business rules) between independent TSPs. Applying the business rules while shopping.

The activities of Travel Shopping will be developed in 2 contexts:

- Urban environment in a context of a MaaS approach
- Co-modal long distance journey in which the long-distance leg (e.g. air) is connected co-modally (with independent

In these two contexts, the needs to Travel Shopping are rather different (regularly vs. singular travels), and require different approaches.

Planning and budget:

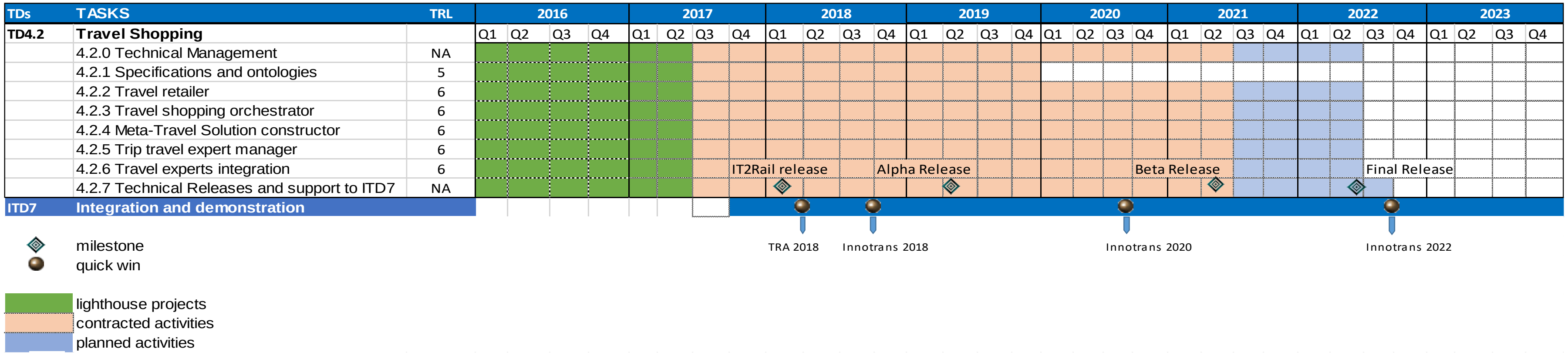


Table 63: TD4.2 quick wins

When	What	Contribution to MAAP
Q2 2018	Integration of IT2RAIL developments in the ITD7 demonstration	• Distributed Offer Building while using existing legacy systems • Interaction with legacy Travel Experts
Q3 2018	In addition, integration of outcome of the CFM16 projects, mainly Co-Active	• Integration of new modes (e.g. private car, Car and Bike Sharing) • Door-2-door capabilities • Working Personal Application following the entire Shopping flow • Integration of management of contracts and business rules between Travel Experts
Q3 2020	In addition, integration of the CFM17 project (CONNECTIVE) and CFM18 project (MaaSive), and demonstration of an integrated approach towards MaaS (mobility as a service)	• Integration of new modes (DRT) • Support of Group and Family travels
Q3 2022	Integration of all the IP4 project features into the iTD4.7	• Demonstration of the Travel Shopping features in Innotrans 2022

Table 64: 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) - IT2RAIL: 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) - Co-Active: Sept 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 of IP4

The estimated total budget for this TD is around 6.7M€

4.3. TD4.3 Booking and Ticketing

4.3.1. Concept

The concept of the "Booking & Ticketing" TD is to allow multi-modality 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 & Ticketing" perspective, fostering multi-modality therefore requires a grand unification of the way the rights to travel are managed by the different Transport Service Providers (TSP). This TD will look at how to provide such interoperability across Europe. This includes cataloguing the "entitlements", unifying the approach to describe their lifecycles (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 functionality included as part of this framework.

Therefore, the key concepts of the TD4.3 approach are:

- **Harmonize** 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
- **Dematerialize** the entitlement: ubiquitous access to entitlement, 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 also a MaaS scenario, 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 multi-modal ticketing:

1. Harmonisation of the Management of the rights to travel (entitlements)
2. Packaging of Entitlements to allow their storage in Cloud Wallets (Travel Companion)
3. Management of entitlements and tokens, and also ancillary services related to the trip (meal, Wi-Fi, etc.), as well as after sale functionalities (cancellations...).
4. Reduction of gap between entitlement and embodiment.
5. Orchestration of processes involving multiple TSP for allowing multimodal booking, issuing, payment and ticketing.
6. Harmonisation of payment, clearing and Settlement for Entitlements
7. Provision of 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 in different components within the '*Ticketing Framework*', the ambiguous notion of travel ticket will evolve toward the new concept of Entitlement / Token / Embodiment (ETE) triple and allow greater interoperability of travel rights across the whole transportation 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 by a potential traveller (e.g. by the virtue of being in possession of a credit card). 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 Triple*. It is essential to ensure that legacy ticketing systems can interact with the IP4 ticketing framework when electronic forms of ticket are not recognised. It is the fare media, linked to an Entitlement-Token, enabling interaction with the legacy devices and infrastructures of the operators and service providers (offering downwards compatibility).

- *Benefiting from the complete dematerialisation of the entitlement*, the '*Ticketing Framework'* will provide interactions with electronic cloud wallets and unique identifiers to allow secured ubiquitous access to traveller's entitlements and itinerary. These mechanisms will provide the traveller with a global identity and associated rights accessible by the European operators and services providers.

- *Additionally, addressing the ticketing interoperability through the 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 eco-system and any contractual schemes.

State-of-the-art	New Generation B&T
Technical limitations in electronic tickets: proprietary, not easy to manage in a multimodal context. Sometimes they need a transition to a physical embodiment (need to be printed, for example)	The Entitlement / Token / Embodiment chain will allow a downwards" compatibility to existing systems, allowing willing operators to join the scheme without forcing them to modify all their existing systems. Components specialized in a specific Booking & 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 component interoperability and modularity. Moreover, 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, multi-modality 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-Ground Transport cases run by Rail Providers) but which do not span all Transport Modes.	IP4 supports a one-stop shop multi-ticketing for all travel modes and inter-modal, overcoming the current interoperability challenges, and proposing the harmonization 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 consider as common modes used for the "first mile", and with its own complexity 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 allowing every actor in the eco-system to communicate and interoperate at the business level without the need for a global single European-wide integration platform or for a central authority structuring and regulating the market.
Fare media offer today is very fragmented. A number of new technological advances are being made in terms of Entitlements, Tokens and Embodiments, 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 at experimental phase, identify the more suitable to reach interoperability, and describe how to integrate these technologies in the Ticketing Framework. In relation with TD4.5 Travel Companion, the TD4.3 will introduce ticketing device and fare media interaction into a connected environment. Allowing dynamic interface between the two items, it will enable seamless usage of the transportation system for the traveler while guaranteeing the security and limiting the risk for the service provider

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

TD4.3 has a close relation with all the other IP4 TDs. Using the services of the Interoperability Framework (TD4.1) , the Booking &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 allow to provide information relevant to the booked journey thanks to the trip tracker (TD4.4). Moreover, BA techniques from TD4.6 could be applied to the ticketing data collected.

There could be also a link among 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 abolish the complexity of a Ticketing scheme adapted to a multi-modal heterogeneous environment:

Strategic Aspect	Key Contribution from the TD
On the economics of the Travel Services Providers ecosystem	Benefiting through the Interoperability Framework (TD4.1), from an access to an open-ended world of booking and ticketing resources and leveraging the Travel Companion (TD4.5) cloud computing capabilities, the 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 later, the TD4.3 will indeed reduce investment costs for multimodal transport offers.
On the creation of a (Digital) Single European Railway Area	The flexibility in the transport offers created by the IP4 TD4.3 "Booking & Ticketing" technical demonstrator will allow better transport policy efficiency for TSP. As the constitution and composition of existing products will integrate multimodal products, the coherence of the public transport policy will be facilitated by the ability of the TSP to control and define precisely 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 lines railways will lead to the increase of rail attractiveness and alongside; increase the usage of rail transportation as the option become more available to the traveler.

This TD will contribute to enable 1 **Innovation Capability** as follow:

Innovation Capability	***TD4.3 Booking & Ticketing enablers & technological building blocks***

2- Mobility as a service	*TD4.3 will contribute to the extension consolidation of MaaS, integrating various forms of transport services into a single mobility service, allowing booking and ticketing from different modes accessible through a unified gateway and allowing single payment channel instead of multiple ticketing and payment operations, contributing to increase the customers' satisfaction and promoting the use of the public transport systems through Europe. Relevant Building Blocks:* - *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)

4.3.5. Demonstration activities and deployment

search Area	Specific Techn. objective	Specification Activities	Demonstrator Market	TRL	Focus of activity
Book-ing & Ticket-ing	Design and specifications	Specifications, ontologies	Generic	5	Identify, formalize and document requirements and global specifications and ontologies related to B&T
	ETE lifecycle	Specification, Architecture & interface, SW devlopt	Generic	6/7	Establish a new concept of travel rights based on Entitlement/Token/Embodiment (ETE) to allow multimodal interoperability. Develop software components for Entitlement Lifecycle functions to manage acquisition, usage and disposal of travel rights
	Orchestration	Specification, Architecture & interface, SW devlopt	Generic	6/7	Reference implementation of orchestration of multiple dialogues and needed mechanisms to support co-modal and inter-modal operations in the booking and ticketing environment (including ancillary services).
	Payment and clearing	Specification, Architecture & interface, SW devlopt	Generic	6/7	Design and implementation of software components to support the operations of ticketing back offices in multi-modal and multi-operators environment, including pricing, payment, clearing, settlement functions. Task will also include business and contractual management aspects.
	Validation and inspection	Specification, Architecture & interface, SW devlopt	Generic	6/7	Focuses on the validation and inspection of the entitlement of the traveler throughout the multimodal transportation networks, in strong relation with TD4.5 "Travel Companion" tapping activities. The task will propose software and hardware components for validation and inspection that facilitate to operate in a variety of modal environment, following different approaches such as card-centric and account-based. It will also aim to offer increased seamless experience for the users when accessing and travelling through the transport networks (e.g. less validation time, less media diversity, less physical barriers)
	Customer relationship management and passenger's rights	Specification, Architecture & interface, SW devlopt	Generic	6/7	Components to manage CRM, passenger´s rights and after sale operations (refunds, cancellations etc.)

The contributors will integrate in a common demonstrator all implemented software components and functions for "Booking & 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 the "booking and ticketing" which will be guarantor of 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 a final release. More information about the scope and the incremental approach is provided in the Milestones table below. The demonstration scenario will take the form of test campaigns for the different system releases. It will cover the full extent of the entitlement lifecycle, the use of multiple entitlement tokens demonstrating multiple validation schemes. Operational scenarios will envision complex cross-providers processes such as refund and claim on intermodal journey as well as fallback scenarios (example given: provider did not meet its commitment when booking or issuing entitlement).

Planning and budget:

TDs	TASKS	TRL	2016								2018				2019				2020				2021				2022			
TD4.3	**Booking & Ticketing**		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
	4.3.0 Technical Management	NA																												
	4.3.2 Entitlement lifecycle software	2 > 6																												
	4.3.3 Commercial management software	2 > 6																												
	4.3.4 Operational management software	3 > 6																												
	4.3.5 Validation management software	3 > 6																												
	4.3.6 Customer relationship management	4 > 6																												
	4.3.7 Technical Releases and support to ITD7	6																												
ITD7	**Integration and demonstration**																													

- milestone
- quickwin
- lighthouse projects
- contracted activites
- planned activities

Table 65: 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, the integration with the cloud wallet and validation 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 & Ticketing, improving the components developed in IT2Rail and providing new functionalities, such as after sales (cancellation, re-fund), 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 com-patible with a MaaS concept, as a result of the works to be accomplished in MaaSive project. This quick win also expects to cover aspects such as cus-tomer relationship and travels 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 the iTD4.7	Demonstration at Innotrans 2022

Table 66: TD4.3 milestones

When	What
Q2 2018	Integration of all features developed in the IT2RAIL project (for detail, see in demonstration activities and deployment) - IT2RAIL : May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRAcKTIVE project (for detail, see in demonstration activities and deployment) - ATTRAcKTIVE: Sept 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 12.2M€

4.4. TD4.4 Trip Tracking

4.4.1. Concept

We are living in a society which is characterized as a mobility world. For humans it is absolute normal to use their possibilities in private transport to travel from A to B or to use ones car to go to work in the morning and back home in the evening. For all those humans it is as well normal to be informed about the actual situations on the streets. You switch on your radio and you will be informed about traffic jam, closed roads, closed exits and so on. In the same way a driver will be informed when he starts his navigation device in his car. The system proposes different routes taking into account any kind of obstacles and barriers. During the trip push notifications inform the driver about upcoming jams providing him with alternative routes. All this is normal for us and we all expect that the systems are working like that.

In respect to public transport we are only at the beginning of assistance for travellers like we already have in private transport. Departure timetables presenting us real time information on stations and airports are working but the missing link is the combination of both. The attractiveness of European Railway lies fundamentally in the capabilities to contribute to the social infrastructure by providing smart and green travel services. With an ever increasing complexity of transport solutions, spanning across regions, operators, infrastructures and modes, irregularities and anomalies in planed journeys need to be identified to provide a traveller with a seamless door to door and barrier free travel experience. Door to door in this respect does not mean to use only public transport instead of private transport but any kind of useful combinations of them whether using car, bus, bicycle, flight or train although with more emphasis on public transport. This will be one the most important steps forward to convince humans to use public transport instead of private transport.

TD4.4 “Trip Tracker” will be the task within Shift2Rail Eco-System that will assist a traveller throughout his multimodal journey with technologies which accurately and timely notify travellers of any foreseen or unforeseen difficulties on their individual trip and offer re-arrangement solutions by providing alternative routes to limit impacts of delays. By shielding the travellers from disruptions, Trip Tracker will contribute to key objectives of the Shift2Rail 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 legged journeys
- Increase trust of the traveller due to reliable real time information

Reduce operating costs
- Operators are released from manually calculating and finding out of new alternative multimodal routes
- Reduction of queues at helpdesks

Externalities
- Increase marketing effect as it keeps the customer up-to-date especially in case of problems for inter cross boarder trips
- Contribution to the objective of greener transport by promoting modal shifts

Respect and adaptations of TSI

- To maximise the journey tracking capabilities adaptations to TAP TSI will be proposed
- Existing standards will be 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 re-organisation of planned timetables across modes but as well access near real-time traffic data. Trip Tracker will also take advantage of the emergence and availability of social media technologies which 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 current status of the transportation means. Objective is to provide the capability to:

1. Identify patterns in the transportation operations and to predict with accuracy future irregularities, thus pre-empting mitigation actions to safeguard the traveller's trip before the advent of the disruption itself.
2. Deduct 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 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 and emanating from sources not necessarily intrinsically 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
Mono modal with services per each mode	Combined services for multimodal journeys
Closed system with high barriers for new business opportunities	Due to the integration of an Interoperability Framework an "unlimited" number of TSP can be taken into account
Dedicated closed modal schemas	Open multimodal schema
Statistical information is partly available for each mode	With the integration of Business Analytics a complete picture of the travel situation is available
Disruptions has to be handled by the traveller	Automatic handling of disruptions including the proposal of different alternatives
Entitlements, tokens and embodiments are valid for a dedicated trip	In addition to the proposal of alternative journeys it will be proofed if existing entitlements, tokens and embodiments of the journey are still valid

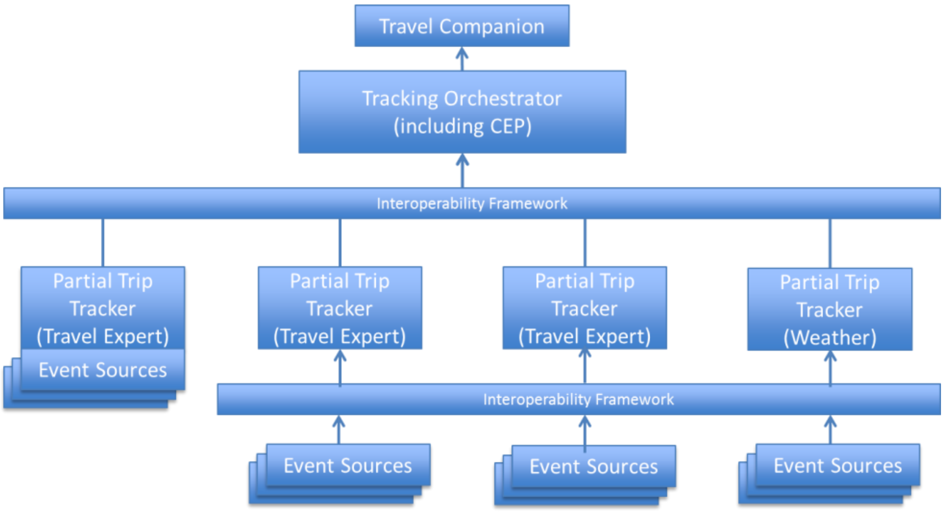


Figure 40: Proposed TD4.4 architecture

Interaction with other TPs

- TD 1.2 → Any train related data which could be relevant for travellers while traveling
- TD 1.6 → detailed occupancy
- TD 1.7 → Display the actual vehicle layout to the traveller
- TD 2.9 → Information with high quality about real time train arrival

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 proof Entitlement/Token/Embodiment (ETE) of the original journey
  - To provide necessary ETE for the chosen alternative route
- TD4.5 CW to
  - Get Traveller data
  - Store information
- TD4.6 Business Analytics
  - Forward information to BA to taking them into account to improve the Shift2Rail 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 improve the quality of services offered to the travellers of European multimodal trips. By improving perceived reliability of the transportation system, especially in the Rail and Urban modes, offering Customer targeted information and re-arrangement mechanisms, and finally allowing operators to enhance the capacity of their infrastructure, Trip Tracker will promote the attractiveness of rail services and contribute to 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. reduced mobility travellers) in order to cope in the most efficient manner with disruptions. Disruptions could be considered as opportunities as they will trigger a 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 will rely on the Trip Tracker services, operators and services 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 to the travellers even more reassurance and limited 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) services, a better understanding of network difficulties, bottlenecks and bypassing strategies will emerge. This will in turn allow operators, services providers and policy makers to optimise their offers and to propose a 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).
Rise convenience to travel	Release the traveller from finding a new route by checking several sources and data bases on his own; automatically calculated new routes will be optimal in respect to costs, time and convenience due to his personal preferences
Support to proof tokens	Release the traveller from the task to check all embodiments, tokens and entitlements on validity regarding a new selected route

This TD will contribute to enable two **Innovation Capabilities**:

Innovation Capability	***TD4.4 Trip Tracking enablers***
2- Mobility as a Service	Trip Tracking will act as a guardian angel taking the traveller by the hand to guide him to his destination if any obstacle occurs. Taking the Interoperability Framework into account a door to door multimodal travel will be observed in accordance the philosophy of Mobility as a Service. 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 for Data	Spread over Europa a huge amount of date for travel services is available, is it time table 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. - 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 & interface, SW developed	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 & interface, SW developed	Urban (MaaS)	6/7	Analyse real-time changes compared to published data/schedules/topologies, identify travel conflict and needs for alternative, inform the traveller, all based on preferences
			Co-modal long-distance journey	6/7	
	Construct alternative itinerary	Specification, Architecture & interface, SW developed	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-Tracking will be developed in two contexts:

- Urban environment in a context of a MaaS approach
- Co-modal long distance journey in which the long-distance leg (e.g. air) is connected co-modally (with independent ticket)

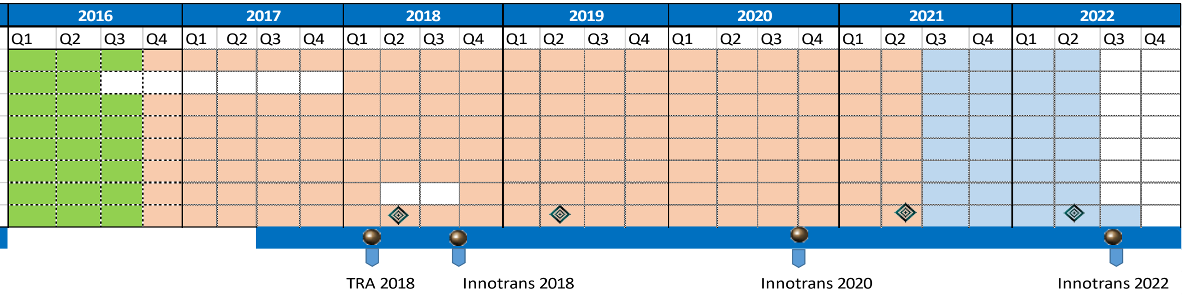
In these two contexts, the impacts of a disruption are rather different (financially and legally), and require different approaches.

The first release has been developed within the Lighthouse project IT2Rail.
The second release is the alpha release delivered end 2018.
The third release is the beta release allowing MaaS which is expected end 2020.

The fourth release is the Final Release expected end 2022).

Planning and budget:

TDs	TASKS	TRL
TD4.4	**Trip Tracker**	
	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 Demonstrator & Support to iTD7	6
ITD7	**Integration and demonstration**	



milestone
quick win

lighthouse projects
contracted activities
planned activities

Table 67: 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 Travel Service Providers mapped to one itinerary • Calculate alternative routes in case of delays or disruptions • Alternative Manager to proof if calculated alternative routes are compliant with real time information
Q2 2019	New Trip Tracking structure that integrates an Trip Tracking Orchestrator and several connected partial Trip Tracker	• Trip Tracking architecture will be split up into a Tracking Orchestrator and several attached partial Trip Tracker • Partial Trip Tracker will consider different methodologies with special event sources o SIRI SX event source o GFTF-RT event source o Prognosis event source component o Mobile Device event source • Provide 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 Tracker • Integration of Interoperability Framework into partial Trip Tracker to include different Event Sources • Proof if all ETE in an alternative route are still valid
Q3 2022	Integration of the Trip Tracking functionalities into the ITD4.7	• Demonstration at Innotrans 2022

Table 68: 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) - IT2RAIL: May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRACkTIVE project (for detail, see in demonstration activities and deployment) - ATTRACkTIVE: Sept 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 8.4 M€

4.5. TD4.5 Travel Companion

4.5.1. Concept

The 21st century travellers have high expectations for efficiency and low tolerance for barriers to mobility. Information technologies have recently made significant progresses especially in the field of mobile applications.

However, a more in-depth analysis reveals that these "apps" are actually very limited. They are indeed very fragmented and do not bridge the gaps between services such as shopping, booking, ticketing, etc. Global seamlessness for door-to-door multimodal travels at European scale, including public transports as well as personal transports, is hence not accessible.

This make 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 a traveller can use to access the whole ecosystem. In this way, he is able to access multimodal transport services through a unique user interface, allowing him 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 enable to guide the traveller reaching the transit checkpoints along the travel journey.
- The online counterpart Cloud Wallet serves as the secured repository for the users' personal information. Storing this information in the Cloud prevents the user not only to re-enter information multiple times but as well enables him to use different devices. 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 represent the main technical objectives of this TD:

1. Provide a Secured Cloud-based platform hosting each travellers' virtual space, including ID, profile, preferences, payment means and tickets, etc.
2. Passenger services that will provide a homogeneous and innovative multimodal user interface enabling travellers to ubiquitously access heterogeneous services to the Shift2Rail IP4 services such as Travel Shopping, Ticketing and Trip Tracking.
3. New forms of location-based experiences aiming to make travels more engaging and attractive for the passengers.
4. Adaptive and seamless indoor/outdoor navigation for the users in transit between modes of transports at interchanges or within infrastructures and transportation means. Navigation function will take into consideration the traveller's preferences and potential 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 on 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 man-machine interfaces, mixed realities, smart devices.	New forms of location-based experiences aim to make travels more engaging and attractive as well as homogeneous and innovative user interfaces enabling travellers to ubiquitously access heterogeneous services such as Travel Shopping, Ticketing and Trip Tracking.
Not all basic services needed to organise a travel are covered	The Travel companion provides access to all services provided by the S2R ecosystem.
Application are mostly dedicated to a specific transport provider	The travel companion is linked the S2R ecosystem and not to transport provider
Share of information between operators for multimodal journey 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
Application are independent from the traveller	The user experience is adapted to the traveller profile which is updated according to the trajectories of the traveller.
Public transport applications do not take into account the location of the traveller	New generation will include a navigation app and the underlying positioning infrastructure supporting indoor and outdoor environments, as well as the seamless transition between both

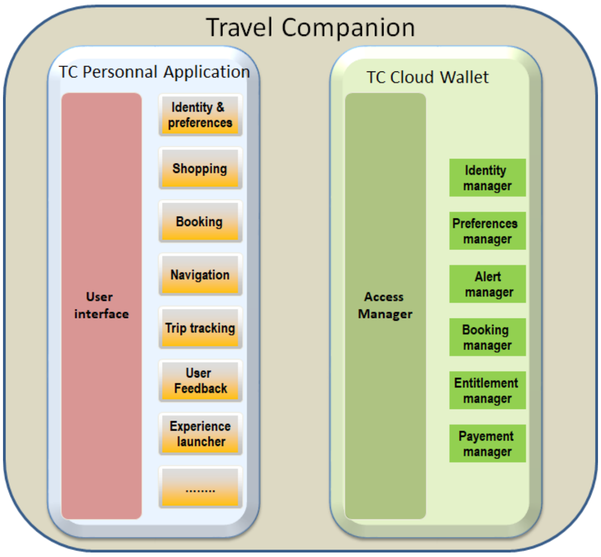


Figure 41: Proposed Travel Companion architecture

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

The Travel Companion is the access point to all services through a homogenized user interface, allowing him to leverage all the capabilities of the system (shopping services, booking services, trip-tracking services, location base services). On that point TD4.5 interact strongly with the other TD of IP4:

- TD4.1 : Interoperability framework
- TD4.2 : Shopping
- TD4.3 : Booking and ticketing
- TD4.4 : Trip tracking

The inter-connections with other IPs are with IP1/ Door & access IP3/stations and to some extent with CCA/social networks. Information from these TDs can be potentially be monitored and taken into account to improve the service provided to the passengers.

4.5.4. Impact and enabling Innovation Capabilities

Strategic Aspect	Key Contribution from the TD
On the economics of the Travel Services Providers ecosystem	The capacity of the Travel Companion to alter for the better the traveller's perception of transportation eco-system and improve the quality and attractiveness of the travelling experience, from door to door, is one of the most significant expected impact. The enhancement of the traveller experience will result in an increase in the use of railway and collective transport, providing benefits to operators and accelerating the adoption of S2R solutions globally
On the creation of a (Digital) Single European Railway Area (SERA):	User-centric services of new generation enabled by the Travel Companion will help ensure not only the emergence of a Single European Railway Area, 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 1st, mid and last mile transport provided by participating public transport authorities.

This TD will contribute to enable 2 **Innovation Capabilities** as follow:

Innovation Capability	***TD4.5 TC 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 a multimodal door to door travel as promoted by Mobility as a Service (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 for data	The data related to the travels of the passenger is a wide amount of varied data including public data, business data as well as private data, long-term data as well as real time data. Taking into account all this fragmented data for an optimized 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 Market	Demonstrator TRL	Focus of activity
Travel Compan-ion	Define the services	Specifica-tion, 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 Plat-form	Specifica-tion, Architecture & interface, SW devlpt	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 execute services;
	Develop the access to Passenger Services	Specifica-tion, Architecture & interface, SW devlpt	Generic	6/7	Develop a wealth of components that will: • enable the interaction of the user all along her/his journey with the Shift2Rail IP4 services • Deliver personalised interactive experiences adapted to each traveller.
	Ensure Ex-ternal Con-nectivity	Specifica-tion, Architecture & interface, SW devlpt	Generic	6/7	Develop the components dedicated to the interaction between the travellers and the Travel Companion framework using smart devices as well as the smart objects (e.g. smartwatch, AR glasses, public displays, ibeacons…) that populate their environment all along their journey.
	Provide Navigation	Specifica-tion, Architecture & interface, SW devlpt	Generic	6/7	Develop the software components for geo-navigation functions available to the users in transit between modes of transports at interchanges or within infrastructures and transportation means. These components will provide adaptive and seamless indoor/outdoor navigation functions taking into consideration the traveller's preferences and potential disabilities.
	Allow De-vice Tap-ping	Specifica-tion, Architecture & interface, SW devlpt	Generic	6/7	Develop the software components that will use the travel rights stored in the travel wallets for validation and inspection purposes by field devices within heterogeneous operators' infrastructures.

The first release has been the IT2RAIL release.
The second release is the alpha release (delivered end 2018).
The third release is the beta release allowing MaaS (expected end of 2020).
The fourth release is the Final Release (expected end 2022).

Planning and budget:

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
TD4.5	**Travel Companion**		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
	4.5.0 Technical Management	NA	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦		
	4.5.1 Specifications and ontologies	5	🟩	🟩	🟩	🟩				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦		
	4.5.2 Secured Cloud-based Platform	2 > 6	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟦	🟦	🟦	🟦		
	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**								🟦	🟦	🟦	🟦 ●	🟦 ●	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦 ●	🟦	🟦	🟦	🟦	🟦	🟦	🟦 ●	🟦
												TRA 2018	Innotrans 2018									Innotrans 2020							Innotrans 2022	

◈ milestone
● quick win

🟩 lighthouse projects
🟧 contracted activities
🟦 planned activities

Table 69: TD 4.5 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 of MaaSive.
Q3 2022	Integration of all the functionalities of the Travel Companion into the ITD4.7	Demonstration at Innotrans 2022

Table 70: TD 4.5 milestones / Projects

When	What
Q2 2018	Integration of all features developed in the IT2RAIL project (for detail, see in demonstration activities and deployment) - IT2RAIL : May 2015 until April 2018
Q2 2019	Integration of all features developed in the ATTRACkTIVE project (for detail, see in demonstration activities and deployment) - ATTRACkTIVE: Sept 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 12 M€

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.

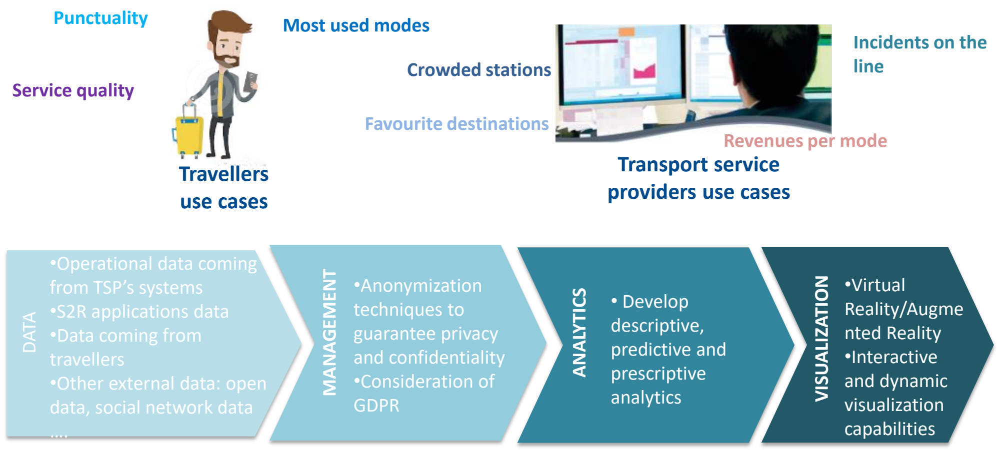


Figure 2: Business Analytics overview

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 Shift2Rail transport product and service providers based on the access to open-ended web of transportation data offered by the Interoperability Framework (TD1). More specifically, the expected results are:

1. Provide to all Shift2Rail transport product/service providers a common business intelligence foundation to monitor IP4 target strategic indicators, structured in execution / operational KPIs, and to manage service lifecycle for continuous improvement of rail-centric travel experience of European travellers.
2. Enable decision tools for rail and multi-transport operators (and all S2R eco-system service providers), with planning, monitoring and reporting capabilities from data collection, filtering, and analysis to build end-user travel and transport intelligence.
3. Synthesize Big Data in Travel-Transport Analytics over multisource channels for Rail Business Executive (Sales, Marketing, and Customer Service) and Mobility & Traffic Management Control Rooms (Operation support for passenger's mobility and freight logistics).
4. Collect historical business data (within IP4, from Ticketing) and travellers behaviour on all channels (mobile, social, web,) (within IP4, from Travel Shopping, Companion, Tracker, …) to allow clearing-house among operators, as well as dynamic personalized service in real time (in memory-computing).

4.6.3. Technical Vision

The general ambition of Business Analytics (TD4.6) is to propose a general platform and a set of tools allowing a better analysis of the passengers flow in the network, in order to improve the operations with adapted transport means, or with adapted offers (tickets less expensive at some hours, coupling of transport tickets with specific event…).

Data Warehouse, Customer Database and single mode business optimisation strategies and tools exist today only internally to single Transport Operators (Rail or Public Transport), making not possible a multimodal, door-to-door trans-European Green Mobility Intelligence.

Furthermore, some recent and powerful tools like Big&Open Data capability 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 & Transport Operators.

Critical Operator Infrastructure Data Security and Travellers Information Privacy are not often guaranteed, and it is not possible to propose and deliver seamless travels, as all partners work on different datasets.

State-of-the-art	Advances of the 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 load, recovery, manipulation and analysis of data
Analysis of personal data not considering carefully privacy issues. Much more constraints with GDPR, operational in 2018	Development of different anonymization techniques and strategies to guarantee privacy
Data availability: in a multimodal environment, with different transport service providers, data collection is challenging	Development of a Digital Twin World based on a realistic synthetic world with data generation techniques based on machine learning.

State-of-the-art	Advances of the Business Analytics
Analytics based mostly on KPIs and statistics 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 understanding by human operators based in particular on virtual reality

Interaction with other TDs (of the same IP and/or of the 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 the passenger.

4.6.4. Impact and enabling Innovation Capabilities

The main benefits that the Business Analytics platform will bring include:

- On the economics of the transportation ecosystem.

By providing a detailed and unprecedented understanding of the complex dependencies within the fragmented transportation ecosystem, the business analytics platform will allow public transport operators to better allocate their funds (on more precise items or on more efficient investments) resulting in lowering the costs of operations and increasing service availability. This will reinforce the capacity to anticipate potential crisis and better prepare 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 travellers-operators relationship.

By allowing passenger feedback to be taken into account, the business analytics platform will place the traveller at the centre of the transportation eco-system. Being proactive, the traveller perceived influence on the eco-system will foster a change of attitude toward the transport services. In the same way the business analytics platform will initiate a first answer to the complex environment of public relationship for the public transport operators. Although public transport operator have Customer Relationship Management (CRM) that allow them to define their commercial policies, the social network capable intelligent tools provided by the business analytics platform will allow the transport operators to leverage the social network capacity to involve their customers and build a smarter customer relationship.

- On the access to top-talent skilled resources

The business analytics technologies join together many complex technologies and IT services which are now being extensively developed in academic environments as an area of excellence and future major economic growth. The natural association of transportation ecosystem with business analytics in order to work with the very large amount of data produced by the systems across Europe will generate demand for innovative technology solutions and turn the Rail Travel Industry into an attractor of top talents, which in turn can contribute to its self-sustained ever-greening. Creating intelligent mobility services and the ICT applications to support them will become at least as gratifying as working in advanced 'pure-internet' services.

Strategic impact:

Strategic Aspect	Key Contribution from the TD
Improved perceived reliability	By providing the tools for operators and services providers to monitor, analyse and understand global travel flows associated not only to their own services but, critically, across the entire ecosystem, Business Analytics will offer the capability to model resilient travel multimodal services, adapted to the wide variety of travellers' profiles and infrastructure environments, thus increasing the 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 user's typology, preferences, payment patterns, etc., will allow the transit agencies to offer innovative transport products better matched with demand.
Enhance Capacity	With better insights in the travels 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 congestions at stations and hubs.
Lower investment costs	As business analytics platforms offer valuable insights and feedback on services provided, they provide competitive edge and are fast becoming a necessary management and decision tool for the transportation 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 current high investments necessary to benefits from those services.
Reduce operating costs	With capability from the business analytics to perform predictive analysis on a vast amount of transport data, operators will foresee with greater accuracy required adaptation of their infrastructures to meet the demand and evolutions of 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 lifecycle costs and increase revenues.

This TD will contribute to enable one **Innovation Capability** as follow:

Innovation Capability	***TD6.4 Business Analytics enablers & technological building blocks***
4- More value for Data	Through its global analysis capabilities of the European multimodal transport ecosystem, Business Analytics will provide an in-depth understanding of the transport modes usage 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 actors and competitors of the transportation 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 rest of the ecosystem analysis.

4.6.5. Demonstration activities and deployment

Research Area	Specific Techn. objective	Specification Activities	Demonstrator Market	Demonstrator TRL	Focus of activity
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 transport service providers oriented use cases and travellers oriented use cases
	Anonymization techniques	Algorithms	Generic	6/7	Development of anonymization 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	SW components	Generic	6/7	Development of SW components for visual Analytics and for virtual & augmented reality

The first release has been the IT2RAIL. First KPIs and statistics have been computed. And some visualisation based on dashboards has been proposed. Three other releases will be performed:

- The second release is the core release (end of 2019)
- The third release is the beta release (expected end of 2020)
- The fourth release is the final release (expected 2022)

The demonstrator will provide an in-depth understanding of the transport modes usage and will provide useful information for the TSPs and the user.
It will enhance the capacity, providing the TSPs with better insights in the travels 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 congestions at stations and hubs.

Planning and budget:

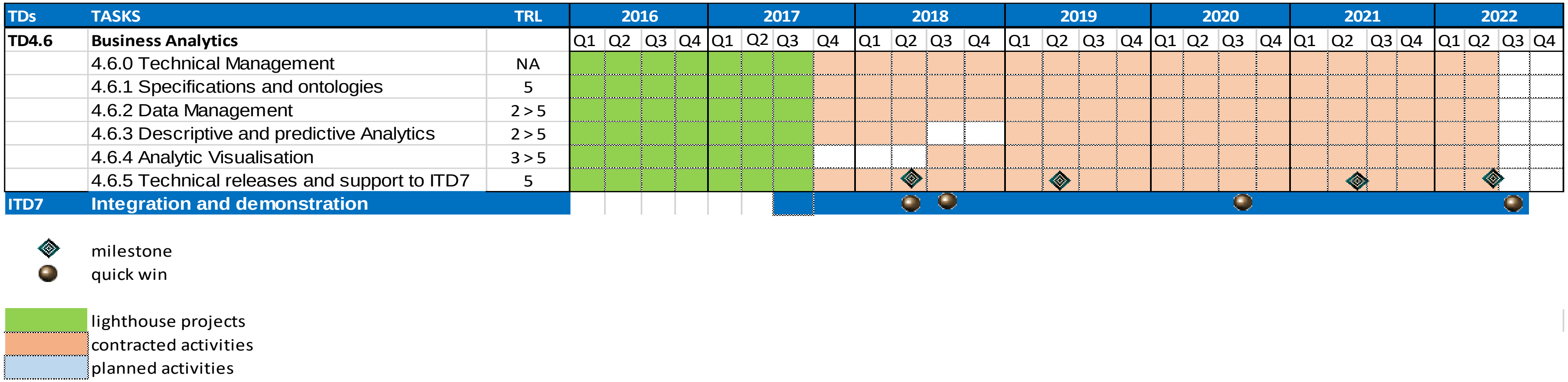


Table 71: TD4.6 quick wins

When	What	Contribution to MAAP (specific per TD)
Q2 2018	Integration of IT2RAIL developments to perform the IT2RAIL final event and TRA 2020	• KPIs 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 anonymization • Big data architecture • Visualization
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 CONNECTIVE project.
Q3 2022	Integration of Business Analytics features during Innotrans event	Innotrans 2022 demonstration will be based on the features of CONNECTIVE project, integrated into iTD4.7

Table 72: TD6.4 milestones

When	What
Q4 2018	Integration of all features developed in the IT2RAIL project (for detail, see in demonstration activities and deployment) - IT2RAIL : May 2015 until April 2018
Q2 2019	Integration of all features developed in the CONNECTIVE project - CONNECTIVE: Sept 2017 until June 2022
Q2 2021	Integration of all features developed in the CONNECTIVE project - CONNECTIVE: Sept 2017 until June 2022
Q2 2022	Integration of all features developed in the CONNECTIVE project - CONNECTIVE: Sept 2017 until June 2022

The estimated total budget for this TD is around 9 M€.

4.7. ITD4.7 Overall IP4 Coordination and demonstration

4.7.1. Concept

The attractiveness of the European Railway lies fundamentally in its capabilities to provide smart and green Travel services as a mean to engage in commercial, cooperative and leisure activities. It relies on an efficient railway network, but also on a better integration of this network in the overall mobility ecosystem, by providing to the passengers an attractive and seamless access to all the services supporting their multi-modal journey. Whilst IP4 aims to offer this attractive and seamless access through 6 Technical Demonstrators encompassing all IP4 research areas, the Integrated technical demonstrator (ITD4.7) ensures the overall IP4 technical synchronization and the consistency of the developments made in the IP4 TDs, and maximizes the IP4 impact by proposing end-to-end demonstrations.

4.7.2. Technical Objectives

The integrated ITD4.7 is significantly different from the other TDs as it will not provide ground-breaking technologies or concepts, but will orchestrate the implementation in a consistent, coherent and transparent manner, and will deliver an overall demonstrator that satisfies the IP4 community and meet the Shift2Rail Master Plan objectives.

The ambition of ITD4.7 is to foster a coordinated effort in the deployment of innovative IT solutions for the transportation ecosystem: to bring together through a global technical framework multimodal travel services (such as Travel Shopping, Booking & Ticketing, Trip Tracking) at the European scale, and to integrate those in a “unique ID” Travel Companion 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 a smooth synchronization 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 share 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 Shift2Rail community and toward 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 transportation ecosystem, but also to create a complete technical enabler encompassing the innovations of each TD in reference implementations. As such, convergence of integration, testing and verification activities, will allow to build a functional and representative IP4 ecosystem with the objective to reach a global Technical Readiness Level 6 (TRL6) 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 full multimodality including ticket shopping is still mostly mono-mode 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, allows for any choice of the syntax used for representation of its terms and allowing that exchanged messages are unambiguously defined and understood by different systems;
Interoperability is often handled via the definition and agreement 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 one rules and interoperability is reduced or none.	Use of ontologies and semantic web to provide open components and interfaces to registry and connect elements and standardize the way they interoperate with the IF;
The variety and number of different systems and processes available, for example in a city the reasonable size, makes it difficult to understand the transportation network as a whole and to extract information to better understand and improving it benefiting 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 spatiotemporal 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 (of the same IP and/or of the other IPs)

Within IP4, ITD4.7 will be mainly involved in interactions with other TDs.

The interactions will be general will 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 Demonstrator
    - On-board information management and distribution and , systems interaction
    - Use of train to ground communication for PIS interaction
- TD1.6: Doors and Access Systems Demonstrator
    - Interaction for information exchange (counting, flow, occupancy)
    - Information to support people with reduced mobility
- TD1.7: Train Modularity In Use (TMIU)
    - In-train layout and mobility information to passengers
- TD2.9: Traffic management evolution
    - Traffic status information to support Passenger Information services
- TD3.11: Future Stations Demonstrator
    - How to address Information related to the station such as people flow, accessibility, guidance or emergency management

Figure 42 depicts the main interactions between IP4 TDs and other IP TDs

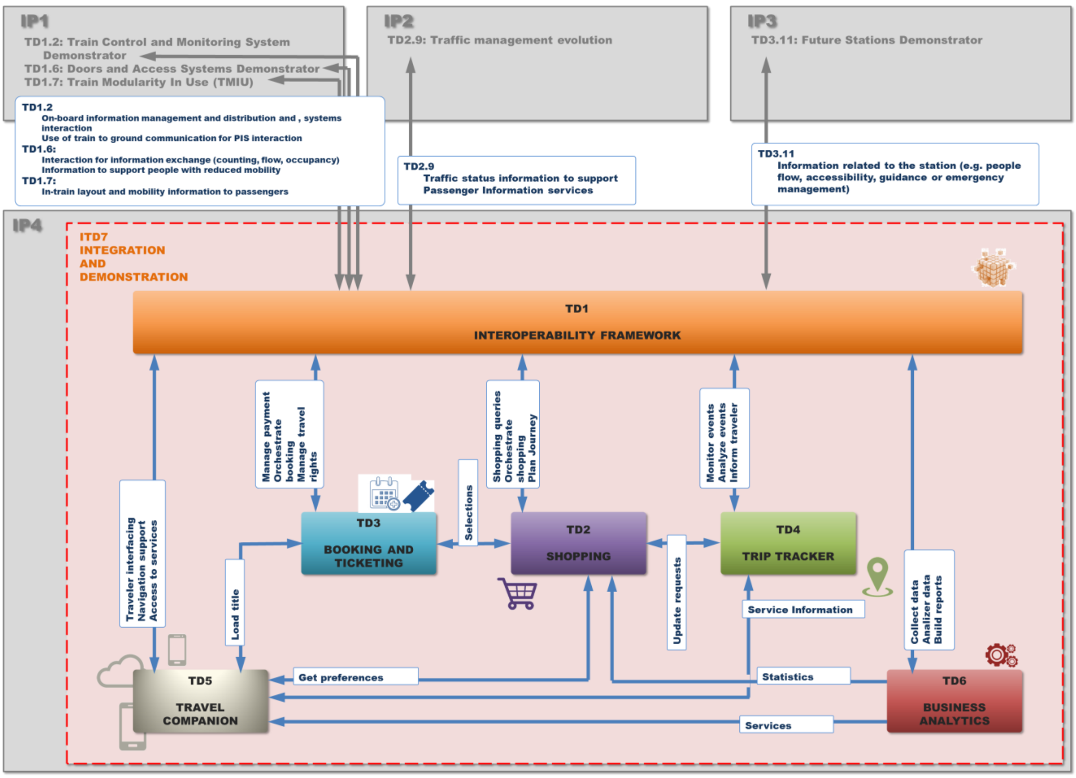


Figure 42: Interaction with other TDs and IPs

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, due to the complexity and scale of the market, ITD4.7 will allow a more effective transition of the transportation ecosystem to IP4 disruptive and innovative technological concepts. By including a wide base of stakeholders in the consistency works, principles will be shared and accepted in 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 in the speed of adoption by the market. Moreover, the dissemination of the overall approach towards the transport community will be monitored by ITD7.

- On the consistency of engineering approach & deliverables:

ITD4.7 will allow a common approach to the description and implementation of overall IP4 open specifications, conceptual architecture by each Technical demonstrator. This will result in a more effective, globalised engineering approach and consequently on the production of deliverables more widely recognised and accepted by stakeholders. An indicator of this impact could be performed through standard engineering progress indicators (requirements, stability, etc.)

- On the convergence of a global IP4 technical demonstrator:

To demonstrate the satisfaction of the objective for an overall IP4 demonstrator integrated, verified and validated, 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 indicator (percentage of requirements tested, defects and change management, etc.), standard validation progress indicator (percentage of use cases demonstrated, percentage of functions accepted, percentage of acceptance by Stakeholders and 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 a faster entry point either for testing existing solutions and/or, due 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 that can be further streamed 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 to travellers

The nature and scope of the ecosystem will be wider than current approaches, including not only multimodal travelling information needed for routing from all over Europe but also knowledge from previous travellers and links to attraction centres; Since the traveller will be directly linked according to his/her expectations and will receive personalised answer or alerts he will have a clear perception of better accuracy of the information received; The reliability in the contents, since through the framework and operational modes the data providers will still have a control on the interpretation of the utilisation of their data.

Strategic Aspect	Key Contribution from the TD
Coordinated integration	The ITD will focus on the technical monitoring and synchronization of the different CFM IP4 projects to guarantee aligned progress of the various TDs enabling the different releases and demonstration phases to reach the objectives
Integrated consistency engineering management	ITD4.7 will focus on the building an engineering methodology and on the strategies to ensure robust engineering processes and methods. Associated to these processes a set of documents will be addressed to cover aspects shared by the different TDs encompassing comprehensive lists of terms, acronyms and concepts. By identifying high level requirements and harmonizing ontologies and interfaces ambiguity and inconsistencies will be minimized guaranteeing uniformity of integration and the interoperability and openness needed to have successful demonstration of the integrated concept

This TD will contribute to enable […] **Innovation Capabilities** as follow:

Innovation Capability	***ITD4.7 enablers***
2- Mobility as a service	*The integrated environment opens the opportunity to create seamless access to mobility services. This TD integrates all Building Blocks for Capability Mobility as a Service*
4 – More value for data	*The data acquired from traveller interactions for example for trip planning, booking and follow-up is a valuable source of information related to mobility. This TD integrates all Building Blocks for More value from data*
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, the integration of successive batch of results coming from the IP4 TDs. To reach 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 as well as Agile software development approaches.

The initial phase of each release includes:

- Evaluation results of the previous iteration, if any; identification of requested evolution and/or correction;
- The identification, definition, or refinement of specific use-cases, which can be supported by the activities performed in parallel by the others projects.

The results of this initial phase are used to interact with the other IP4 projects, in order to freeze the technical specifications, the features and the technological choices.

Research Area	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
Integration/ Demonstration	Use cases definition	Specification of consistent use cases	Generic	6	Definition of consistent use cases that may cover the different components and functionalities that will be used
	Components and interfaces specification	Coherent specification of interfaces	Generic	6/7	Definition of a coherent set of components' functionalities and adequate specification of the needed interfaces
	Modules and components integration	Consistent specification of interfaces and interactions	Generic	6/7	Integration of the different components to guarantee consistency 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:

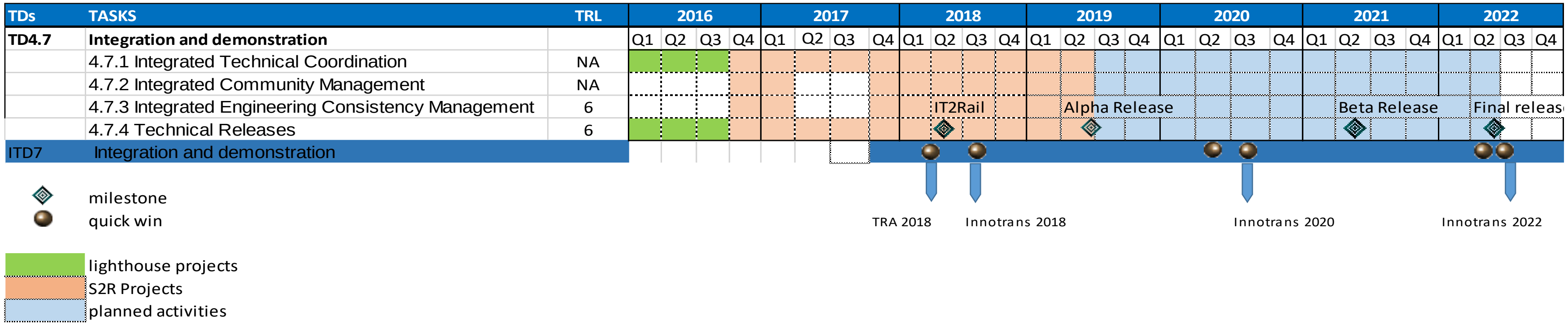


Table 73: ITD4.7 Milestones

When	What	Contribution to MAAP
Q2 2018	Integration of IT2RAIL developments in the ITD7 demonstration First presentation of the concept aiming to raise awareness among on the sector. A prototyped version will be presented	Demonstration of the initial set of functionalities integrated in a stable environment
Q3 2019	DeIntegrating the outcomes of the ATTRACkTIVE, Co-active and Connective projects	Demonstration of the Alfa release functionalities
Q2 2021	Integrating the Connective and MaaSive Projects, aims to demonstrate the evolution of the developments in IP4 towards a MaaS concept	Demonstrations of the Beta release functionalities
Q2 2022	Integration of all the outcomes of the IP4 projects. Demonstration in real en-vironment	Demonstrations of the Final Release Functionalities

Table 74: ITD4.7 Quickwins

When	What	
Q2 and Q3 2018	Seamless multi-modal door to door Travel	Demonstration of the first release with integrated functionalities in TRA 2018 and Innotrans 2018
Q2 2020	Integrated multi-modal ecosystem	Driven by the Alfa release from ATTRACkTIVE, Co-Active and CONNECTIVE eco-system which enables pan European intermodal travels
Q3 2020	Towards the MaaS concept	With support of MaaSive and Shift2MaaS (use the content of the Alfa release + MaaSive CREL) eco-system which enables also 1st 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 pre-final release. scalable eco-systems which enables pan European intermodal travels 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 eco-systems enables pan European intermodal travels and MaaS, including cross-platform approaches

The estimated total budget for this TD is around 7M€.

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 in the past decade 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 to 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 nature, which impact 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 trains hours;
- long- and unreliable lead-time in terminals, hubs and marshalling yards accompanied with high operational costs and lack of synchronization of different operations;

- low reliability and high operational cost 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 of operational costs and of LCC for Assets and infrastructure;
- limited train weight, length and speed due to limits in the strength of standard couplers and propulsion concepts of locomotives as well as due to limits in the railway infrastructure capabilities;
- low performance and flexibility in serving the first and the last mile in single wagon traffic;
- restricted payload-deadweight ratios, especially in the market most emerging segments of containerized single goods transports;
- missing electrification of freight wagons to benefit from intelligent sensors and communication systems;
- Partial or no visibility of goods towards shippers and end-customers due to not integrated data processing along the supply chain.

The members participating in IP5 are convinced that a significant share of the issues mentioned above is 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 TSI implementation, which prescribes standardized data exchange platform between stakeholders;
- Lack or restricted interoperability among 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 two-fold:

- To acquire a new service-oriented profile for rail freight services based on excellence in on time delivery at competitive costs, interweaving its operations with other transport modes, addressing the needs of the clientele among others by 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 in the logistics value chain. Reliability, lead times, deliveries on-time and in full, frequencies and cost must meet customer requirements for different goods segments. Investments in rail innovations should be compatible with anticipated 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 and integrate new developments that are impacting other parts of the logistics chain, in particular digitalisation, which can help to drastically reduce LCC and operation costs, as well as novel processes and technologies such as 3D printers or FAB-LAB capacities or blockchain.

Standardized 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 pre-condition. For making use of innovative applications, technologies and processes, and towards a 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 due to 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 holistic system approach where 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 is also be instrumental for 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.

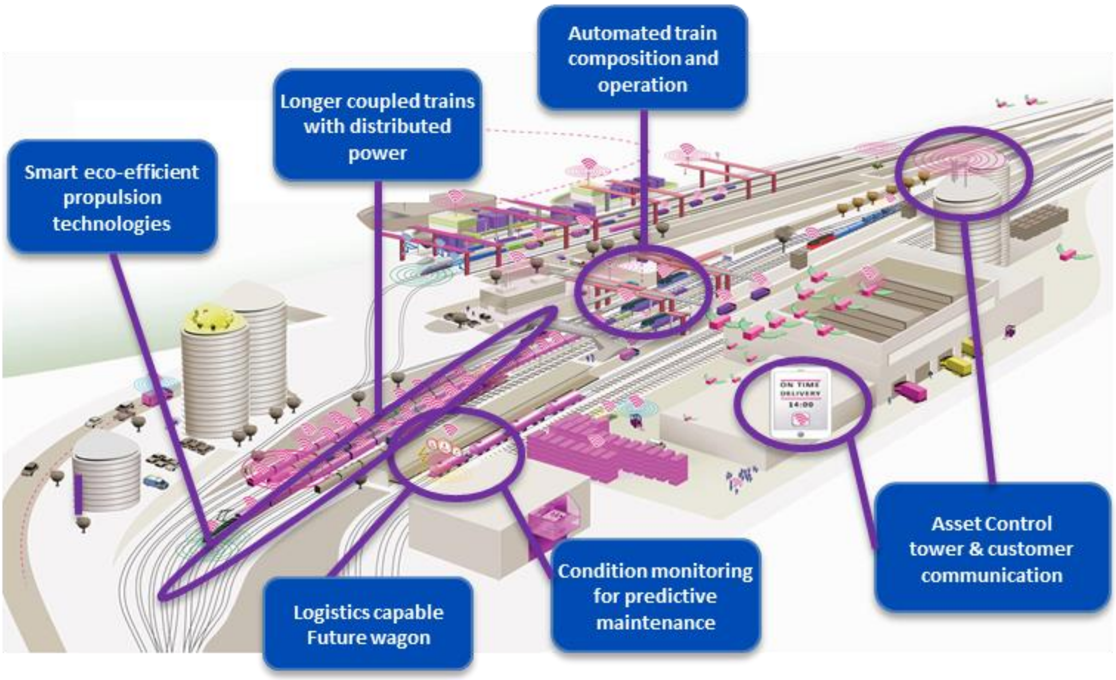


Figure 43: Vision picture of IP5

In particular, the huge potential offered by digitalisation, built on the 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 are expected to raise productivity, reliability and reduce cost dramatically.

Automation in train composition and operation are 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 lifecycle-costs 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 respective TDs 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 regards to TAF/TSI must be followed by each TD in 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.

Objective	Result	Practical (concrete) Deliverable
Capacity increase	Wagons with optimum pay-load, maintainability, lower noise and track attrition. Flexible, faster train compositions & decompositions, and shunting. Environmental 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 & virtual coupling
	Better control on the wagons, the train and its actual 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 analysis Developed propulsion
	Smart operation and on-line information systems	Combination of border crossing path allocation and slot planning & dispatching real time data processing Improvement of the 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
Railway system life cycle cost reduction	Faster Return of Investment (ROI) of the 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 needed number of vehicles for a given capacity	Vehicles with increased productivity and availability will produce more and have less down-time.

Objective	Result	Practical (concrete) Deliverable
	Reduction in the cost of vehicle maintenance	Modern and reliable system architectures and component technologies Better and more standardised on-line monitoring of actual condition
	Reduced wear and tear of the infrastructure	Track friendly vehicles with better running properties. Smoother running
	Reduction of damage of the infrastructure	Sensors noting abnormal circumstances
	Reduction in the energy consumption	As defined below
Energy Efficiency	Lighter wagons	Modern modular wagon design Distributed braking allowing for reduced tare weight Monitoring of the running properties
	Reduction of 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	

Table 75: Objectives and challenges of IP5

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 Picture of IP5 and the concrete project work on task and sub-task level.

MAAP level | **Project level**

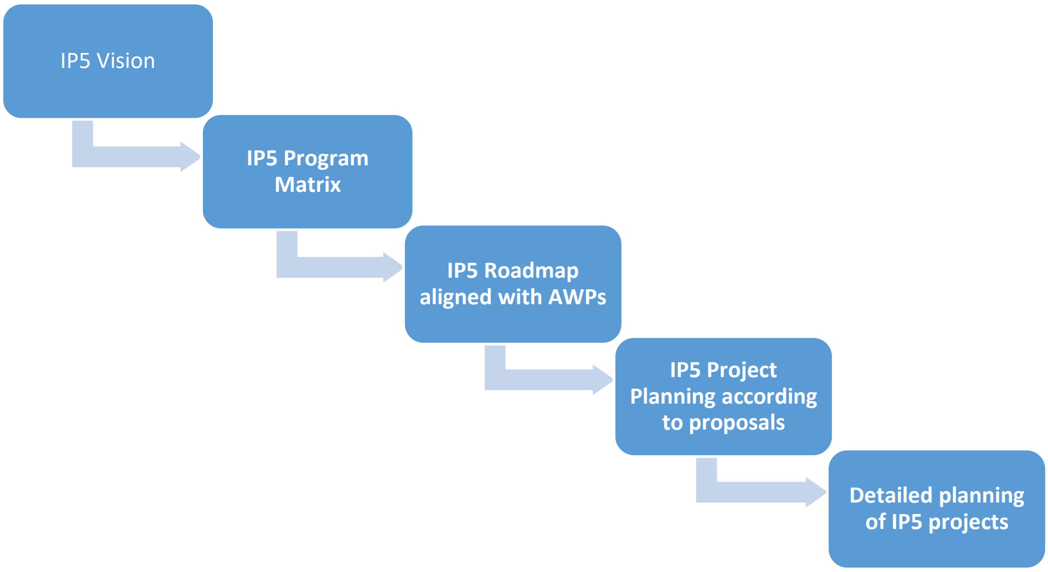


Figure 44: IP5 steering hierarchy

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 the 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 Shift2Rail. 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.

Input to the Vision	Freight wagon	Freight locomotive	Infrastructure (incl. IT infrastructure)
Input to "Automated train composition and operation" *incl. yard/terminal*	• Wagon condition monitoring • Wagon load monitoring • Wagon identity • Technical concept automated coupling + potentially prototype • (Train integrity control) • (Optimized train dynamics)	• Radio remote control of a locomotive • Automated couplers of a locomotive • Functional integration of DAS/ ATO on board • Obstacle detection • Interface to Traffic management for ATO/ C-DAS	• Integration concept to connect yards and terminals in the network • Train with wireless backbone for communication services on board, incl. 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, incl. IDs and load schemes • Damage control in terminals
Input to "Longer trains with distributed power"	• Technical concept automated coupling + potentially prototype • Brake control • (Light weight construction)	• Radio communication with no "shadows" • Control of the slave locomotive • Optimized train dynamics incl. Coupling/ Loading concepts • Intelligent end-of-train device	• Train with wireless backbone for communication services on board, incl. EOT
Input to "Smart eco efficient propulsion technologies" *LOCO*	• Low friction running gear • Wagon design optimized 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 & tear, track friendly • battery-relevant lifecycle, lower LCC • modular design	• Network Management system connected to TMS maximising energy efficiency for entire network

Input to the Vision	Freight wagon	Freight locomotive	Infrastructure (incl. IT in-frastructure)
Input to " Asset control tower & customer com-munication"	• Wagon condition mon-itoring • Wagon load monitor-ing • 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 fre-quency of information sent from assets • Clarification of infor-mation forwarded to the operator • Demonstrate interop-erability between IT pro-duction applications of different suppliers
Input to "Condi-tion monitoring for predictive maintenance" *incl. depots*	• Wagon condition mon-itoring • Wagon identification • CBM-Method, pro-cesses, roll-out new maintenance regime	• Sensors and OBU for condition monitoring • reduction of lifecycle cost through future loco design	• Backbone for wireless communication on the train • Definition of overall IT infrastructure • Common understand-ing of the processes for condition-based mainte-nance • Applications for live data analysis • Condition-based maintenance regime
Input to "Logis-tics capable fu-ture freight wagon" *WAGON*	• Light weight for higher payload • Low noise running gear • Low wear & tear, track friendly • Capable to communi-cate automatically • shorter lifecycle, lower LCC • modular design • market relevant top speed • operational concept for new markets • automatic coupling	• Concepts for gathering data from the wagons on the locomotive • Interfaces between lo-comotive and freight train (mechanical, elec-trical, data)	• Wireless backbone for wagon monitoring • Clarification of data in-terface between wagon and locomotives Railcar communicates with terminal

Table 76: IP5 Programme Matrix

The programme break-down in the matrix provides a view on what IP5 does in order to jointly reach the vision, within the Shift2Rail lifetime. It serves to identify interfaces between the locomotive, the wagon and the infrastructure which 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.

Freight wagon	Freight locomotive	Infrastructure (incl. IT infrastructure)
• Running gear **• Core market wagon 2020** **• Extended market wagon 2020, incl. OBU's for wagon monitoring and cargo monitoring sending communication to landside**	• Distributed power technology • Radial steering of bogie • Last mile application with homologated Li-Ion battery • Hybrid powertrain prototype for real operation • Hybridization 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

Table 77: Overview of planned demonstrators

Past and ongoing European & 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. Shift2Rail 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 etc. Furthermore, they will seek links to the CAPACITY4RAIL project and to the project SMART RAIL.

Set-up and structure of IP5

Structure of the IP

The IP is structured in 5 TDs with the ambition to deliver demonstrations at TRL 6-7. The main red thread is a more intelligent equipment and automated processes and operations, with digitalisation as an enabler.

The five TDs are axed 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. Below the overview of the TD structuring, highlighting the changes compared to the previous version:

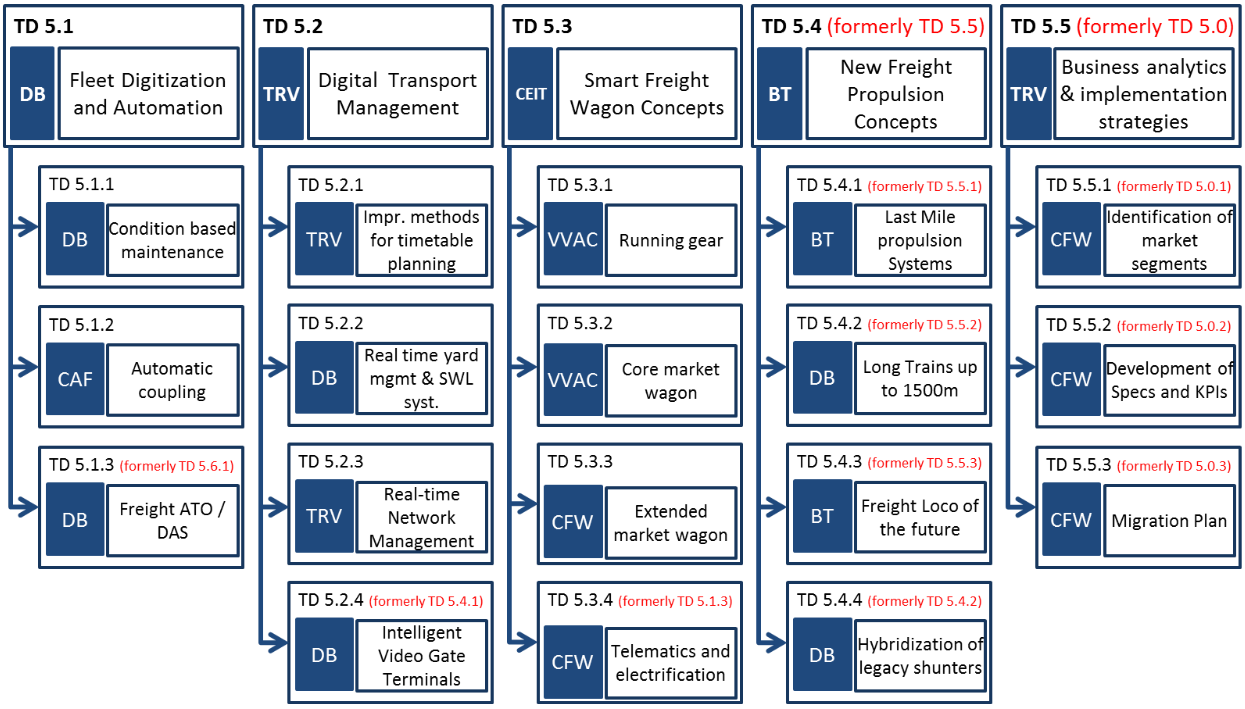


Figure 45: TD structure

Links to other IPs

There are increasing synergies in IP5 within its TDs, as well as with regards 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 demonstrator*				x	
	TD1.3	*Carbody Shell Demonstrator*				x	
	TD1.4	*Running Gear Demonstrator*			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 & Crossing System Demonstrator*			x		
	TD3.2	*Next Generation Switch & Crossing System Demonstrator*			x		
	TD3.3	*Optimised Track System*			x		
	TD3.4	*Next Generation Track System*			x		
	TD3.6	*Dynamic Railway Information Management System (DRIMS) Demonstrator*			x		
	TD3.7	*Railway Integrated Measuring and Monitoring System (RIMMS) Demonstrator*			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 socio-economic research*					x
	WA6.2	*KPI method development and integrated assessment*					x
	WA6.3	*Safety, Standardisation, Smart Maintenance, Smart Materials & Virtual certification*	x		x		
	WA6.4	*Smart Mobility*	x	x		x	

	WA6.5	*Energy and Sustainability*	x	x	x	x	
Input from Forerunner 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 TD´s of IP5 take into account the work on on the S2R system architecture performed in IPx.

The Technical Demonstrators of IP5

5.1. TD5.1 - Fleet Digitalisation 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 reach the goal of a digital railway that boosts the quality on international freight relations and the cost efficiency of rail freight, IP5 introduces the idea of a Digital Single European Railway Area. IP5 sees the stepwise approach to these goals, outgoing from the enablers on the technological level and intelligent assets onward to the process level. In the final evolutional step, these processes will lead to the digital SERA.

The digitalised and automated railway system (TD5.1) builts up on all technical innovations in scope of TD 5.2 “Digital Transport Management”, TD 5.3 “Smart Freight Wagon Concepts”, and TD 5.4 “New Freight Propulsion Concepts”, which focus firstly on freight infrastructure, secondly freight wagons and thirdly freight locomotives. In a systemic view of rail transport, TD 5.1 focusses on such topics, which concern multiple of the three dimensions.

As key technologies to enable a digital and automated rail freight system, TD 5.1 includes the three core topics Condition-based Maintenance (CBM), Automatic Coupling, 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.

TD 5.1 will accelerate the development of the “Digital Railways” towards an overall integrated and highly performant system with the following activities:

- Elaborating the essential building blocks for the digital railway system by paving the migration concept for a **European wide standard for automatic coupling in the freight sector**. This will serve as an catalyser for all Freight train related digitalisation activities, including Condition Based Maintenance and Automated Train Operation;

- Fostering Condition Monitoring and including assets across Europe into the **condition based maintenance activities with the goal of a smart European fleet;**

- Minimizing the energy consumption by **connecting advanced driver advisory systems (C-DAS) on legacy infrastructure to traffic management systems** of the IMs, harmonized across Europe and upwards compatible to future ATO architecture;

- Beyond C-DAS, **t**aking direct control of throttle and brake via an intelligent ATO module, for ETCS-based advanced grades of automation (GoA), which maximize energy-efficiency in safe, predictive mainline operation.

The technical objective of this TD is to develop demonstrators of rail freight digitalisation and automation, including showcases of CBM and ATO. The aim is to actively pursue the objectives of Freight Digitalisation as basis for Automation, realized progressively until 2035 in order to increase railway's competitiveness with road freight, achieve operational efficiency gains and optimised resource utilisation.

5.1.2. Technical Objectives

TD 5.1 has the objective to foster and accelerate 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 (CBM) is in turn an enabler of further condition-based operations and eventually of rail freight automation at the highest grade (GoA 4), which represents the final target state of the IP5 vision according to the MAAP.

The following represent the main technical objectives of this TD:

1. Automatic coupling and decoupling including power, air and data connectivity shall serve the electrification of long and heavy trains for condition monitoring of wagon and goods, electro-pneumatic brake (eP), 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 shall 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 in a first step and built on it fully automatic train operation shall improve current autopilots for mature, target-oriented application in rail freight, improving the quality in terms of punctuality, reliability and flexibility on the one hand, while reducing the operating costs on the other

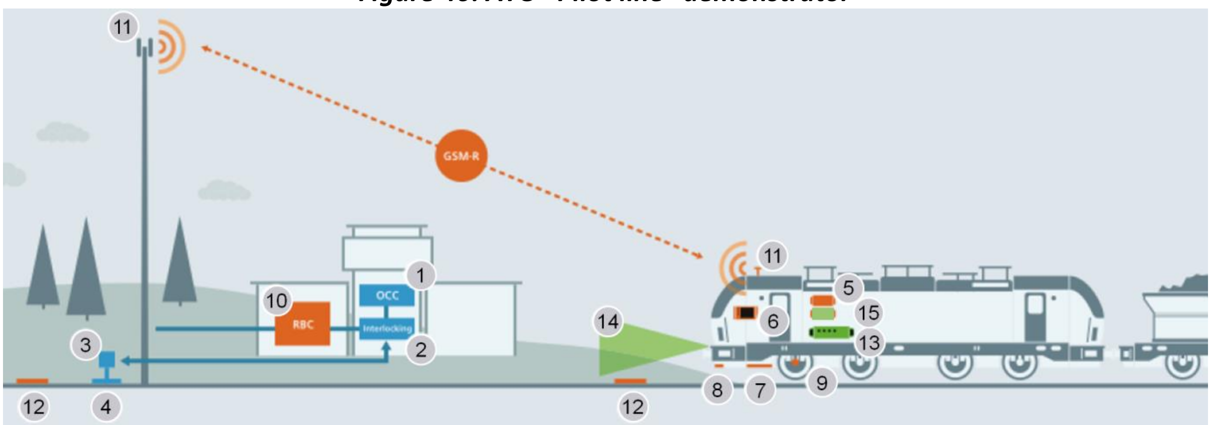
5.1.3. Technical Vision

The vision of Shift2Rail IP5 can be summarized in two words: Digitalisation and Automation. TD 5.1 is a core contributor to this vision.

The Automatic Coupling for European rail freight business is urgently needed as enabler for digitisation and automation and will pave the way for asset intelligence, condition-based operations, automation train operation and train composition. . Asset digitalisation and condition monitoring are essential building blocks for Automated Train Operation allowing the vehicle to be self-monitoring to run in a fully automated mode under European train protection.

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 due to missing condition monitoring data	End-to-end solution for predictive maintenance, including processes, data handling, analytics, dashboards for locomotives and wagons
Personalised expert knowledge and an aging 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 have been implemented so far and are limited to one operator or region	Definition and implementation of an European standard for DAS systems connected to the local traffic management systems, including the required interfaces and a demonstration
Manual train operation where a train driver controls starting and stopping and handling of incidents (GoA1)	Automatic train operation (ATO) where starting and stopping and handling of incidents are fully automated (GoA4)

Figure 46: ATO "Pilot line" demonstrator



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

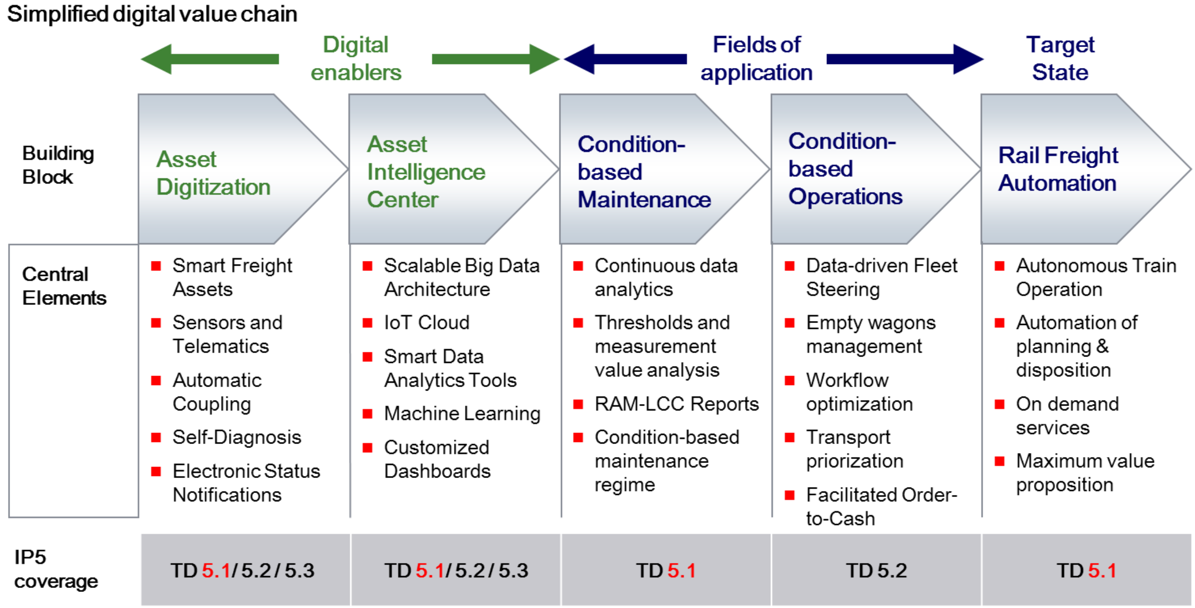
<u>Interaction with other TDs (of the same IP and/or of the other IPs)</u>

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:

- IP5 – TD 5.2 « Digital Transport Management »; interfaces for data communication between locomotive, wagons and data centres
- IP5 – TD 5.3 « Smart Freight Wagon Concepts »; automatic coupling need to be installed on the wagons and will enable telematics and electrification; condition monitoring on wagon bogies overlaps with CBM activities
- IP 5 – TD 5.4 « New Freight Propulsion Concepts »; “Long Trains up to 1500m” researches communication technologies for trains and locomotives that can be applicable for C-DAS and ATO
- IP5 – TD 5.5 « Business analytics & implementation strategies»; migration plans for the uptake of the researched technologies and KPI for measurability of the impact
- IP2 – TD2.2 « Railway Network Capacity Increase (ATO up to GoA4) »: The freight pilot will implement prototypes developed in the scope of TD 2.2.
- IP2 – TD2.3 « Moving Fluid Block »; interaction with the Train Regulation and Traffic Management issues related to ATO
- IP2 – TD2.4 « Fail Safe Train Positioning »; Fail safe train positioning is an important prerequisite for safe ATO operations
- IP2 – TD2.5 « On-board Train Integrity »; constant monitoring of train integrity is a prerequisite for safe ATO operations
- IP2 – TD2.8 « Virtually Coupled Train Sets »; joint understanding how the train regulation and automatic driving can be performed dynamically inside a convoy of train
- IP2 – 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 TD 5.1 and its sister TDs.

Figure 47: Interaction between the TDs of IP5



5.1.4. Impact and enabling Innovation Capabilities

TD 5.1 has a major impact in the Shift2Rail system-level KPIs. The relative weight of the benefits provided by this work are estimated (over a total of 100%) 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 competitive-ness 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: • Provide real time information, alert notifications on goods and/or train conditions ○ Improve LCC (20% reduction), and goods and vehicle real time health monitoring, wagons automation, control and monitoring of dangerous goods. • Improve dynamic train performances, on conventional trains and/or on trains supported by electronic technologies ○ Train setup and uncoupling automation, longitudinal dynamics improvements (reduce 75% damage to the railway infrastructure) ○ Optimisation of service intervals (condition-based maintenance) • Technological leadership supported by the rail freight demonstration of ground-braking technology for the European industry • Tangible benefits 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 will make rail freight automation a priority development
Compliance with EU objectives	• Promotion of modal shift: A big impact brought 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 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 in TRL 3-4. At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 6 to 7. For the recommended pilot showing GoA 2 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 enable the Shift2Rail **Innovation Capabilities** as follow:

Innovation Capability	***TD5.1 Fleet Digitalization and Automation***
1- Automated Train Operation	Automated (passengers and freight) trains run closer together with increased flexibility, optimized energy-consumption, increased punctuality, cost reduction : • BB 5.1.2 Automatic coupling • BB 5.1.3 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 • BB 5.1.2 Automatic coupling • BB 5.1.3 Freight ATO / C-DAS (TRL 6/7)
4- More value for Data	Big Data analytics enables a range of new and improved services to be developed. Secure ICT services, protection of the rail system and business continuity in case of an incident: • BB 5.1.1. Condition-based maintenance (TRL: 6/7) • BB 5.1.3. Freight ATO / C-DAS (TRL 6/7)
5- Optimum energy use	Automated Train Operations (ATO) improves energy efficiency • BB 5.1.2 Automatic coupling • BB 5.1.3 Freight ATO / C-DAS (TRL 6/7)
6- Service timed to the second	Automated recovery from perturbation (a “self- healing” process) quickly restores normal service • BB 5.1.1. Condition-based maintenance (TRL 6/7) • BB 5.1.2 Automatic coupling • BB 5.1.3. 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. • BB 5.1.3. Freight ATO / C-DAS (TRL 6/7)
8- Guaranteed asset health and availability	The Internet of Things (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 Internet of Things (IoT) environment feed the predictive maintenance decision-making process. Artificial Intelligence (AI) supports predictive maintenance decision-making to reduce manual interventions on infrastructure and rolling stock. • BB 5.1.1. Condition-based maintenance (TRL 6/7) • BB 5.1.3. Freight ATO / C-DAS (TRL 6/7)
9- Intelligent Trains	Autonomous trains can monitor and regulate themselves. Communications is possible between trains, between train and infrastructure and between train and freight customers • BB 5.1.3. 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. • BB 5.1.2 Automatic coupling • BB 5.1.3. Freight ATO / C-DAS (TRL 6/7)

5.1.5. Demonstration activities and deployment

The following table summarises the contribution of TD 5.1 “Fleet Digitalization and Automation” to the different ITDs of Shift2Rail are shown in the following table:

	Specific Techn. objective	Specification Activities	Demonstrator		Focus of activity
			Market	TRL	
Research Area	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 to integrate also wagons in the CBM framework, to enable e.g. longer trains (TD 5.4) and train automation (TD 5.1). Automatic coupling will include heavy load, electric and data connectivity and minimize 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, dashboards, for locomotives and wagons. Beyond data handling, statistical and empirical analysis and development of neuronal prognostics, the core innovation of PM takes place at the process level, including new roles and responsibilities in the interaction of the areas asset, fleet and maintenance managemen.

	Driver Information for optimization of speed profile in real-time	Technology, functional requirements, interfaces	Freight	4	Concept development for bilateral communication layout. Development and demonstration of selected Connected Driver Advisory System (C-DAS) functions. Evaluation of effects of selected C-DAS function on capacity, punctuality and energy consumption. Specification of interfaces to external systems (e.g in-terlocking, TMS, maintenance systems) and further innovations planned, e.g. free float optimisation C-DAS
	Freight ATO Max. quality and minimum energy consumption, flexible disposition, reduction of factor cost	Technology, functional requirements, standardized plug & play interfaces and vendor indepent 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 interchangebility 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 Cross-Cutting-Activities have proposed ways to integrate the technical objectives of IP5 in a future ITD in Sweden, where also innovative features of the remaining IP5 TDs shall be shown.

Planning and budget

TDs	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
TD 5.1	**Fleet Digitalisation 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
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 78: TD5.1 milestones

When	What
Q4/19	ATO over ETCS - GOA2 freight specification
Q4/19	GoA2 Pilot Line freight demonstration
Q4/22	C-DAS/ ATO interface assessment

The estimated total budget for TD 5.1 is around 21 M€.

5.2. TD5.2 Digital Transport Management

5.2.1. Concept

An improved accessibility to rail freight and the provision of highly reliable and flexible solutions is of highest importance for the competitiveness of the system, especially in market segments like the 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 a better utilisation of the available capacity.

Within the digitalisation scope 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 better operate 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 in this segment can progress significantly with the optimisation of terminal design and operations – e.g. through improved information transported and better data exchange between involved parties along the intermodal transport chain. The focus will be on train in- and outbound detection, documentation and transfer of wagon and on Intermodal Loading Units (ILU) data.

Important issues are also a greater performance in *total* dwell time/lead time for the transport and a higher grade of accessibility/connectivity as key factors.

5.2.2. Technical Objectives

The following represent 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 to automation processes and customer information via tracking & tracing, routing, combining systems of different operators and transport modes, booking procedures, visibility of available services creating quality improvements of 15%. Dwell times and handling times in intermodal terminals are reduced, reliable throughput is maximized, enhancing intermodal capacity
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 will give 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 in supply chain management, meaning a great benefit for e.g. automotive or chemical customers who rely on just-in-time delivery. Improved customer experience due to 100% reliable delivery of consignments according to 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/less costs of 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 connection the whole chain from nodes to different countries through Europe.
Simplified business processes	Automated processes for trains based on real-time data reduces lead-time by 25 % between RU and IM.

<u>Specific achievements to be delivered by this TD:</u>

1. Improved methods for annual and ad-hoc timetable planning
2. Methods to analyse 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 sensible targets along the route)
4. Improved methods handling larger 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. Standardized data formats / new interfaces in coordination with current TAF/TSI standards
10. Increasing speed of freight trains during day time traffic to increase line capacity
11. Systems for shared usage of marshalling yards between different service providers
12. Optimize 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 intermodal loading units (ILU) handled, as well as visible damages. 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 perturbation and incident management, in order to achieve on-time delivery according to 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.

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 low.	A Real-time yard management system can optimize resource-allocation and connect with external systems to improve network planning.
Intermodal terminals are not making use of the potential of digitalisation. They are not equipped with visual or sensing technology for detection of wagons and ILUs, signs and of damages.	Intermodal terminals will be equipped with video gates for automated detection of incoming and outgoing wagons and ILUs, signs and of damages 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 standardized, based on automated data exchange and transaction. Established standard communication between terminals based on TAF TSI messages.
To improve Real-time network management. There is an automation potential to better handle deviations in timetables and disturbances in operational traffic.	Real-time network management system - improved decision support and digital automation. Today disturbances are handled manual and sequential in many parts of the process. 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 stop and help to increase line capacity and defend and increase market shares.
The flexibility in ad-hoc planning is low	Improved Ad-hoc time-table planning system meets the freight markets 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 of them.

Figure 48: Future Digital Transport Management

The main interaction envisaged, both from the point-of-view of technologies employed and of interaction in performance and objectives, includes coordination with other TDs of IP5, namely TD5.1, TD.3 and TD 5.4 , as well as coordination with IP2 (in particular TD 2.9 for ad-hoc timetable planning, methods handling major disturbances, ETA and Slot issues / Definition of methods, concepts and requirements in IP5 and development in IP 2/TD9, such as optimised speed profiles for ATO / driving style assistant), TD 2.2 and TD 2.4 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 competitive-ness of the EU industry	Standardisation and open systems that can be used everywhere in Europe open up for a bigger market than before. Video gates will Increase degree of automation, operational capacity and reliability of intermodal transport and terminal operation.
Compliance with EU objec-tives	Support to capacity increase: Better planning tools in real time increase the capacity in the lines. Greening of transport through reducing the lead time in yards and optimizing loads on trains. Promotion of modal shift will lead to a big impact brought by the imple-mentation of cost-cutting and performance-enhancing technologies towards a more competitive rail freight offering
Degree of ma-turity of the en-visaged solu-tions	Currently most of the proposed technologies are in TRL 1,2 (Principles observed and the possibility of using them formulated) . At the end of Shif2Rail it is expected that the suc-cessful concepts are brought to TRL 6 or 7.

This TD will contribute to enable 6 **Innovation Capabilities** as follow:

Innovation Capability	***TD5.2 Digital Transport Management***
1- Auto-mated Train Oper-ation	Rail operations are partly or fully automated. New operational approaches are employed. • 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
3- Logistics on demand	Better planning, tracking and shipment information capabilities combine to offer custom-ers flexibility and capacity. Planning and scheduling are synchronised in real-time to cus-tomer demand. Shipments are moved effectively, efficiently, safely and securely through-out the “physical internet” logistic chain. • 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

4- More value for Data	Rail manages a growing volume of data to provide reliable services through optimized operational processes. Secure, robust, scalable and resilient open architecture and protocols allow full interoperability. • 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
5- Optimum energy use	Railways maintain their position as the most environment-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 • 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
6- Service timed to the second	Situational awareness, where each train's location is known at all times and in real-time, supports service operation timed to the second. • BB 5.2.1. Improved methods for time table planning • BB 5.2.3. 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 • 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

5.2.5. Demonstration activities and deployment

The following table summarises the contribution of TD 5.2 Digital Transport Management to the different ITDs of Shift2Rail are shown in the following table:

Research Area	Specific Technical. objectives	Specification Activities	Demonstrator (TRL)	Focus of activity
Digital Transport Management	Improved Methods for time table 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 Terminal (TD 5.4.1)	Specification of terminal design transhipment processes in terminals equipped with intelligent video gate and information management	7	Based on a typical terminal along a European corridor, develop 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 day time traffic to increase line capacity	Simulation of scenarios on freight corridors	5	Focus on simulation with time-tabling systems and evaluation.

Planning and budget:

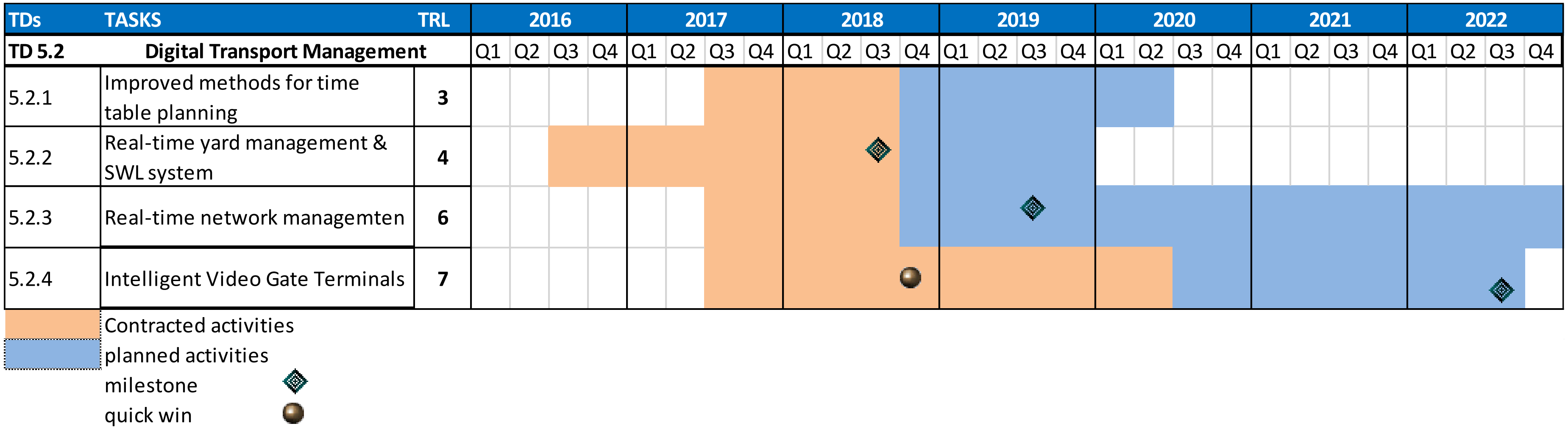


Table 79: TD5.2 quick wins

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 of FR8HUB together with possible other acquisition sensors (e.g. RFID, etc).

Table 80: TD5.2 milestones

When	What
Q3 2018	End of project “real time yard management” the findings will be used in the “network management” and the “intelligent video gate”
Q3 2019	Network management has now identified the communication requirements between the yards and terminals
Q3 2022	End of project network management and intelligent video gate.

The estimated total budget for the TD is around 9.5 MEUR

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 a proactive maintenance.

A new efficient wagon design with better performance for different categories of freight will be achieved leading to a step change within Shift2Rail. A better payload per meter of train is one of the key efficiency factors, as is getting a greater volume per meter of train, particularly for light density freight. High performance freight wagons lead to massive improvements in the rail network 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. A faster transport in the rail sector also means a cheaper transport cost for the freight. The high speed freight wagons will be designed for a maximum speed of 120 – 160 km/h whilst 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 for rail freight automation due to integration of electrification, telematics and automatic coupling concepts. Due to low noise solutions 24/7 freight operation will be possible and the energy consumption will be reduced significantly thanks to 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 car-body design, improved passive suspensions and wheelset steering technologies for higher speeds and track friendliness, capability for advanced diagnosis and monitoring functionalities for increased customer experience and reliability).

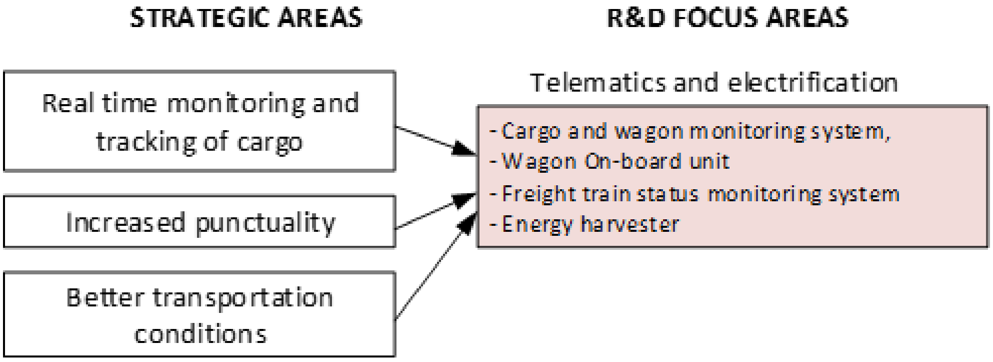
The *Freight Wagon 2020 body for extended markets* aim to increase existing and expand future new market share for cargo transport by application of new technologies beyond state of the art (e.g. reducing weight by using low cost composite materials in the body & chassis design, aerodynamic and acoustic fairing for lower energy consumption and lower noise, system integration to supply intelligence on board for i.e. reefer transports). It will consist of a common chassis with different top units addressing container, groupage and combined intermodal transport needs respectively. A successful opening of market segments which will be identified in TD 5.5.

Previous EU funded projects such as ON-TIME, SPECTRUM, SMARTRAIL, CAPACITY4RAIL have already analysed and identified strategic areas which will enable an increase in the transportation market share. The strategic areas for the 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 of the wagons have to be developed towards the Smart Freight Wagon Concept. Moreover, the introduction of sensors for the wagon monitoring system and a better understanding of the wearing of components, as well as the big data analysis techniques is enabling the better scheduling of the maintenance works [OPTIRAIL 2015]. This is expected to bring reductions in the order of the 10% of the maintenance costs. Therefore, within TD5.3 it is foreseen the development of three focus areas which are illustrated in the next figure:

Figure 48: Focused market areas for telematics and electrification



Technological output to be delivered by this TD:

- Low-noise, lightweight, high speed & track friendly Freight Running Gear
- Freight Wagon 2020 – for core market share increase & extended markets
- Telematics applications and electrification built on TAF TSI standards will provide new and innovative functionalities on real time monitoring and tracking of cargo for logistic purposes and provide information to TMS about the convoy (end of train – EoT), real time conditioned 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 share of the issues addressed in IP5 is due to the limitations in wagon technology, and these limitations lead to uncompetitive offerings to the logistic 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 compared to passenger traffic prevent exploiting the remaining capacity of the network in daily hours while introducing high damage to the infrastructure.
- Payload-deadweight ratios are poor, especially in the most emerging market segments of containerized single goods transports
- Low energy efficiency due to poor aerodynamics and high noise levels due to legacy technology in suspension and braking.
- Missing electrification of freight wagons limits the market access as attractive market segments like temperature controlled transports (reefer market) cannot be served and the digital integration in the leading logistic process is not possible (electronic freight orders and tracking – specially 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 of the 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:

1. Track friendly, low weight, high speed Running Gear (in order to be as flexible as possible for Wagon Designs 2020, but also for other wagon topologies) – *Running Gear*

2. Wagon Design 2020, modifications for core markets- *Core Market Wagon 2020*

3. Wagon Design2020, for increased share and new market segments – *Extended Market Wagon 2020*

5.3.3. Technical Vision

Table 81: 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 & 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 are 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 gears not optimised regarding higher speeds, curving resistance, noise, wheel-rail and track degradation	Wheel and track-friendly running gears 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)
Wagon On-board unit **(wOBU)**	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 WSN services from external systems. Specific communication services will be implemented and deployed over the train wireless back-bone infrastructure in order to fulfil data exchange requirements across train composition. Additionally, it will offer positioning services.
Wagon monitoring system (WMS)	Smart cost efficient sensors HW and SW for wagon components 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 (WMS)	Smart cost efficient sensors HW and SW for cargo monitoring.
Freight train status monitoring system (FTSMS)	Information to the driver about the wagon and cargo status. Display of real time information about convoy composition, integrity (EoT), efficient driving, max braking profiles and noise sensitive driving.

State-of-the-art	TD5.3 Progress beyond state-of-the-art
Energy management system (EMS)	Ultra-efficient, robust, autonomous power generator providing basic cost-efficient freight wagon electrification is attached to a bogie's axle box bearing In combination with an on-board unit and energy-management-optimised battery system, different functionalities like end-of-train device and wireless communication to wagons, loco and ground systems can be developed and integrated

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

The main interaction envisaged, both from the point-of-view of technologies employed and of interaction in performance and objectives, are**:**

- IP5 – TD 5.5 « Business analytics & implementation strategies »; migration plans for the uptake of the researched technologies and KPI for measurability of the impact
- IP5 – TD 5.1 « Digitalisation and Automation Rail System » Condition based Maintenance of Wagon Components incl. driver advisory systems
  based on Components condition and health, Wagon Electrification and Telematics
- IP5 – TD 5.2 « Digital Network Management »; Interfaces for data communication between locomotive, wagons and data centres
- IP 5 – TD 5.4 « New Freight Propulsion Concepts »
- IP1 – TD1.4 "Running Gear"
- IP3 – Infrastructure (TD3.1 – TD3.4. criteria and models for the assessment of track friendliness, TD3.6 – TD3.7 measuring, monitoring and maintenance)

5.3.4. Impact and enabling Innovation Capabilities

<table>
<tr><th>Strategic Aspect</th><th>Key Contribution from the TD</th></tr>
<tr><td>Support the competitiveness of the EU industry</td><td>Technological leadership through intelligent freight assets:

Improved customer services and quality

Modular Interoperable lightweight Wagon Design
Intelligent Wagon Concept with real time condition and health monitoring functions
Smart Wagon Integration in asset management systems

Reduced total costs of ownership

Condition and Predictive Based Maintenance
Wheel/Track friendly design
Automation of manual services on a wagon (e.g. enabling a automatic brake test)

Maximized Interoperability through standardization 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

Provide real time information, alert notifications on goods and/or train conditions

Improve LCC (20% reduction), and goods and vehicle real time health monitoring, wagons automation, control and monitoring of dangerous goods.

Enable trains to interact and exchange information with Ground Systems

New non-conventional train configurations validation before service tests (time reduction 10%-50%). Improve reliability since better ETA estimation

Improve dynamic train performances, on conventional trains and/or on trains supported by electronic technologies

Train setup and uncoupling automation, longitudinal dynamics improvements (reduce 75% damage to the railway infrastructure)
Optimisation of service intervals (condition-based maintenance)

Reduction of energy consumption through efficient driving profile based on real time traffic information and actual convoy characteristics (10% reduction).
</td></tr>
</table>

Strategic Aspect	Key Contribution from the TD
Compliance with EU objectives	• Promotion of modal shift: ○ Wagon Design for integrating it in multi-modal goods/wagons transhipment concepts supporting the modal-shift ○ A big impact brought by the implementation of these new technologies by demonstrating the economic benefits of new improved logistics making rail freight more attractive • Maximize Capacity ○ Modular lightweight freight wagon design with increased payload and platform wagon frame ○ Wheel- and track-friendly running gears for higher speed and low-noise with interfaces to vehicle & 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 minimization of cost od operation 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 method ○ Noise reduction and wheel- and track friendly running gears for lowest wear and tear ○ Larger volume/higher payload improves utilisation of the wagon, resulting in the relative reduction in needed number of vehicles of given capacity • Enhance Interoperability ○ Increased standardisation of wagon frames and running gear for different segment together with vehicle & goods status and localisation • Simplified business process (speed-up market entry) ○ Virtual development and certification, multidisciplinary optimisation • Greening of transport through energy reduction and lower noise can be achieved by providing information with 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 in TRL 3-4. At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 6 to 7.

This TD will contribute to enable the Shift2Rail **Innovation Capabilities** as follow:

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" logistic chain • 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
4- More value for Data	Secure, robust, scalable and resilient open architecture and protocols allow full interoperability • BB 5.3.2. Core market wagon • BB 5.3.3. Extended market wagon • BB 5.3.4. 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 • BB 5.3.2. Core market wagon • BB 5.3.3. Extended market wagon • BB 5.3.4. 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 reduce cost of the freight railways services. • BB 5.3.1. Running gear • BB 5.3.2. Core market wagon • BB 5.3.3. Extended market wagon
8- Guaranteed asset health and availability	The Internet of Things (IoT) enables real-time monitoring through connected sensors (ground/air/embedded) • BB 5.3.4. Telematics and Electrification

9- Intelligent Trains	Communications is possible between trains, between train and infrastructure and between train and freight customers • BB 5.3.2. Core market wagon • BB 5.3.3 Extended market wagon • BB 5.3.4. Telematics and Electrification
10- Stations and "smart" city mobility	The Internet of Things (IoT) enables real-time monitoring of the assets through connected sensors (ground/air/embedded) and therefore contributing to the stations operation and "smart" city mobility. • BB 5.3.4. 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) summarized in the table below:

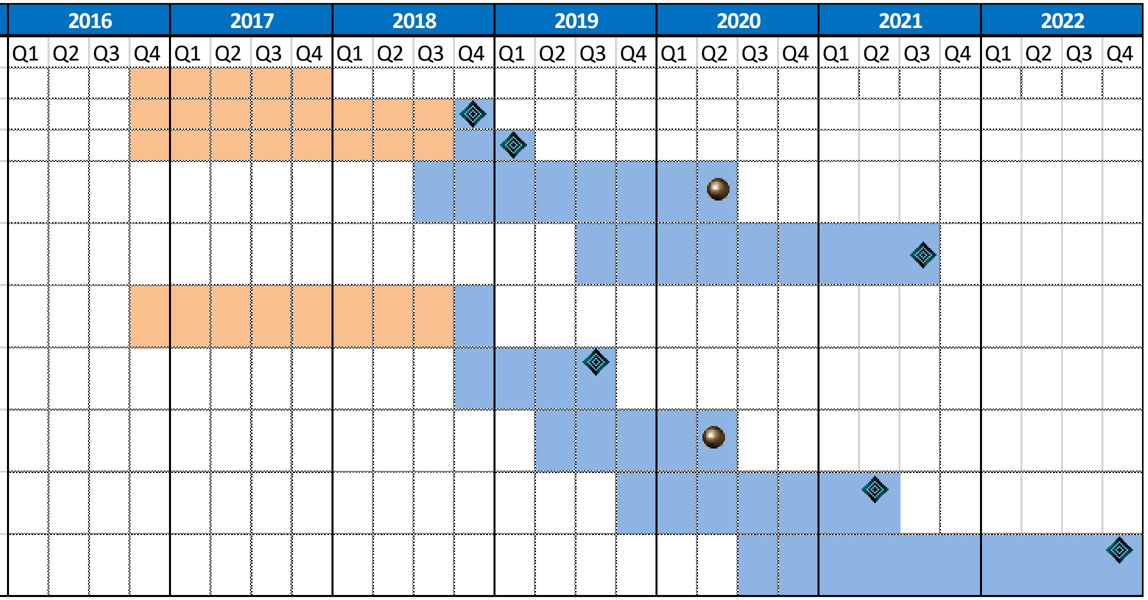
Table 82: contribution of TD 5.3 Wagon Design to the different ITDs

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 to run under standard wagon bodies and the freight wagons 2020 will be demonstrated **in hardware in relevant environment** in a freight train
	Core Market Wagon 2020	Freight	5-6	Modular, logistic capable and cost-efficient, low weight, payload and aerodynamic optimised **Freight Wagons 2020 for Core and Extended Markets** will be demonstrated together **in hardware in relevant environment** including electrification, diagnosis and monitoring, telematics and communication and automatic coupling) in a freight train
	Extended Market Wagon 2020	Freight	5-6	

TD	Focus Areas	Demonstrator Market	Demonstrator TRL	Demonstrator
	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
	Telematics and electrification	Freight	6	Integration of the information provided by the convoy with the real time network management
	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
TD 5.3	**Smart Freight Wagon Concepts**	
5.3.0	Scanning of innovations	1
5.3.1	Wagon design	4
5.3.2	Running gear	4
5.3.3	Definition of components and running gear and wagon manufacturing	4
5.3.4	Complete freight wagon demonstrator implementation	5-6
5.3.5	High level specification definition, feasibility analysis and preliminary testing of telematics	1
5.3.6	Conceptual / architecture design of telematics	3
5.3.7	Detailed design, implementation and unitary testing of telematics	5
5.3.8	Integration of components of telematics	5
5.3.9	Demonstration activities of telematics	6



milestone

quick win

ongoing activities

planned activities

Table 83: TD5.3 quick wins

When	What
Q2/20	Running gear and wagon manufacturing
Q2/20	Telematics components manufactured

Table 84: TD5.3 milestones

When	What
Q4/18	Wagon design completed
Q1/19	Running gear design completed
Q3/21	Wagon demonstrator completed
Q3/19	Telematics architecture completed
Q2/21	Telematics components integrated
Q4/22	Telematics demonstrator completed

The estimated total budget for the TD is around 17.5 MEUR

5.4. TD5.4 New Freight Propulsion Concepts

5.4.1. Concept

The major objectives of the EU White Paper like the Shift of 30% of road freight over 300km to rail by 2030 or doubling the transport by rail freight compared to 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 maximizing 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 in non-electrified and in electrified lines, allowing private and public operators to offer broaden rail freight services according to demand without the need of changing the locomotive or allowing the new production concepts;
- Feature remote control for distributed power, thus, allowing the increase of the train length up to 1500m and consequently improving the cost efficiency of rail transport;
- Feature reduced LCC;
- Recuperate braking energy as much as possible, store it onboard and reuse it whenever required, for traction purposes, for power peak shaving, to supply auxiliaries and other systems;
- Provide more traction force;
- Increase the operational efficiency by automating various activities such as train start-up, train preparation, start of mission, stabling and parking, generally shunting.

Some of the results achieved in this TD will be of valuable interest also for passenger locomotives, thus supporting even more the overall goal of the modal shift.

5.4.2. Technical Objectives

TD 5.4 has the objective to accelerate the development of the features and systems mentioned in the section above. More in detail, the technical objective is the development of:

1. Powerful and/or flexible dual power (hybrid) traction chains for future freight locomotives (mainline and shunter). Removing diesel propulsion system results in a reduction of fuel consumption of up to 30% for hybridized legacy vehicles, otherwise up to 15%.
2. Innovative last mile propulsion systems based on powerful Li-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, being able to recuperate braking energy and store it on-board, e.g. with Li-Ion batteries or other energy storage systems, being able to implement peak power shaving features, being 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 of LCC 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 is to finally implement a locomotive equipped with the features stated above and consequently actively supporting the shift to rail.

Table 85: Ambitions and advance beyond state-of-the-art for TD5.4

State-of-the-art	Ambitions and expected advance beyond state-of-the-art
4 axle multi system or diesel locos, no combination on the market capable to pull heavy train 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 LCCs
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 Li-Ion batteries only, giving possibility to run on a last mile with high power during a relative short time e.g. over 1MW for 15-30min. This includes an optimized 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.
Train lengths usually limited to 750m in some special cases up to 850m. No radio remote controlled distributed power implemented so far in Europe	Definition and implementation of a standardized radio remote control for distributed power allowing trains up to 1500m length with up to 4 locomotives, including authorization of such 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 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:

- 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
- IP5 – TD 5.5 « Business analytics & implementation strategies»; migration plans for the uptake of the researched technologies and KPI for measurability of the impact
- IP5 – TD 5.1 « Digitalisation and Automation Rail System
- IP5 – TD 5.2 « Digital Network Management »; interfaces for data communication between locomotive, wagons and data centers
- IP5 – TD 5.3 « Smart Freight Wagon Concepts »; automatic coupling need to be installed on the wagons and will enable telematics and electrification; condition monitoring on wagon bogies overlaps with CBM activities
- IP 5 – TD 5.4 « New Freight Propulsion Concepts »; "Long Trains up to 1500m" researches communication technologies for trains and locomotives that can be applicable for C-DAS and ATO

5.4.4. Impact and enabling Innovation Capabilities

TD 5.4 has a major impact in the Shift2Rail system-level KPIs, as it focuses on the traction system of the freight eco system. The relative weight 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: • Increase the flexibility of rail freight system for operation under the TEN-T corridors, the main EU lines and under the non-electrified feeder lines, providing cost savings by using the most efficient traction mode according to the infrastructure. • Allow the free circulation of freight trains for cross-border transport. • Operation of longer trains and reduction of 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 is expected with the improvement of rail freight competitiveness. Support to capacity increase, which is expected by lengthening the trains up to 1500m. Greening of transport through the implementation and demonstration of environmental friendly solutions and optimisation of energy consumption, hence contributing to the EU target for CO2 reduction too.
Degree of maturity of the envisaged solutions	The proposed work involves a big step in the degree of maturity of the technologies to be applied in the freight rail transport. At the end of Shif2Rail it is expected that the successful concepts are brought to TRL 7.
Authorisation as key to success	A successful integration and authorization of the locomotive including the last mile traction battery will have enormous impact on future battery related developments. In fact, a variety of battery based implementations is foreseen, consisting of different sizes of battery systems, of battery systems with different chemistries and different characteristics, and even consisting of battery systems with modules dispersed along whole trains.

This TD will contribute to enable the Shift2Rail **Innovation Capabilities** as follow:

Innovation Capability	**TD5.4 New Freight Propulsion Concepts**
1- Automated Train Operation	Providing features for the automation of processes not directly related with ATO during driving (E.g autonomous train stabling, train preparation, etc.) • BB 5.1.3. Freight ATO/C-DAS

3- Logistics on demand	Flexible, interchangeable, multipurpose and smart freight transport units increase handling flexibility and unit utilisation. Freight trains are able to integrate within high-intensity passenger operations. Shipments are moved effectively, efficiently, safely and securely throughout the “physical internet” logistic chain. Last mile and dual mode propulsion concepts support logistics on demand through the operational independence • 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
5- Optimum energy use	Alternative propulsion concepts are introduced. Hybrid powertrains 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 • BB 5.4.1. Last mile propulsion systems • BB 5.4.3. Freight Loco of the future • BB 5.4.4. Hybridisation of legacy shunters
7- Low Cost Railway	A low-cost, affordable rail system supports the rural economy. Integration of low maintenance systems and devices, including wheel and track friendly running gear solutions • BB 5.4.1. Last Mile propulsion systems • BB5.4.4 Hybridisation of legacy shunters
9- Intelligent Trains	Trains feature advanced mechatronics, reducing dependence on wheel conicity and permitting simplified running gear design. Automated train and loco preparation, stabling and parking • BB 5.4.2. Long Trains up to 1500 m • BB 5.4.3 Freight Loco of the future • BB 5.1.3. Freight ATO/C-DAS
11- Environmental and social sustainability	Reduced energy consumption • 5.4.1. Last Mile propulsion systems • 5.4.2. Long Trains up to 1500 m • 5.4.3. Freight Loco of the future

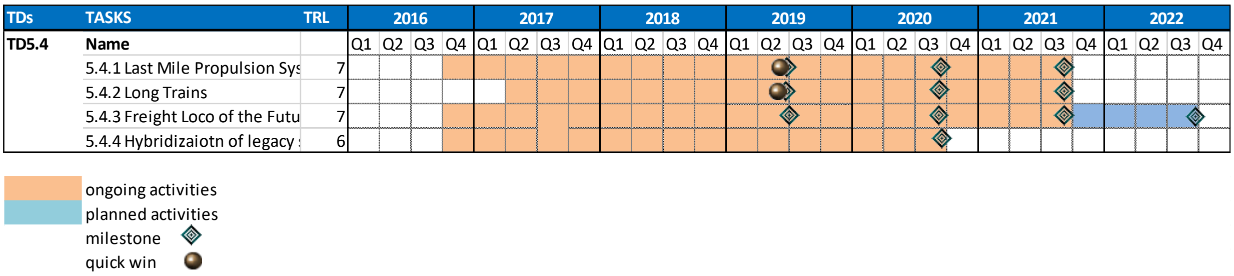
5.4.5. Demonstration activities and deployment

The overall S2R goals will be addressed by the four (4) focus areas summarized in the following table.

Rsearch 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 TRL7	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 on retrofitted locomotives. Subsystem specification and validation with functional mockups 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	Li-Ion batteries, recuperation, authorisation, mission management system, maintenance, system optimisation, definition of last mile, assessment of batteries Both for new and retrofitting of Locos Demonstrator Loco in operation (TRL7)

Rsearch Area	Focus area	Specification Activities	Demonstrator TRL	Focus of activity
	Long Trains up to 1500m	Development 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 2nd Loco Phase 1: Development of a European Longer Train Concept including the coordination of an European recognized certification method for operating Longer Trains and identification of the operational and infrastructural constraints Phase 2: Realisation of Technology Demonstrators by developing and testing of a distributed power solution by radio remote control Phase 3: European Authorisation and Rollout preparation including the development of a European roadmap for the implementation of Longer Trains
	Hybridization of legacy shunters	Hybridisation of legacy shunting locomotives for environmental friendly second life	7	Reduction of implementation time and enhancing cost competitiveness for environmentally friendly innovation Improvement of the ecological footprint and lifecycle cost of diesel shunters Increase of the flexibility and freight operational efficiency

Planning and budget:



*Error! Reference source not found.: **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 at developing the building blocks for more efficient and environmental 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 540m 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 of the train length from today 750m to future 1500m length. Also increasing energy efficiency is achieved, especially in train configurations such as the one depicted on the left. The loco at the end can brake dynamically much stronger, thus recuperating more energy.

*Error! Reference source not found.: **TD5.4 milestones***

When	What
Q3/2019	End of the 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 project FR8RAIL III /& FRRAIL IV (Advanced Aux Propulsion, Battery technology), Automation

The estimated total budget for the TD is around 13.5 MEUR

5.5. TD5.5 Business analytics & implementation strategies

5.5.1.1. Concept

The core objective of IP5 is to increase competitiveness of European Rail Freight by:

1. Maintaining its market position in today's transport segments making use of digitalisation, and
2. Opening up new market segments so that in total an effective gain of the 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, and 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, which rail customers are not ready to pay.
- Substantial technological advancement 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 migration concept towards new technology, especially in areas with considerable investments and long life cycles.

With this regard, IP5 perceives the rail freight transportation as an integral part of the transport and logistic 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 socio-economics and environmental constraints.

5.5.2. Technical Objectives

The following represent the main technical objectives of TD5.5:

1. Overview of relevant segments of the transport and logistics market which are currently served by rail (fully or partly) and of segments which could be served with appropriate technical improvements and adequate business models (focus on wagon design and components)
2. Definition 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 realize 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 European-wide roll-out of key technologies following Shift2Rail. 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 & implementation strategies
SPECTRUM project (Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets), 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 technology demonstrator in the strict sense. The tasks of TD5.5 is to serve the needs of TD5.1-TD5.4, regarding certain prerequisites for better performance. Furthermore TD 5.5 will contribute to a migration plan.

5.5.4. Impact and enabling Innovation Capabilities

Strategic Aspect	Key Contribution from the TD
Support the competitive-ness of the European rail industry	• Specification of market prerequisites for development of automated concepts and equipment in TD5.1-TD5.5 which will have advanced capabilities compared to 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-TD5.5); implementation of respective EU law – TAF TSI
Degree of maturity of the envisaged solutions	• The Analytic nature in TD 5.5 and the connection to SmartRail etc should be seen as a basis for reaching higher TRLs in TD5.1-TD5.5, to which they contribute. Beyond that the migration plan will facilitate the dissemination to real operations.

This TD will contribute to enable 4 **Innovation Capabilities** as follow:

Innovation Capability	***TD5.5 Business analytics & implementation strategies***
3- Logistics on demand	The Migration plan, following the findings in the business analytics will propose a step-wise change of the 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 KPI's
7 – Low Cost Railway	A low-cost, affordable rail freight system and services to support the rural economy. Efficiency in running assets with help of information and intelligence leads to low cost as well as more automatized solutions. • BB5.5.1 Identification of market segments
8 – Rapid and reliable R&D delivery	R&D based on effective collaboration ensures the rapid integration of technology into the railways, remove barriers to the adoption of new technologies and decrease 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 technology demonstrator in the strict sense. The tasks of TD5.5 is to serve the needs of TD5.1-TD5.4, regarding certain prerequisites for better performance. Furthermore TD 5.5 will contribute to a migration plan.

Planning and budget:

TDs	TASKS	TRL	2016				2017				2018				2019				2020			
TD 5.5	**Business analytics & Implementation strategies**		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																				

	Light house projects
	Contracted activities
	planned activities

The estimated total budget for the TD is around 0.5 MEUR

6. CCA – 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 reach the ambitious goal, Shift2Rail must introduce novel and innovative technologies applied in each of the components of the system. Introducing new technologies at the component level and in different technology demonstrators (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 Shift2Rail, and that take into account the interactions between IPs and the different subsystems that have been defined. These cross-cutting activities (CCAs), organised around working areas, will also contribute to develop 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 Shift2Rail'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 are necessary to be taken into account by the different Innovation Programmes.

The following table summarises the main objectives of the CCA and provides an overview of some of the deliverables that will result from the activities undertaken in the CCA.

Objective	Result	Practical (concrete) Challenge
Socio – economics: Bring an understanding on how rail can be a catalyst in transformational societal changes.	The added value of the WA is that it opens up the railway system to a wider audience with interest in mobility but disinterested in the modes.	The value of Shift2Rail lies in its capacity to address the challenge to enable a better accessibility and connectivity through the delivery of a high capacity and cost effective rail system seamlessly interconnected with other modes and embedded in a local, regional and cross border context.
KPI and Integrated assessment – The objective of the Integrated Assessment (IA) is to show, that the results of the JU are fulfilling the expected results of the key Shift2Rail targets and the other expected benefits – in advance, during the project run time, and after the completion of the TDs' work.	Prognosis of KPIs at the beginning of the JU activities, as well as constant monitoring of the TDs' progress, and a comparison of the predicted outcomes against the demonstrated results	KPI development anticipates a huge added value for research in the railway sector and future projects is generated. It embodies a systematic approach to the understanding of the complex interrelations 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, their influence on the Shift2Rail goals and, if necessary, prioritisation of activities.
Enhanced Interoperability Safety, Standardisation, Smart Maintenance, Smart Materials & Virtual certification	Safety: To develop a global approach of the safety of the railway system Quantify the safety improvements carried out in Shift2Rail 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: To transfer Shift2Rail results and outcomes of innovation activities into standards or normative documents.	Addresses Shift2Rail target to remove remaining administrative and technical barriers, in particular by establishing a common approach to safety and interoperability rules to decrease costs.
	Smart Maintenance: The development of an overall maintenance concept taking into account all Smart Maintenance developments within Shift2Rail	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 digitalisation will have strong impact on reliability, availability and LCC and thus on attractiveness and competitiveness of rail traffic.

Objective	Result	Practical (concrete) Challenge
	Smart Materials: To explore the latest research in designing of smart materials and possibilities of applying various techniques and innovations in material science for railways.	Smart materials help in removing the boundaries between structural and functional materials, which may result in significant revolution in materials science development. It Is a challenge for the railway sector to be on top of this development.
	Virtual certification: reduction of authorisation costs, facilitating cross-acceptance procedure, reduction of time and cost of (sub)-Systems Authorisation Process.	Proposal for mixed experimental/numerical processes for authorisation, resulting in less on-site testing, more lab or vehicle testing and more simulations. Common methods and processes for authorisation considering standardised lab tests, vehicle tests, on-track tests and simulations procedures. Easier cross-acceptance process, by introduction of virtual testing.
Operational reliability increase Railway system life circle cost reduction Smart Planning	Smart Mobility: To 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. RU with their fleet and staff planning processes, IM whose assets are in a certain condition), to schedule planning and external parameters.	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: To specify, develop and integrate all necessary Elements into the Traffic Management System to integrate actual and forecasted Traffic Asset and Freight Operations status information into a seamless operation process	Challenge addressed is to be smart and based on a 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	Reduce the operational costs through a reduction of energy consumption.

Objective	Result	Practical (concrete) Challenge
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 Shift2Rail	To reduce the annoyance and exposure to noise and vibration (N&V) related to the railway sector in Europe. This will enable an increase of traffic and enhance the attractiveness of the rail as mean of transportation
Operational reliability increase Human Capital	Increasing flexibility for both, employer and blue collar employees Making use of the benefits of digitisation and automation for job profiles and skills	Overcome the challenges imposed by demographic change and comprehensive and radical technological innovations

Past and ongoing European & 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 Shift2Rail. Shift2Rail has here a potential to enhance the investment that European society has made in railway research in recent years.

Details on the projects are presented in the section devoted to each technology demonstrator, but some of the most relevant ones to the activity proposed in Shift2Rail are listed hereafter:

- Noise and Vibration: outcomes from 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) on electric and diesel Main Line trains energy reduction: Osiris (started on January 2012): This programme has many similar targets as RailEnergy but focus on urban railway systems
- Safety: Many European projects like TrioTrain, Acoutrain, Euraxles, Secret are dealing with the safety level of the components of the railway system. Safety and authorisation are closely linked together in these projects. For example, the OPENCOSS ("Open Platform for EvolutioNary Authorisation of Safety-critical Systems") FP7 project, which aims at developing the first European-wide open safety authorisation platform.
- Standardisation: examples include project BRIDGIT, or "Bridging the Gap between Research and Standardisation" to demonstrate that standardisation is a significant instrument for the dissemination of research results in a due time, as well as the market uptake of innovations. Also, the

group STAIR or Integrated Approach for “STAndardisation, Innovation and Research”, a group created to provide strategic advice to the CEN and CENELEC Technical Boards on the synchronisation of standardisation with innovation and research

- KPIs: Experiences from the work on the Technology Evaluator of Joint Technology Initiative (JTI) Clean Sky 1 and Clean Sky 2 can be used, in terms of methods for the definition and calculation of KPIs

- Human capital: EU FP7 projects FUTURAIL and SKILLRAIL, which have contributed to increase the knowledge on human capital in the railway sector

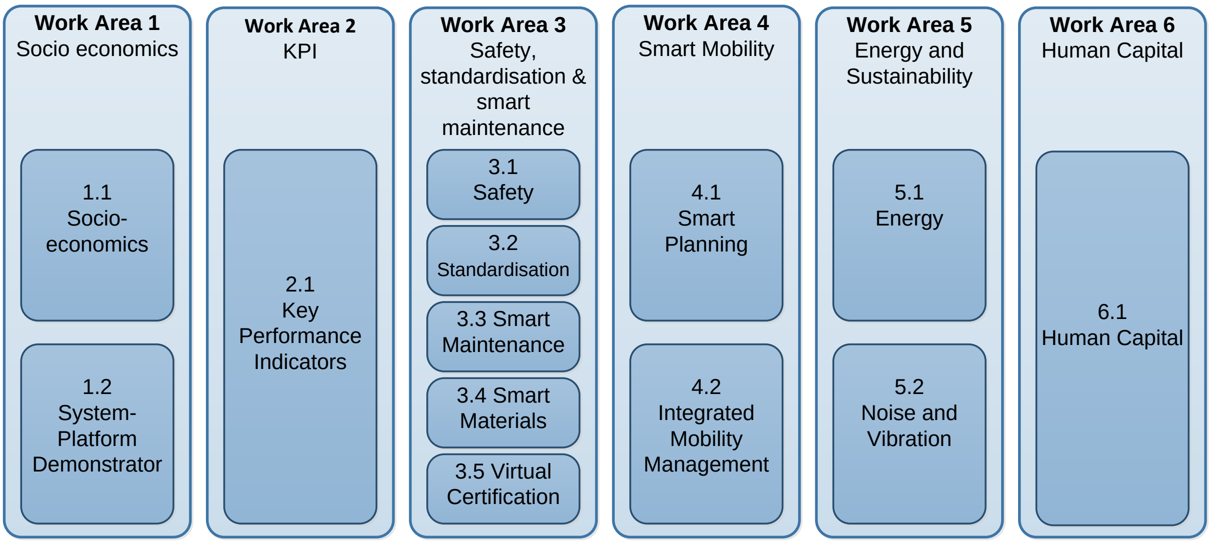
Finally, the ROLL2RAIL and IN2RAIL “lighthouse” H2020 projects, were orientated towards pre-starting some of the work lines of Shift2Rail. CCA areas included are Integrated Mobility Management in IN2RAIL and Energy and Noise in ROLL2RAIL. Results of IN2RAIL and ROLL2RAIL have been incorporated into the corresponding CCA area and will constitute an essential element towards the end result of the programme.

One or more members of Shift2Rail working within the CCA areas have participated in most of the finalized and ongoing EU projects, so the information flow and leverage from these will be automatically ensured.

Set-up and structure of the CCA

Structure

The Cross Cutting Activities are structured into work areas and are shown and described in the tables below:

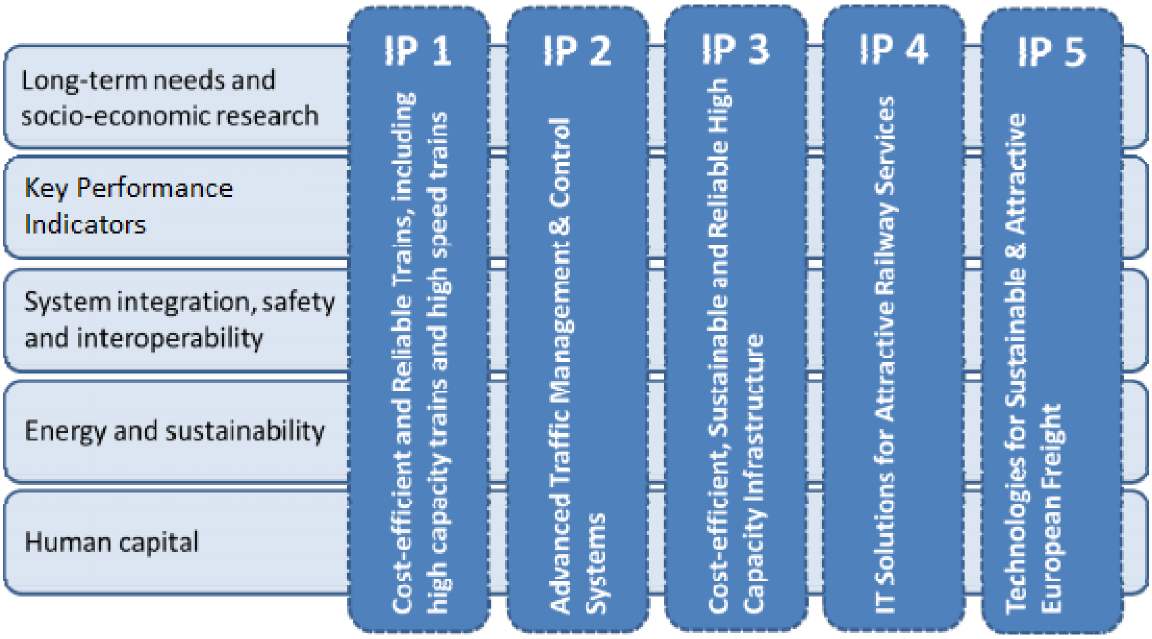


Work Area	Aim and activity related to Master Plan
1.1 Socio-Economics	Create knowledge of success factors for a future railway system based on customer needs and the mobility behaviour of users and better understanding of key trends, such as urbanisation, demographic changes, ageing of society, hyper-connectivity, etc.
1.2 SPDs	Definition of the 4 **SPDs** (**System Platform Demonstrators**): Freight, Urban, Regional and High Speed railway system demonstrators.
2. KPI	**KPI method development** and integrated assessment – Methodology for assessing the achievement of the Shift2Rail 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	Perform a **global approach of the safety** of the railway system Manage the safety level of the existing railway system, Quantify the **safety improvements** carried out in **Shift2Rail TDs**
3.2. Standardisation	Coordinate and address **standardisation issues for all IP** to assure it is possible to meet overall S2R targets.
3.3. Smart Maintenance	**Lowering maintenance costs** by using the new opportunities of **knowledge about vehicle's conditions by digitalisation**. This will have strong impact on reliability, availability and LCC and thus on attractiveness and competitiveness of rail traffic.
3.4. Smart Materials	This activity is relevant for more segment of the rail system. However, dedicated activities are carried out in dedicated IPs such as in IP1 which is looking into new materials for rolling stock components.
3.5. Virtual certification	Developing methods and processes for design validation for the purpose of obtaining an authorization to put into service Transfer of 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**. Its concept will cover all phases of railway planning and include an outlook on operation.
4.2. Integrated Mobility Management	Specification and Implementation of sub-structures 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 toward a European shared understanding of energy figures in railways. Link energy and sustainability actions with existing initiatives outside Shift2Rail in order to align understanding and positions from railways and energy stakeholders

Work Area	Aim and activity related to Master Plan
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 **NoV aspects are properly considered and integrated in all relevant Technology Demonstrators** within the different Innovation Programmes of Shift2Rail
6. Human Capital	Achieve a number of benefits and **overcome the challenges imposed by an aging workforce through:** • **Increasing diversity** and flexibility for both, employer and (blue collar) employees • Healthier workforce because of the use of automated and robotic systems to **reduce the physical strain on humans** • **Life-long development of new skill**s and change in job profiles

Approach within the CCA

The CCA activities are part of the S2R System Integration Working Group and within it, they have a dedicated organisation, with a CCA Coordinator and Steering Committee.



A 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 Shift2Rail TDs (Technical Demonstrators) and further 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 on different TDs. Experts from CCA can also provide their know-how in many TDs and IPs especially to translate local Performance Indicators (PI) into the Shift2Rail macro indicators.

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

6.1. WA1 Long-term needs and socio-economic research and System Platform Demonstrator

6.1.1. Sub-WA1.1 Long-term needs and socio-economic research

6.1.1.1. Concept

The Work Area will assess the railways from a wider social-economic perspective and bring an understanding on 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 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 is important for the investment in assets with such longevity as rail.

The rail system is part of the multi-modal transport chain and it aims to support the development of an attractive sustainable society which 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 a better accessibility and connectivity through the delivery of a high capacity and cost effective rail system seamlessly interconnected with other modes and embedded in a local, regional and cross-border context. 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 enlargements of regions and 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 works developed within Shift2Rail bring to the European context in terms of social and economic benefits.

WA1.1 will look at the rail system from a wider perspective, and on it as a part-function in a much bigger societal and transport context.

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, 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 to make 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 examine how robust these impacts are considering different future scenarios of the development of society as a whole. The cost efficiency of implementation of S2R achievements needs to be evaluated in Cost Benefit Analysis (CBA). 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 railway 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 (5-8% of railway usage for distances over 50km). This WA will assess the obstacles and benefits of rail transport and how to make the system fit to the needs of the future society to make it more accessible and attractive.

Sometimes railway systems are more successful than the existing physical possibilities (Paris, London, Munich, and connection like Copenhagen – Malmö, Paris – Marseille, and Frankfurt – Nuremberg) with the effect that lines are crowded and more or less uncomfortable. In this case of "crowded system" capacity improvements are necessary, with this being one of the main objectives of Shift2Rail. 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 for customer behaviour. The knowledge about both key factors in governance of rail and customer behaviour should be enhanced for responding to the customer and mobility needs in Europe.

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

The main interaction envisaged with the IPs and WAs listed below, both from the point of view of technologies employed and of interaction in performance and objectives are:

CCA WA1.2 "KPI method development and integrated assessment": Definition of the four System Platform Demonstrators (SPDs) that will be used to demonstrate the effects of the Shift2Rail (S2R) activities.

CCA WA2 "KPI Integrated Assessment": The SPD definition will be refined and extended with more technical details and population 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 system 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 the 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 digitalisation. Digitalisation of society and economy will impact the way people live, work, consume and move. A new industrial revolution that rewrites the manuals on how products are being engineered, produced and marketed to end costumers could significantly alter the supply chains, as well as human contacts, behaviour and interests. Macro changes in the global economy will influence trade patterns and travels, thus the goods being shipped and the mobility of passengers. Therefore Shift2Rail through the WA1.1 CCA needs to pave the way for the enhancements of the European Rail system by studying the societal and economic implications and preparing the necessary evolutions 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 is supporting the EU policies on smarter, connective and more affordable transport system. It looks at the rail contribution to the multimodal transport chain and ensuring to provide a better passenger services
Degree of maturity of the envisaged solutions	Existing methods for analysing the effect of different measures with the purpose to improve the transport system are scientifically based, generally accepted and widely used, especially on a national level. The experience to analyse systems on a European scale is more limited.

This TD will contribute to enable 12 **Innovation Capabilities** as follow:

Innovation Capability	***WA1.1 Long-term needs and socio-economic research***
1-12 capabilities	The contribution of WA 1 is to provide 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:

1. Provide S2R with analysis methods and tools appropriate for exploring the future market for the railway and performing cost benefit analysis of S2R achievements
2. To explore the actual 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			
WA1.1	**Long-term needs and socio-economi earch**		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	Societal needs analysis	-																												
WA1.1.2	Influences to 2025, 2035, 2050 from Mega-Trends...	-									◆																			
WA1.1.3	Societal development by transportation	-									◆																			
WA1.1.4	Key success factors for a successful railway system	-																							◆					
WA1.1.5	Rail Transport Governance	-																												
WA1.1.6	Shift2Rail Societal Effects	-																					◆							
WA1.1.7	Rail as a design tool in societal development	-																												

◆	milestone
	lighthouse projects
	contracted activities
	planned activities

Table x: WA1.1 milestones

When	What
Q2 2018	Future trends and scenarios
Q1 2021	Long term changes and future needs
Q1 2022	Socio economic Impact
Q2 2022	Key success factors
Q4 2022	Cost Benefit analysis

The estimated total budget for WA1.1 is around 2M€.

6.1.2. Sub-WA1.2 System Platform Demonstrators

6.1.2.1. Concept

The objective of WA1.2 is to define the four System Platform Demonstrators (SPDs) that will be used to demonstrate the impacts of the Shift2Rail (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 for improving customer attraction and requirements for the future define desired dimensions will be analysed based on the SPDs. Therefore, the WA1.1 results together with Technology Demonstrators (TDs) and Integrated Technology Demonstrators (ITDs) also give the requirements imposed on the SPDs to analyse rail systems with the objective to identify 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 fore-casting tools that make up the SPDs.

To achieve as far as possible a 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 represent the main technical objectives of this WA:

1. Define and refine the four System Platform Demonstrators (SPD) for High Speed, Regional, Urban/Suburban and Freight to evaluate on this examples the impact of Shift2Rail
2. Identify the relevant conditions to perform the socio-economic impact in WA1.1
3. Prepare the relevant set-up to perform the integrated assessment of KPI in WA 2
4. Ensure coherence between both refined sets of SPDs for WA1.1 and WA2

6.1.2.3. Technical Vision

The main aim is providing the basic definition of the four System Platform Demonstrators (SPD) to be used in the socio-economic impact analysis in WA1.1 and the integrated assessment in WA2.

The technical vision for the SPD definition proposed in Shift2Rail is based on the following:

- Defining overall SPDs to be used for all KPIs
- Time and cost efficient validation of the SPD

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 on 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 (of the same IP and/or of the other IPs)

The main interaction envisaged with the IPs and WAs listed below, both from the point of view of technologies employed and of interaction in performance and objectives are:

CCA WA1.1 “Socio-economic impact analysis”: The SPDs were 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 population 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: 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 system based on IT-services.

All TDs of IP2, IP3 and IP5: Deliver input for the definition of the one SPD for rail freight transport.

Figure 49: Interaction with other TDs and IPs

6.1.2.4. Impact and enabling Innovation Capabilities

The SPD definition shall be used to show the impact of all TDs in the Shift2Rail system-level KPIs as well as the socio-economic impact.

Strategic Aspect	Key Contribution from the WA
Support the competitive-ness of the EU industry	• Early evaluation of technological developments with respect to their impact on the four SPDs in cooperation the KPI integrated assessment.
Compliance with EU objec-tives	• Supporting the definition of the different system platform demonstrators and the de-fining an integrated railway system with efficient mixed traffic.
Degree of ma-turity of the en-visaged solu-tions	The SPD itself have no TRL and the KPI model and the tool will be brought to TRL 5.

This TD will contribute to enable 12 **Innovation Capabilities** as follow:

Innovation Ca-pability	***WA2 KPI method development and integrated assessment***
1-12 capabili-ties	To evaluate the impact of this Innovation Capability it needs to be applied on 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, Disrup-tions. 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 Shift2Rail Societal Effects • BBA1.8 SPD use case and scenario specification, application, result, analysis and wider effects

6.1.2.5. Demonstration activities and deployment

The S2R System Platform Demonstrators will be used to simulate and test the effects of, and interac-tions between, the various innovative systems resulting from the S2R activities in the specific environ-ments 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, its particular challenges and needs, allowing analysis of market opportunities.

Planning and budget:

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA1.2	**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
WA1.2.1	SPD use case and scenario specification	-																												
WA1.2.2	SPD application	-																												
WA1.2.3	SPD result analysis and wider effects	-																												
WA1.2.4	Future SPDs	-																												

	milestone
	lighthouse projects
	contracted activities
	planned activities

Table 86:WA2 milestones

When	What
Q1 2017	Scenarios as of today
Q3 2017	Shift2Rail 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 KPI method development and integrated assessment is around 0.6 M€.

6.2. WA2 KPI method development and integrated assessment

6.2.1. Concept

A technology and impact evaluation is an essential element within Shift2Rail. The objective of Work Area 2 is to show, how the expected results of the key Shift2Rail targets are achieved through the TDs' work. The overall Shift2Rail targets defined in the regulation will be assessed based high level KPIs defined in this work area. This requires an agreed model and baseline scenarios of Key Performance Indicators (KPIs) at the beginning of the Shift2Rail programme, as well as constant monitoring of the TDs' progress, and a comparison of the predicted outcomes against the demonstrated results.

The achievement of the Shift2Rail 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 Shift2Rail objectives, by defining which 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 respective 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 Shift2Rail, 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 by 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 Shift2Rail goals and, if necessary, prioritisation of activities.

To achieve as far as possible a 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 by further parameter to describe as far as needed the scenarios.

6.2.2. Technical Objectives

The following represent 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 / KPI LCC, capacity and reliability

6.2.3. Technical Vision

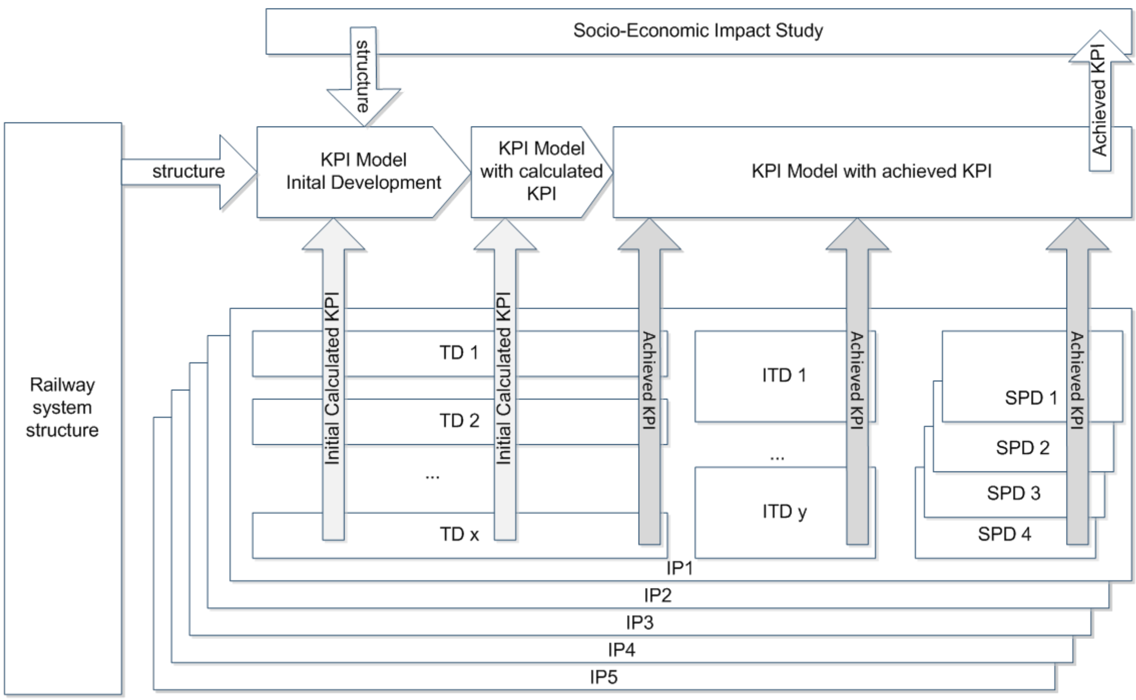
The final target is providing a tool implementing the KPIs and their interrelations in one consistent model. The model shall be implemented in a tool and so giving the possibility to continuously monitor the effects of the different technologies developed in all TDs.

The technical vision for the KPI method development and integrated assessment proposed in Shift2Rail 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 on all defined performance indicators and their interrelation
Application on 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 attractivity

Figure 50: Schematic representation of how the KPI model reflects the project structure

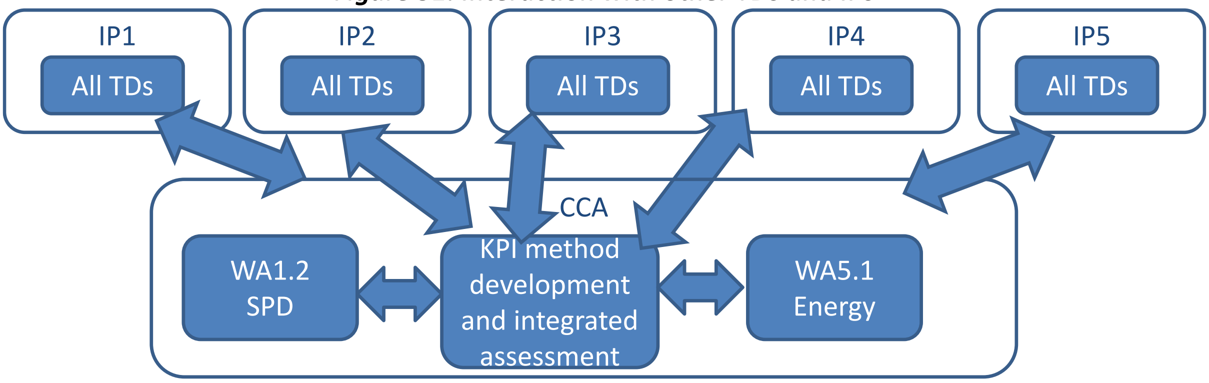


Interaction with other TDs (of the same IP and/or of the other IPs)

The KPI activity is impacting the entire S2R Programme and all IPs and TDs. The main interaction envisaged with the following TDs and WAs, both from the point of view of technologies employed and of interaction in performance and objectives are:

- **All TDs in IP1 to 5**: Providing their impact with respect to the targets of Shift2Rail given in the master plan. The individual description and quantification is objective of individual discussions between WA2 and the TD.
- CCA WA1.2 "System Platform Demonstrators (SPD)": The SPDs were defined on a higher level in WA1 and then given to WA2 for refinement and population with values.
- CCA W5.1"Energy": Reference Scenarios and Trains are defined there and given to WA2 to be used in the SPD definition.

Figure 51: Interaction with other TDs and IPs



6.2.4. Impact and enabling Innovation Capabilities

The KPI model shall show the impact of all TDs in the Shift2Rail system-level KPIs. The relative weight 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 enable 12 **Innovation Capabilities** as follow:

Innovation Capability	***WA2 KPI method development and integrated assessment***

1-12 Capabitlities	This Innovation Capability needs to be evaluated for the 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 Sub-system Structure • BBA.2.3 Sub-level 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 the WA2 is to show, how the expected results of the key Shift2Rail targets are achieved through the TDs' work.

KPIs have to be aligned with the overall Shift2Rail targets: improved services for users and customer quality, reduced system costs, simplified business process and enhanced interoperability can be reflected. They have to be characterized in terms of their units, their lower level performance indicators and their relation to KPIs of capacity, reliability and life cycle costs (LCC). Each TD's contribution has to be defined to feed into the target achievement. Additionally, 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 inter-dependencies of the KPIs horizontally between 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
WA2.0.1	Reference Scenario	-																												
WA2.0.2	Subsystem Structure	-									◆																			
WA2.0.3	Sublevel KPIs	-																												
WA2.0.4	Tool specification and development	-											◆								●									
WA2.0.5	Validation	-																												
WA2.0.6	Monitoring	-																											◆	

◆	milestone
●	quick win
(green)	lighthouse projects
(orange)	contracted activities
(blue)	planned activities

Table 87: 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 88:WA2 milestones

When	What
Q1 2018	Qualitative KPI-tree initial issue defined
Q3 2018	Initial quantitative KPI model defined
Q3 2022	Final SPD integrated assessment (SPD-IA)

The estimated total budget for KPI method development and integrated assessment is around 1.9 M€.

6.3. WA3 – Safety, Standardisation, Smart Maintenance, Smart Materials & 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 of the safety of the railway system. The end result of this work is to provide mainly to the infrastructure managers and operators, and in general decision makers, an integrated management system for the safety of their railway system.
The term safety (risk) management includes the process which is followed, the means used and measures taken in order to achieve a specific goal related to the aspect of 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, manpower, financial resources, equipment, 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 represent 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 in the existing railway system (and in particular the innovation introduced in the different TDs).

6.3.1.3. Technical Vision

WA3.1 proposes a global approach of safety in the railway system. This approach is based on a global risk assessment model, and will provide key results to reach the following objectives:

- manage the safety level of the existing railway system
- quantify the safety improvements carried out in Shift2Rail 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 of 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 a combination of both. The aim is to assist towards the qualitative improvement of the initial risk level.

2. <u>Definition according to incident "indicators"</u>, 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
Automotive and especially aerospace domains have a long experience in risk assessment methods compared to the railway sector	A complete state of the art survey of risk assessment will cover all the methods used in railway domain but also methods in use in automotive, aerospace etc. The most appropriate methods will be selected in a very large panel of existing methods and industrial applications.
Risk assessment can lead to theoretical results that can not 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 the safety every day. Risk analysis is a useful tool to support decision makers.

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

Potential impacts on railway operation (I2M smart planning in CCA) but also on IP3 Infrastructure Maintenance. No formal links with others 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 the WA3.1
Support the competitiveness of the EU industry	• Safety is a key issue in European railways. All industrial partners, operators, infrastructure managers are involved, from the conception phase to the operational one. A safe management system is also a competitive skill that can be exported.
Compliance with EU objectives	• Enhance the safety and interoperability of the railway system
Degree of maturity of the envisaged solutions	• The work on safety will start at low TRL as it will select and promote new risk assessment methods. These methods can be already used in other sectors like automotive and aerospace or developed by academics. They will be transferred to railway operators and industrials. • The day to day management of the safety based on risk assessment can also be innovative for the management of some subsystems. This innovation will be illustrated in application cases, moving the project from TRL3 to TRL5.

This WA will contribute to enable two **Innovation Capabilities** as follow:

Innovation Capability	**WA3.1 safety**
1- Automated Train Operation	• The global approach of safety developed in 3.1 will contribute to assess the new safety rules developed for ATO. In particular, the impact of the reduction of the train headways and the impact of automation on human factors will be addressed.
8-Minimal Disruption to train services	• 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 events 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 System Platform Demonstrators (SPDs) of Shift2Rail:

Research Area	Specific Techn. 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 on 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 optimization of maintenance planning and identifying short and long-term risks Development of emergency management for the case of critical events

Planning and Budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA3.1	**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
WA3.1.1	State of the art of risk assessment methods	2						◆																						
WA3.1.2	Requirements to conduct a risk assessment study	2									◆																			
WA3.1.3	Requirements to apply the risk assessment method	2											◆																	
WA3.1.4	Development of a saftey monitoring system	2														◆														

◆	milestone
	lighthouse projects
	contracted activities
	planned activities

Table 89: WA3.1 milestones

When	What
Q1-2017	State of the art of risk assessment methods
Q1-2018	Requirements to conduct a risk assessment method
Q3-2018	Requirements to apply a risk assessment method

The estimated budget for the sub-WA is around 0,85M€.

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 EU's research and innovation activities, reaffirming the important role of standards for innovation, as sources of competitiveness and in underpinning a 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 Shift2Rail appears as an essential lever to foster the 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 Shift2Rail results and outcomes of innovation activities into standards or regulatory documents when needed and beneficial as well as to coordinate the approach across the Shift2Rail 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 the strategic analysis of the Shift2Rail research activities in terms of standardisation potential
- To manage the process transforming the Shift2Rail 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 process at EU and international level.
- To monitor the European standardisation processes of the Shift2Rail activities
- To develop a mapping and roadmap for closing TSI open points in coordination with ERA

6.3.2.3. **Technical Vision**

The benefits of integrating standardisation into the Research and Innovation process are numerous[3,4] 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 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 policy makers 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:

1. Enhanced synergies and coordination between European and worldwide official standardisation bodies, professional standards organisations, standardisation initiatives and Shift2Rail
2. Innovative and time efficient mechanisms and processes to foster future standardisation of European research results, taking part to the continuous improvement of recent links between research and standardisation
3. Improved standard framework conditions for the implementation of new and emerging markets and technologies
4. Production of new and/or improved set of innovative technology standards

The following table shows the most relevant advances to be achieved with reference to current knowledge and practice in the different fields considered in the proposal

[3] Blind Knut : "*The impact of Standardization and Standards on Innovation*" – Manchester Institute of Innovation Research, February 2013.

[4] CEN-CENELEC "*How to link standardization with EU research projects: Advice for CEN and CENELEC Members*"

State-of-the-art	Standardisation advance beyond State-of-the-art
Standardisation can sometimes be a lengthy and expensive process	Definition of improved innovative processes to harmonise and speed up the standard development and deployment from collaborative research results.
Diverse level of awareness and integration of researchers into standardisation activities and processes	Harmonised templates and guidelines to help researches drafting standards from their results in a harmonised and efficient way.
Need for standard mapping at EU level	- Contribution to the European standard mapping - Contribution to the definition of future EU research objectives

Table 1: WA3.2 Vision to achieve progress

WA3.2 interacts in 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, cost effective and lead to sustainability efficient rail system attractive to end users whilst maintaining a very high level of safety performance.

A harmonised set of specifications on standardised interfaces and operational rules will contribute to an optimisation of the production with increased economies of scale and the delivery of components more easily interchangeable and deployable throughout Europe.

The WA3.2 monitors and addresses through its activities **the TSI open points**, in continuous cooperation with the EUAR.

The Shift2Rail activities will in general affect technical standardisation and regulation in the following way:

1. contributing to closing existing TSI open points
2. contribute to improve existing standards and TSI
3. create new standards or regulation based on the outcome of disruptive technology innovation

Table 2: 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 with master plan objectives • Identifying harmonised products, components and processes to be standardised
	Enhancing capacity	
	Customer experience	
Reduced system costs	Lower investments costs	
	Reduced operating costs	
	Externalities	
Enhanced interoperability	Respect and adaptation of TSIs	
	Removal of open-points	
Simplified business processes	Improved standardisation	
	Simplified authorisation	

This WA will contribute to enable the following **Innovation Capability**:

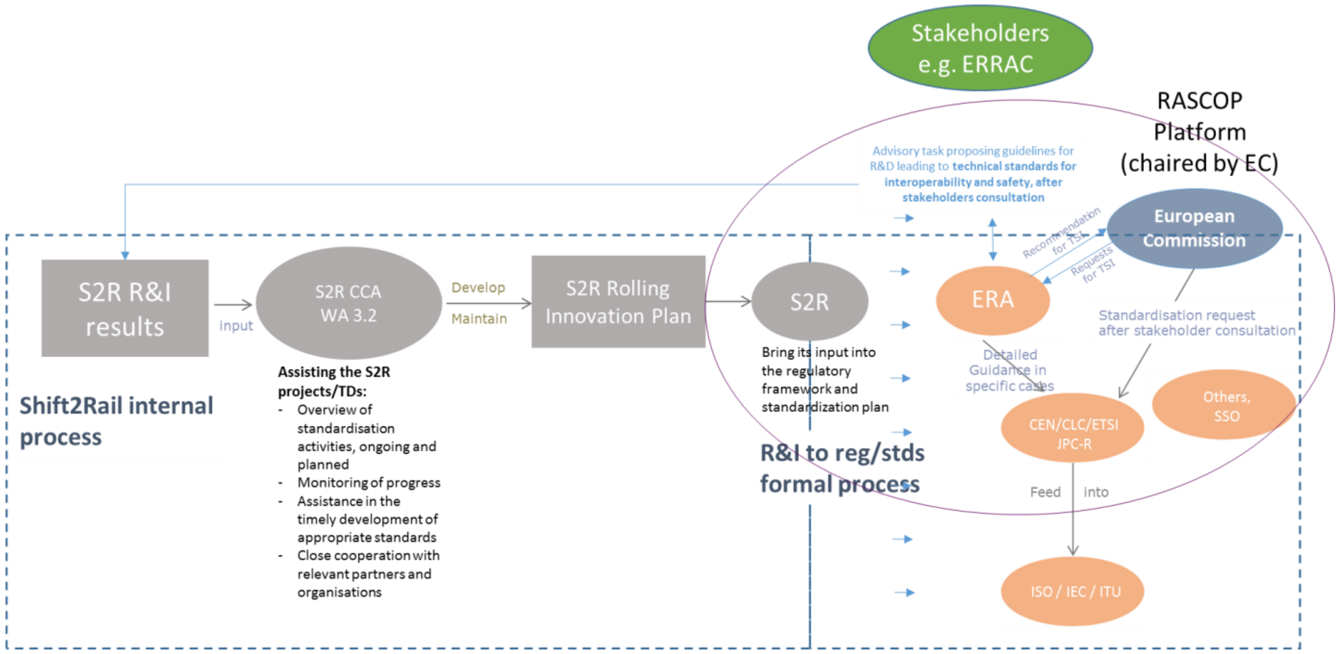
Innovation Capability	*Work Area 3.2 Standardisation*
1- Automated Train Operation	Enhance the close cooperation within the sector for standardisation to accelerate market deployment. Reduce the duration and cost of validation of new sub-systems through efficient standardisation activities. • By fostering 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 it is applied. • Therefore, standardisation is likely to have a positive effect on all Shift2Rail 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. 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 an efficient deployment of the future railway capabilities
3 - Logistics on demand	
4 - More value from data	
5 - Optimum energy use	
6 - Service operation timed to the second	
7 - Low cost railway	
9 - Intelligent trains	

6.3.2.5. Demonstration activities and deployment

Working in close cooperation via RASCOP EU Rail Standardisation Coordination Platform with the standardisation bodies and with the Sector Forum Rail (SFR, ex- Joint Programming Committee Rail, JPCR). WA 3.2 will play a pivotal role between the research and the standardisation respective communities, allowing the identification and selection of best standardisation targets and a 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 to be adopted in the appropriate standardisation context.

Figure 1: WA3.2 connections to standardisation and regulation ecosystem



Planning and budget:

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA3.2	**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
WA3.2.1	Strategic analysis of the Shift2Rail activities in terms of standardisation and regulation	-											◆																	
WA3.2.2	Definition of the S2R organisation managing standardisation and regulation (TSI) matters	-																												
WA3.2.3	Benchmark of existing organisation and processes towards innovative standardisation	-																												
WA3.2.4	Establishment of the Shift2Rail internal standardisation	-											◆																	
WA3.2.5	Transfer of the Shift2rail inputs to standards	-																			◆									
WA3.2.6	Management of Shift2Rail results and regulation (TSIs and open points)	-															◆				◆									

◆	milestone
(green)	lighthouse projects
(orange)	contracted activities
(blue)	planned activities

Table 90: 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 Standardisation sub-WA is 0.2M€

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 and
- unscheduled / corrective maintenance with repair / replacement of parts that have failed.

The introduction of digitalisation 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. But 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 (CBM), 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 CBM 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
- Transfer the data to a central stationary IT-Server
- Development of diagnostic software for CBM 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 in an independent way, 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 contains huge amounts of relevant information regarding other parts of the Railway System, e.g.:

- rolling stock monitoring data contains information about infrastructure components state of degradation
- infrastructure monitoring data contains information about rolling stock state of degradation (wheels defects, axle loadings, …)

6.3.3.2. Technical objectives

WA 3.3 has the following objectives:

1. Paradigm shift to condition-based maintenance
2. Less down time 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 vice versa.

6.3.3.3. Technical vision

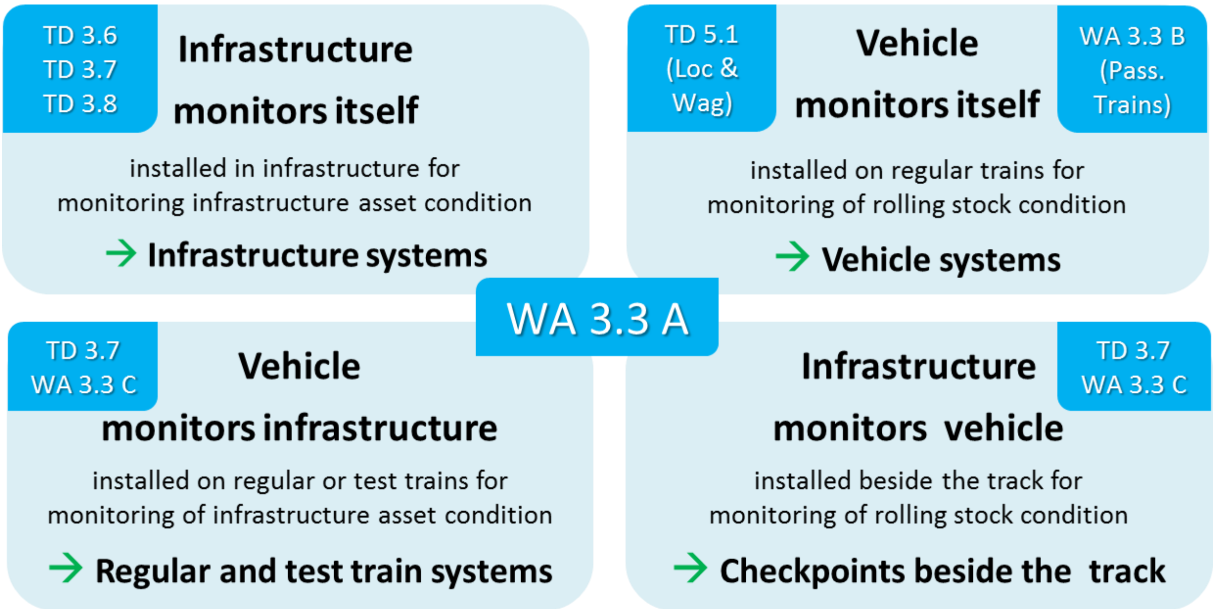
The technical vision of smart maintenance is

- All wayside and vehicle-based sensors and assets of the railway system send diagnostic data of a standardised format to common data servers
- The data can be used by different stakeholders with assigned access rights
- The data is 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 the punctuality is increased

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

Within WA 3.3 a common CBM concept will be developed covering four strategic CBM-areas, as illustrated in **Error! Reference source not found.**. Each area requires a collaboration with work conducted in other TDs.

Figure: Application fields of Smart Maintenance
for railway undertakings and infrastructure managers



The implementation of smart maintenance requires a close cooperation with other S2R TDs:

- TD 1.1 – TD1.7 CBM-concept for vehicle components
- TD 1.2 Transfer of diagnostic data of vehicle components
- TD 3.6 – 3.8 Railway information, monitoring and asset management
- TD 5.3 – 5.4 CBM for freight waggons 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 of 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 preventive maintenance .
Compliance with EU objectives	Enhancement of the competitiveness of the railway sector by means of lowering the maintenance costs and improvement 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 solved for the implementation of CBM 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 CBM – independent from a special rail asset.

Further, smart maintenance will contribute to enable four **Innovation Capabilities** as follow:

Innovation Capability	***TD3.3 Smart Maintenance***
1- Automated train operation	CBM improves the availability and the reliability of all kinds of railway assets. Therefor it improves the basis for all levels of automated train operation.
4- More value for Data	Usage of diagnostic data of railway components for the prediction of 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.
- Guaranteed asset health and availability	Condition based maintenance increases the availability of railway components.
9- Intelligent Trains	Diagnostic data of train assets are used for condition based maintenance and for failure prediction.
12-Rapid and reliable R&D delivery	Development of a standardised data transfer protocols, formats and structures for rolling stock and infrastructure

6.3.3.5. Demonstration activities and deployment

The benefit of CBM for some vehicle components of selected vehicle classes will demonstrated until 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 for common challenges independent from a special 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 the data management standardisation in some key data related areas, especially harmonized data structure and data format would be very helpful.

Planning and budget

Figurexx: WA3.3 Gantt chart

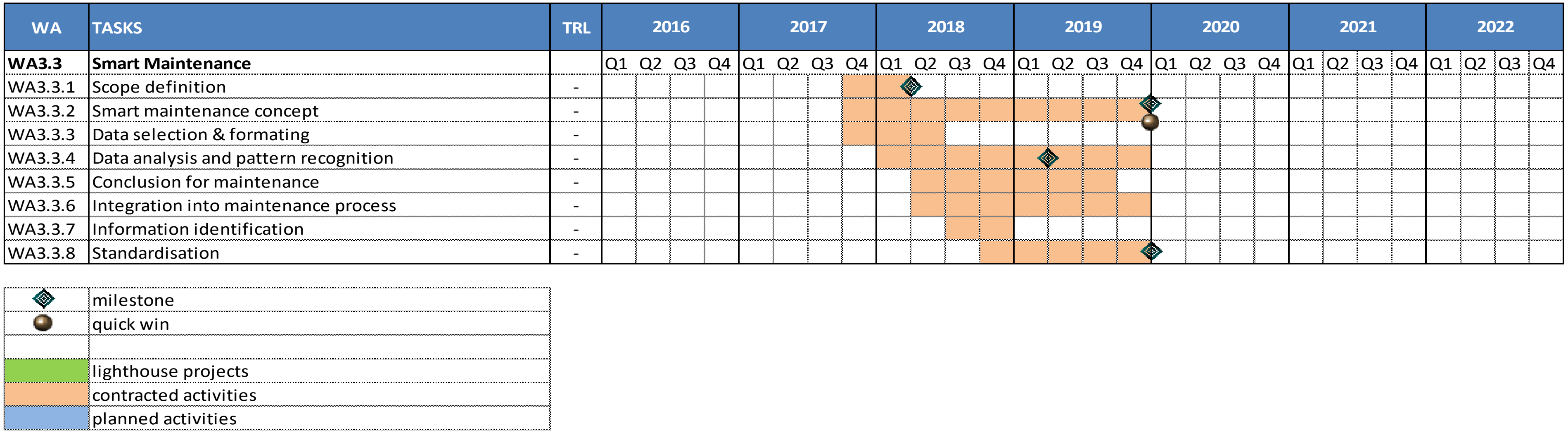


Table 91: WA3.3 quick wins

When	What	Contribution to MAAP
Q1 2020	Smart Maintenance concept	Showing the benefit as well as the obstacles of the implementation of CBM in the whole railway system

Table 92:WA3.3 milestones

When	What
Q1 2018	CBM data structures defined
Q2 2019	CBM 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 1.52 M€.

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 the 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 cost over the whole life span of a train. Passenger comfort can be also improved by new materials leading to better designed interiors.
- Next generation of components for Infrastructure should take benefits of the availability of new materials to ensure significant improvement at LCC and RAMS level, while considering environment impact.

All these aspects can be optimised by using state-of-the-art composite materials and solutions.

In railway industry, the use of smart materials has a threefold goal:

- Relief (energy savings, reduction in axle load, integration equipment and / or increased pay-load)
- 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 there is an indicative list of research activities highlighting some of the innovations on new materials which be materialised in the Shift2Rail programme:

- IP1 TD1.3 Carbody shell - Incorporation of non-metallic parts in the carbodies structure for lighter solution
- IP1 TD1.4 Running gear - Light weight and LCC-optimised materials validated and certified for the running gear environment
- IP1 TD1.6 Doors and Access System – New composite and metallic doors leaves to improve interior noise reduction
- IP3 TD3.2 Next Generation of Switches and Crossings – Advanced materials and enhanced elastomeric components for achieving lower overall life costs
- IP3 TD3.4 Next Generation Track - New materials (re-use, recycling materials) in the design of rail supports, fastening & 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 into service new rolling stocks or sub-systems 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 a million euros. 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 at a more competitive offer in Europe. There is hence a clear need for a reduction of the duration and cost of the process for an appropriate authorisation to put into service. The 4th Railway Package will support simplifying the process by having one single authorisation for placing into market new rolling stock if more than 1 member state is concerned. In that respect, it is a great challenge to propose methods that supports the single European harmonised process for vehicle authorisation defined by ERA. This can be achieved by introducing new methods and tools enabling 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 tests 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 impact the train path capacity, commercial traffic and lead to additional costs for the stakeholder. Additionally, 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 progressively numerical simulation in a mixed virtual/experimental validation process for authorisation, resulting in less field tests.

Some recent work, led within European projects, has helped to progress in this area but simulation is barely used for validation because of the remaining technical “open points”, but also of many non-technical reasons (organisations, cultural habits, availability of necessary data, multiplicity of stakeholders in the process and fragmentation of responsibilities, not allowed by TSI 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 reveals to be the most adequate framework to perform collaborative work, gathering complementary expertise from industrials, operators, infrastructure managers and academia. It will facilitate the convergence towards shared processes and maximise the chance of their translation into standards.

6.3.5.2. Technical Objectives

A mixed physical-virtual process for authorization raises many technical issues, needing the contribution of experts who are specialised in specific domains (braking, traction, car body shell, TCMS, running gear, signalling…). For that reason, the technical developments are carried out within the associated IPs and TDs. However, there is still a need of:

- Appropriate coordination among IPs and relevant TDs to define and share generic approaches and methods when possible
- Common interface with standardisation/regulation bodies (ERA, CEN, CENELEC…)

The main technical objectives of WA3.5 are the following:

- an overview of the state-of-the-art, the gap analysis and the barriers identification for a mixed physical-virtual validation process for authorization in the different railway technical domains
- an overview of the TDs work progress within the Shift2Rail program and the organization of meetings with leaders of the technical tasks related to virtual validation and authorization, task participants, IPs leaders and other railway experts
- proposal of generic methods and procedures for a mixed virtual-testing validation process for authorization
- defining a dissemination plan targeting the relevant standardisation bodies

The goal is to maximise the chance to reach applicable spare methods, but above all, comprehensive practical industrial processes for validation of rolling stock sub-systems and systems based on a mixed experimental/virtual approach, by finding synergies between TDs and coordinating the dissemination activities. The task will aim at steering the projects outcomes in the standards and guidelines.

6.3.5.3. Technical Vision

WA3.5 will give numerical simulations and laboratories tests a higher relevance in the authorization process compared to the state of the art. Although simulations will not totally replace field tests, a mixed virtual/experimental authorization process will make a breakthrough in performance as shown in figure 1.

Irrespective of the type of system to be validated, some generic questions are raised: how simulations can be validated? By who? When and in which configurations simulations can replace field-tests? How do the different stages (laboratories tests, simulations, field tests) should be organized? etc.

Some standards already allow the use of simulations in the validation process for authorization, 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 of approval bodies.

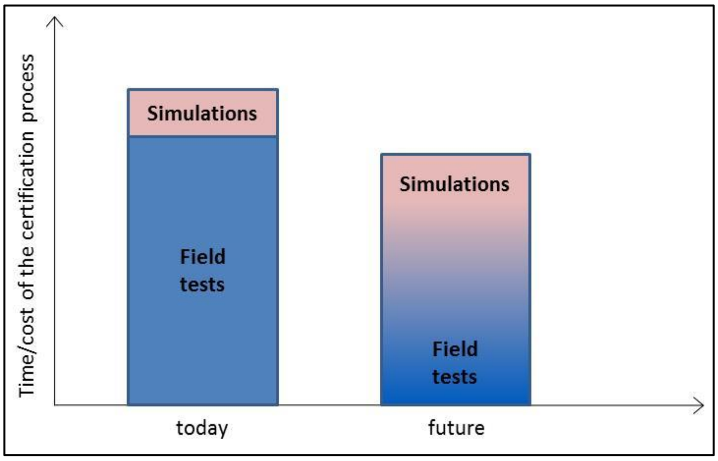


Figure 52: Technical vision for virtual certification

State-of-the-art	New Generation of certification
The authorization process for putting new rolling stock on the market is largely based on line tests, which is 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/virtual methods and practical processes for the certification of components, sub-systems 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 (of the same IP and/or of the other IPs)

The task aims at coordinating 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:

- IP1 – TD1.1. "Traction":
  - Task 1.1.5 – Requirements, specifications & developments for virtual validation and certification (up to TRL 4/5)
- IP1 – TD1.2. "TCMS":
  - Task 1.2.4 – Virtual Placing on the Market
- IP1 – TD1.3. "Car body-shell"
- IP1 – TD1.4. "Running Gear":
  - Task 1.4.7 – Virtual certification of train dynamics
- IP1 – TD1.5. "Braking system":
  - Task 1.5.6 – certification process
- IP2 – 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:

- Life Cycle Costs – reduction in capital costs: reduction of 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 of demands on access to lines for test trains enabling more paths for freight or passenger operations;
- Facilitation of cross-acceptance 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 enabling to test more virtual situations;
- Enhance 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 TRL3 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	• Harmonize and simplify Traction/braking/TCMS/train dynamics/running gear/signaling authorization processes with the aim of putting new vehicles on the market faster ,decreasing cost and duration via introduction of virtual tools • Proof tangible benefits for the end user: LCC reduction
Compliance with EU objectives	• Promotion of modal shift: A big impact brought 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 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	• Depending on the domain, the final results could reach TRL3, in some specific cases TR5. • Recommendations for standards revisions could be given.

This TD will contribute to enable four **Innovation Capabilities** as follow:

Innovation Capability	***Virtual certification enablers***

1- Automated Train Operation	Reduce the duration and cost of validation of new sub-systems (automated trains and signalling systems); help to test new configurations.
4 - More value from data	One of the key-points of success for a virtual approach is the quality and representativeness of input data. Collecting more data will enable to define more realistic specifications and mission profiles, and therefore will improve the whole process for design, validation and authorization for putting in service new trains.
7- Low Cost Railway	By reducing the cost of the certification of rolling stock sub-systems (TCMS, traction, running gear, braking, car body-shell) and signalling systems, with physical-virtual methods will help to reduce the railway LCC.
11- Environmental and social sustainability	By reducing the LCC, mixed physical-virtual authorization will help to promote the railway transportation
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 serenely innovations in their products. The acceleration of the design-validation process will also facilitate the renewal of technologies in the railway sector.

6.3.5.5. Demonstration activities and deployment

WA3.5 will give an overview of the progress in virtual approaches of the different technical domains, share generic methods and define a pracical industrial mixed test/simulation process to reduce time for the authorization for putting on the marketof new rolling stock.
WA3.5 will form a preferential point of contact between the S2R projects and the approval stakeholders and will coordinate the dissemination activities towards the standardization authorities, promoting the derived generic methods and processes.

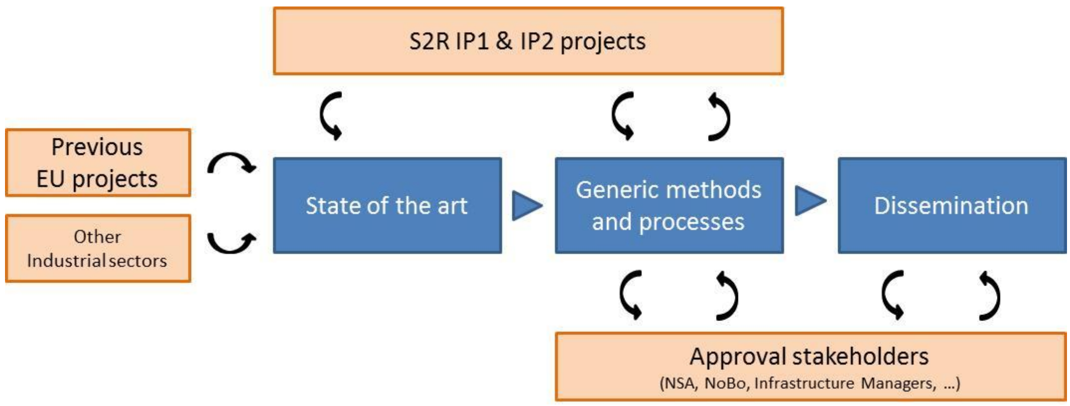


Figure 2: Interactions with stakeholders and deployment

6.3.5.6. 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
WA3.5.1	State of the art, gap analysis and barriers identification	3																												
WA3.5.2	Overview of the generic methods and process	3																												

	milestone
	lighthouse projects
	contracted activities
	planned activities

Table 93: WA3.5 milestones

Q4 2018	Start of Shift2Rail WA3.5 activities
Q4 2019	Plan for the engagement with relevant stakeholders
Q4 2020	Description of generic methods and processes for mixed test/simulation certification

The estimated total budget for Virtual certification TD is around 0,2M€.

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). Sub-WA4.1 Smart Planning

6.4.1.1. Concept

The 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. RU with their fleet and staff planning processes, IM whose assets are in a certain condition, schedule planning and external parameters.

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 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 this data will provide a basis for operating the railway system far more cost-efficient in the long term.

6.4.1.2. Technical Objectives

The goal of the Smart Planning sub-project is to make the effects of planning decisions on large, complex railway networks measurable and predictable, to help decision makers at 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 higher 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 short term.

The main objective is to map the different railway planning activities and basic model development. This meant to lay the fundamentals for an enhanced integrated macroscopic railway simulation system including first development steps concerning impact of disturbances on railway operation.

6.4.1.3. Technical Vision

The end results of WA4 "Smart Mobility" are leading to improved reliability and customer experience, which in turn will lead to reduce system costs and simplify business processes.

Precise railway network simulation will enable Railway Undertakings and Infrastructure Managers to identify operational bottlenecks and harmonise long-, middle-, 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 for the optimum allocation of resources and enhancing the sustainability of the railway system.

The approach for this project will ensure scalability for the task, thereby adding value to the entire European Railway Community.

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

Clear links with WA4.2 and TD2.9 are defined. Once data structure and format of integration layer are clear defined Smart Planning simulations model can be adapted to it and run simulation 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 allow to incorporate substantial detail to 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 to 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 magnitude of stakeholders in the system. This WA addresses the challenge of service quality, the cost challenge and innovation all evoked in the Shift2Rail 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 Single European Railway Area (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 enable two **Innovation Capabilities** as follow:

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 make a reliable planning according to customer requests taking 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 a higher quality delivered to customers
10 - Stations and "smart" city mobility	• give reliable and precise prediction on railway delays due to disturbances relevant for the whole transport chain, especially when travellers taking/ switch to other modes when travelling to/leaving the train station

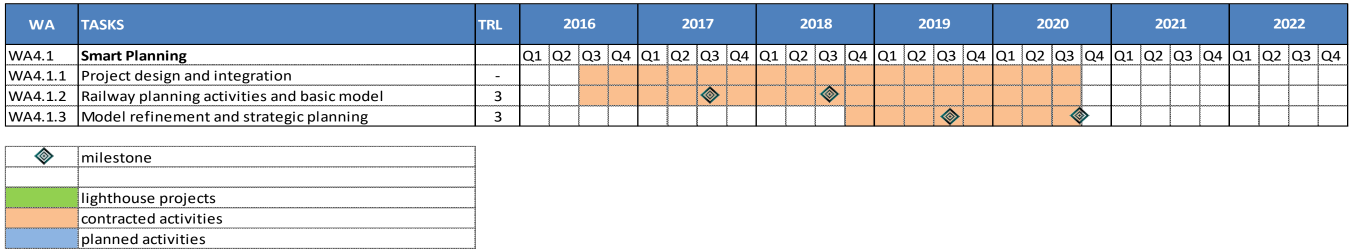
6.4.1.5. Demonstration activities and deployment

A model prototype is developed and the test simulations will be carried out on entire German railway network with runtime of approximately 1 min for one day of operation. Applicability of the model for other networks will be extensively assessed.

Planning and budget

The estimated budget for the sub-WA is around 2,6 M€.

Figure : WA4.1 Gantt chart



Milestones

When	What
Q3 2017	Development of a basic model prototype to 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 (I2M)**

6.4.2.1. Concept

Integrated mobility management must be smart and based on a 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 to ensure compatibility independent from supplier´s 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 level. 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 forecast of traffic status and demand to manage resources such as availability of platforms and terminals, locomotives or coaches, operators, drivers and forecast and others in an efficient way. Maintenance services depend strongly on the dynamic planning of free slots to execute the maintenance activities and updated now-casted and forecasted 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 forecasted traffic asset and freight operations status information into a seamless operation process. The works under WA4.2 are aiming to specify and develop the functionalities needed to deliver in a first step an integrated and automated real-time rail operations process applying now and for-casted data for traffic, asset and freight operations status.

6.4.2.2. Technical Objectives

- Increase of 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 of 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 of the efficiency of Rail Freight Operations: new advanced Business Service SW modules will allow a high precision ETA fore-cast for freight train services and improve the efficiency and the organization of freight handling processes.
- Increase of the efficient 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

WA 4.2 "Integrated Mobility" 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 of all involved services, systems, subsystems, rolling stock and resources applying a standardised data representation format such as the Conceptual Data Model.
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 on-line updates of the current position and status of critical freight for monitoring the consignment, ensuring that emergency activities such as the activation of cooling systems can take place remotely.

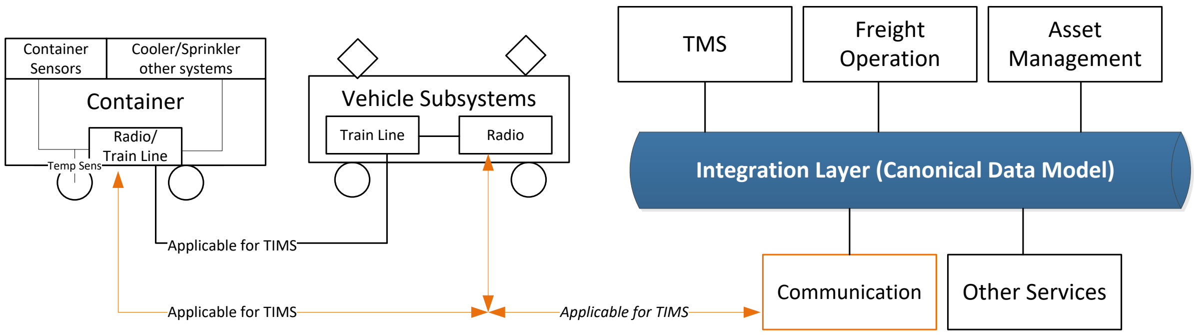


Figure 1: Integrated Data exchange, in a freight scenario

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

- IP2 – TD2.1 "Adaptable Communications": providing concept to utilize the different technologies for a new T2T interface for freight On-board Monitoring and Management technologies
- IP2 – TD2.9 "Traffic Management Evolution" providing Specification for Integration Layer and Canonical Data Model
- IP3 – 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 an effective advantage for the European industry:** WA4.2 I2M will contribute to the following TSIs and official or de facto standards: ○ Shift2Rail Conceptual Data Model to create railway-specific universally applicable data exchange format ○ TAF/TAP TSI (Technical Specification for Interoperability relating to Telematics Applications for Freight/Passenger Services) aiming to define the data exchange between IMs) and RUs. • Increase of operational reliability (less service disruptions) through more robust Traffic Management processes integrating dynamic fore-casted asset status in the decision process and improved efficiency of maintenance operations due to better scheduling following a more precise Traffic fore-cast information • Reduced cost as less disruptions of the train services provide a better utilisation of available resources and energy consumption • Increased capacity due to better tools (applications) enabling to utilize line capacity to a higher degree without de-stabilising the robustness of the time-table
Compliance with EU objectives	• **Achieve single European Rail Area (SERA**): a standardized approach to the integrated data exchange as the one developed within the WA4.2 will reduce the technical obstacles for a proper interconnection of technical solutions. • **Enhanced interoperability:** the usage of a standardized Data format will guarantee that information can be accessible in a to all stakeholders; algorithms, based on a canonical data model, should be able to be easily used by different organizations involved in Traffic Management process
Degree of maturity of the envisaged solutions	At the end of Shift2Rail it is expected some of the successful WA4.2 concepts are 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 works of WA4.2 improve the flow of traffic enabling Automated Train Operations for freight and heavy haul trains and allow automated or remotely controlled monitoring or management of critical freight (food, dangerous goods…) *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* *BBA4.2.6 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 to all subscribed clients or service real time updated status information of the Traffic and information 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 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*
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 high efficient Freight Operations* *BBA4.2.4 Advanced rules and business logic supporting high 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 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*

5- Optimum Energy Use	New functional service application modules of WA4.2 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 *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* *BBA4.2.6 Plug-ins to enable integration of services*
6- Service operation timed to the second	Services, processes and building blocks of WA4.2 optimize 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 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*
7- Low Cost Railway	New application of WA4.2 improve the flow of freight traffic 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 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*

8- Guaranteed asset health and availability	Broadcasting asset status, as well as now- and fore-cast information via an integrated communication network to all subscribed clients/services will lead to an increase 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 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*
9- Intelligent Trains	Innovative applications allow that Critical freight can be monitored during the 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 high efficient Freight Operations* *BBA4.2.4 Advanced rules and business logic supporting high efficient freight operations* *BBA4.2.6 Plug-ins to enable integration of services*
10-Station and “smart” city mobility	• Seamless availability of traffic status fore-cast 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 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*
11-Environmental and social sustainability	• Optimizing the flow of traffic following the introduction of new applications for the TMS will reduce energy consumption and noise and vibration *BBA4.2.1 Technical assessment and integration*

	BBA4.2.2 Upgrade of integration layer *BBA4.2.3 TMS application supporting high e•cient Freight Operations* *BBA4.2.4 Advanced rules and business logic supporting high e•cient 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 close with customers will secure fast deployment in the railway sector *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*

6.4.2.5. Demonstration activities and deployment

Research Area	Specific Techn. 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 according scope of TD2.9	Mainline (Freight)	3/4	Specification and development of new applications
	Interfaces for TMS DB, Asset Management DB and Freight Operation systems	IF for TMS DB, Asset management DB and Freight Operation Services	Mainline	6/7	Specification and development of Interfaces

The partners of WA4.2 which have proposed prototypes for constituents of the system or business application develop 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.

Planning and budget

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA4.2	**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
WA4.2.1	Technical assessment and integration	NA																												
WA4.2.2	Upgrade of integration layer	3/4																			◆				◆					
WA4.2.3	TMS application supporting high efficient freight	4/5															◆								◆					
WA4.2.4	Advanced rules and business logic supporting freight ope	3/4																							◆					
WA4.2.5	Advanced rules and business logic supporting passenger	3/4																					◆				◆			
WA4.2.6	Demonstrator	6/7																						◆				◆		

◆	milestone
(green)	lighthouse projects
(orange)	contracted activities
(blue)	planned activities

Table 94: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 are available Description of Business Rules and Logic to support High efficient Freight Operations
Q3 2022	Prototypes validated

The estimated total budget for WA 4.2 is 8.42 M€.

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 in the European manufacturing rail sector and to limit environment impact.

Energy efficiency simultaneously enables improvement of railways excellent environmental balance by cutting down CO_2 emissions and to improve the economic business model of the Railway Transport sector by reducing the cost of energy, making train travel more affordable and thus promoting the modal shift to rail.

The overall goal is to promote energy savings as well as reduction of CO_2 emission in the whole railway systems including operations, infrastructure, rolling stock, sub-systems (like traction and running gear) and components.

6.5.1.2. Technical Objectives

The overall objective of WA5.1 is to reduce the operational costs through a reduction of 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 objective of the Energy and sustainability WA is:

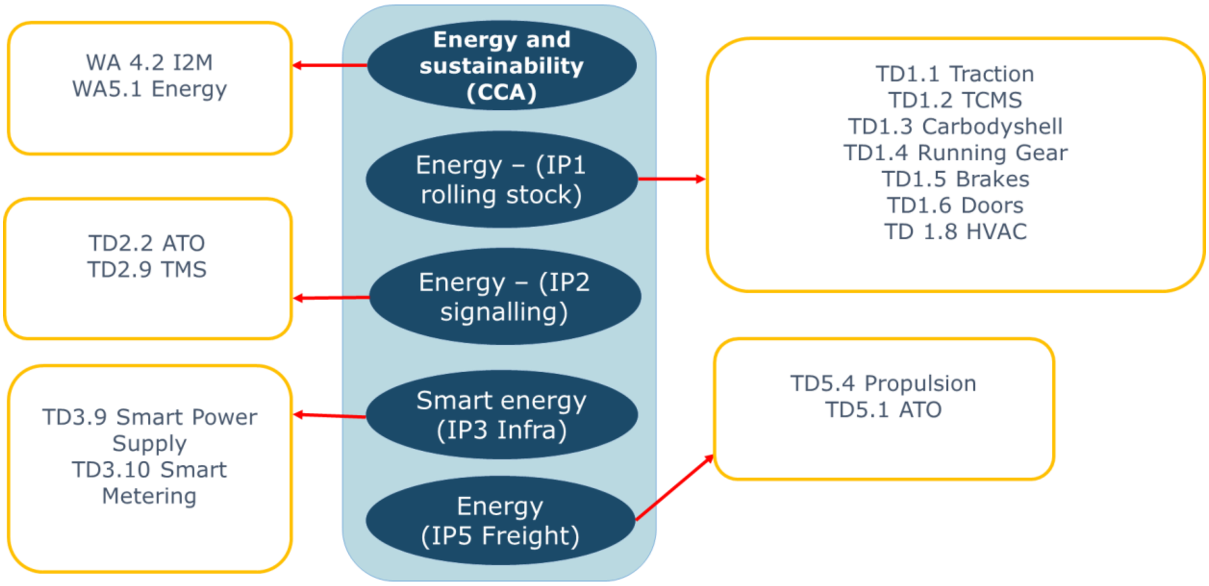
- To define the energy baseline for the four SPDs To achieve and assess the overall energy reduction on all Technical Demonstrators (TD) and System Platform Demonstrators (SPD) as an input to the KPI-monitoring carried out within WA2
- To help and support all energy saving related work across the Innovation Programmes (IP) and TDs
- To stimulate the emergence of pre-normative texts when needed to pave the way toward 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 railway

6.5.1.3. Technical Vision

Developing an energy baseline that covers the speed profiles for the reference lines for each SPD and all energy-relevant data of the reference vehicles. Further, a simulation tool for energy calculation is specified, developed and proofed. Last not least the future railway system concerning energy is described, when all energy-relevant TDs are realised.

The assessment of the energy improvement due to Shift2Rail innovations is 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 how much each TD contributes to the overall Shift2Rail targets. The result of the energy-assessment will be delivered as an input to WA2, where 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 new solution to be deployed on the markets, the framework conditions, existing regulations and standards will be evaluated.

This TD will contribute to enable **Innovation Capabilities** as follow:

Innovation Capability	***WA 5.1 Energy***
1-Automated Train	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 Shift2Rail TDs concerning energy
6- Service operation timed to	Estimation of possible energy improvement due to Shift2Rail TDs for improved service operation
7-Low cost railway	Reduction of energy consumption reduces the LCC

9- Intelligent trains	Estimation of possible energy improvement due to Shift2Rail TDs for intelligent trains
11-Environmen-tal and social	Reduction of energy usage reduces the CO2 impact
12 - Rapid and reliable R&D de-	Standardization of energy quantification enables 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 evaluation 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 railway sector is assessed. In addition, an energy cost sensitivity analysis and EU policies analysis was included.

Technology of the future railway system will consider the implementation of all S2R innovations related to energy, and further relevant technology developments outside of S2R will be analysed. Based on this list of potential energy saving technologies, research activities are suggested that contribute to further improve the energy efficiency of the railway system which will contribute to reduce CO2.

Energy calculation methodology and an energy simulation tool is developed within the programme which considers the 4 S2R System Platform Demonstrators.
Energy improvement coming from the S2R technologies are assessed which feeds into the KPI activity.

Planning and budget

The estimated budget for the TD is around 2,5M€.

Figure 53: WA5.1 Gantt chart

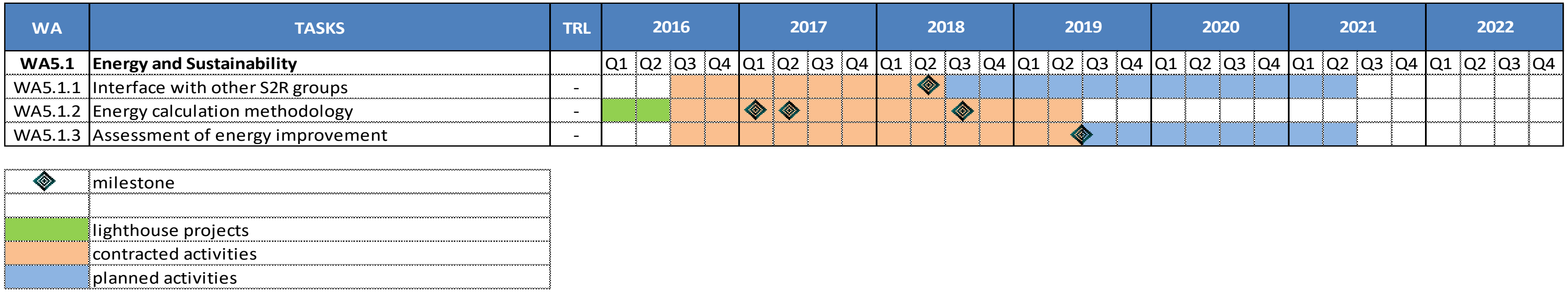


Table 95: TD1.2 milestones

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

6.5.2. Sub-WA5.2 Noise and Vibration

6.5.2.1. Concept

Noise and Vibration (N&V) represent one of the biggest environmental challenges for the railway. The end result of this work area is to support the reduction of exposure to noise and vibration related to the railway sector in Europe. 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 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 system approach and leverage of the results from all the IPs by follow up of 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 a non-acceptable 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 that noise and vibrations are no longer considered a problem for the railways and their neighbours, meaning that noise levels are socially and economically acceptable and allow for 24-hour passenger and goods operations by 2050.*

6.5.2.2. Technical Objectives

The overall objectives are:

- Further develop practically useful methods for predicting noise and vibration performance on system level including both rolling stock, infrastructure and its environment to assure correct decision on sources that need to be reduced to achieve a reduction of the overall levels.
- Calculate the effect considered and integrated in all relevant Technology Demonstrators within the different Innovation Programmes of Shift2Rail
- 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:

i) exterior noise sound emission and prediction, including source contribution separation, to support future updates of TSI for noise;

ii) interior N&V predictions for comfort and attractiveness for passengers and

iii) traffic scenarios including freight segment to reduce disturbance for residents;

iv) auralisation and visualisation of N&V scenarios for future railway systems, and demonstration of mitigation methods and

v) improving prediction models for ground vibration impact studies

In the core of this framework are predictive schemes for interior and exterior noise as well as ground vibrations. Such scheme 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 system level. This in turn is a requisite to arrive at cost effective noise control solutions on system level. Within the project also auralisation methodology are developed for assessment of the expected impact of solutions developed on vehicle and system level as well as on European level.

6.5.2.3. Technical Vision

The end results of this work area should contribute to strengthen the railway sector by improving passenger comfort, facilitating efficient product development and allow capacity increase. Railway vehicles are normally developed and produced in small series with extremely long life-cycles compared to other vehicle types, such as cars, trucks and buses. The small series together with interests to reduce 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 is necessary for the success of the future railway system.

Acoustic design targets are supposed to be defined as a responsibility of each Technical Demonstrator 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 to 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 are covering 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 and acknowledge and point out inherent uncertainties in the state of the art and to allow a 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 method for a virtual design as well as new materials.

Improved certification methods for TSI testing including separating the contribution from the rolling stock versus the infrastructure are of great importance. They will assure that the required noise levels are not obtained only on special low noise testing track. With a development of a 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 the citizens.

The long term goal, to be emphasised in a Shift2Rail2 project, is to move the technology and the simulations a step further to replace costly on track testing with a fully virtual approval for certification as well as customer acceptance for both noise and vibration.

Interaction with other TDs

The basic idea for handling noise and vibration control in Shift2Rail 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 assure 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 the CCA Work Area 5.2. Hence a close cooperation with the TDs controlling the main sources is of great importance for WA 5.2. In the figure below connections for the major sources included in S2R are depicted:

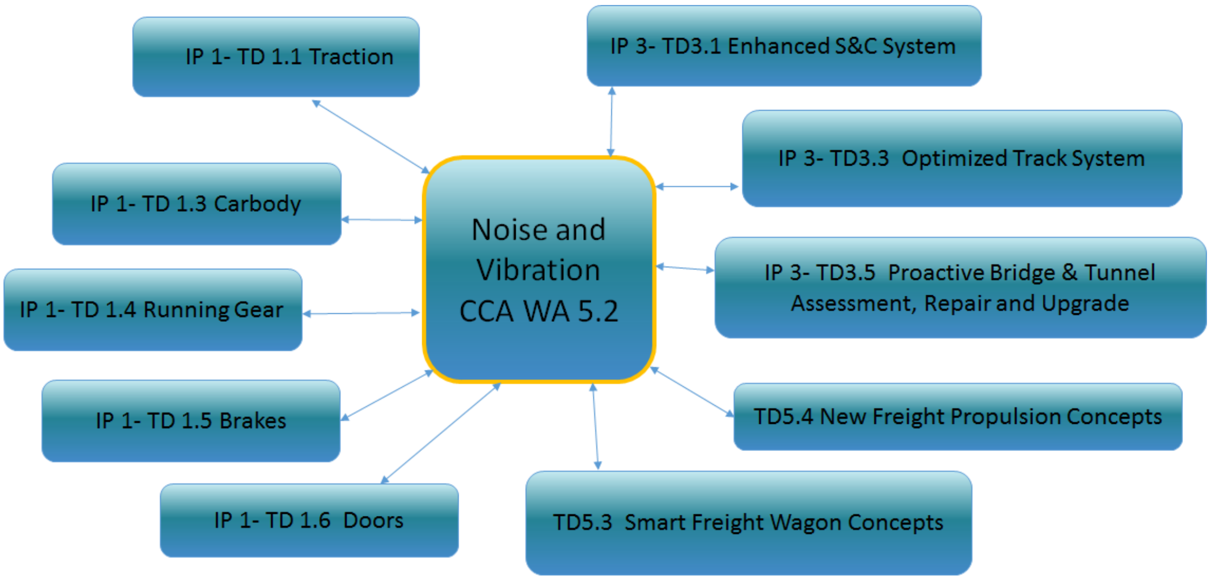


Figure 1: Interaction with other parts of S2R

6.5.2.4. Impact and enabling Innovation Capabilities

The most important impact is to show the effect of S2R development on reduced noise and vibration levels for real traffic scenarios that the public are exposed to. Table below shows the impact of WA 5.2 to overall objectives

Strategic Aspect	Key Contribution from the WA
Support the competitiveness of the EU industry	• More cost efficient N&V mitigation methods thanks to proper ranking and system level analysis • Increased passenger comfort and attractiveness of railways with improved interior noise and vibration
Compliance with EU objectives	• Avoid limiting capacity due to restrictions on noise • Develop simulation methods for virtual design and testing
Degree of maturity of the envisaged solutions	The models and tools will be brought to TRL 5.

This WA will contribute to enable **Innovation Capabilities** as follow:

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 investments 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 – noise and vibration 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 system level i.e. including both rolling stock and infrastructure and considering the 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 long-term to fully virtual certification for new rolling stock on Europe

Promote new technologies to be studied for applications to reduce N&V.

Planning and budget

The estimated total budget for WA 5 is around 8.0 M€.

WA	TASKS	TRL	2016				2017				2018				2019				2020				2021				2022			
WA5.2	**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
WA5.2.1	Technical assessment and integration on system level	-																												
WA5.2.2	Evaluation and monitoring of impact on traffic noise	-																												
WA5.2.3	Exterior noise simulation model and separation	-																												
WA5.2.4	Interior noise simulation model	-																												
WA5.2.5	Ground Borne Vibration Prediction Methods	-																												
WA5.2.6	Sources and sub-assemblies characterisation methods	-																												
WA5.2.7	New methodologies and technologies	-																												

	milestone
	quick win
	lighthouse projects
	contracted activities
	planned activities

Table x: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.

6.6. CCA Work Area 6 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 and
- Massive introduction of technical innovations (e.g. digitalisation and automation).

The overall objective of this Work Area is to study the effects of these developments on the human resources and manage the changes on the human capital side (e.g. change 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

WA 6 has the following objectives:

1. Study the impact of demographic change and the massive introduction of technology on human capital in the railway sector
2. Develop a concept on the management of changes on the human capital side (e.g. change 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 railway sector is

to support the availability of an adequate number (quantity) of human resources in the railway system that 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 which contribute to digitalisation 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 1.

Table 1: WA6 links to Master Plan objectives

Strategic Aspect	Key Contribution from the WA
Support the competitiveness of the EU industry	Innovative technologies such as digitalisation 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 trainings and opportunities to move to more attractive job profiles and to train experts with specific skills
Compliance with EU objectives	It will support the life-long learning principle by providing trainings and means to adapt to the skills needed for the future jobs
Degree of maturity of the envisaged solutions	The sector analysis the impact of the new technologies on human capital aspect, preliminary ideas for the changing job profiles are developed.

Further, human capital will contribute to enable the **Innovation Capabilities** as follow:

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.
3-Logisitcs on demand	Planning and scheduling are synchronized 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	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 for reduced time and cost of product deliveries and 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	HC assures 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 sys-tem 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 the 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 on the management of these changes on the human capital side (e.g. change in job profiles, skills, and organisation) of the sociotechnical railway system, imposed by the massive introduction of technical innovations. Furthermore, WA 6 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

The estimated total budget for WA6 is around 520 k€.

Figure 1: WA6 Gantt chart

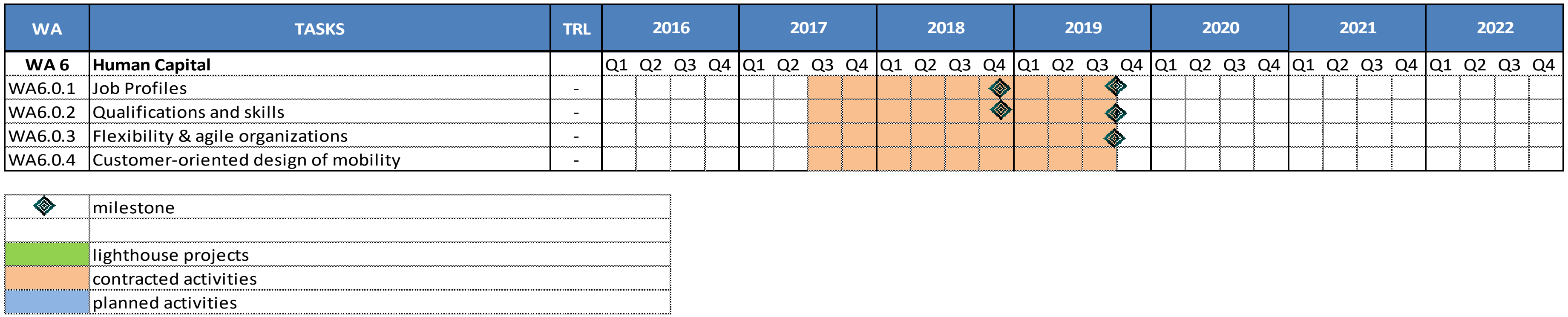


Table x:WA6 milestone

When	What
Q4 2019	Defined job profiles
Q4 2019	Final skills and qualifications
Q4 2019	Concept for agile organisations

7. IPx

Since the start of its activities, the S2R Programme highlighted in different manner 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 cost-driven evolving needs as well as, 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 launch the S2R Research and Innovation activities and address the programme related issues, 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 of the value chain were duly taken in consideration in a functional approach to the new systems and solutions.

In this respect, more concrete reflections on new system approaches started on the control command and signalling side since the work initiated in 2018 by some Infrastructure Managers with a Reference Command Control Signalling Architecture (RCA) and recently by some Railway Undertakings with an Open CCS On-board Reference Architecture (OCORA). This also in the continuation of 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 Conceptual Data Model (CDM) that will contribute to overcome "data" and "systems" fragmentation with a view to produce 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".

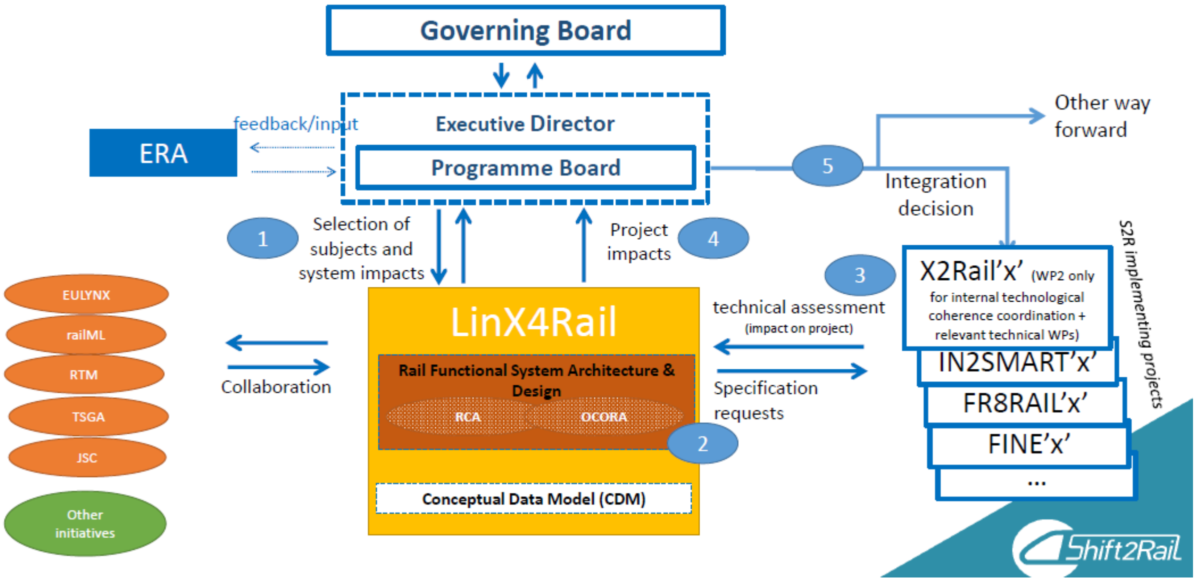
A series of activities under the acronym "IPx" would support the achievement of such a System of Systems Approach and with those "IPx" activities S2R is looking beyond currently planned technology applications (of the Technology Demonstrators described in the Section 2 above) and integrating them with disruptive innovations. In this context, arising and promising disruptive technologies are investigated (e.g. A.I., robotics) as they would enable new concepts for the future autonomous railway vehicles "train-centric", for automation systems and maintenance, for mobility as a service (MaaS), for industry 4.0 (automated industry and industry as a service), for railway clouds and decentralised ownership that will also contribute to shape the new railway architecture.

The work 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 the railway 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 acitivities, starting with the integration in S2R of Reference CCS Architecture (RCA) and Open CCS on-board reference architecture

(OCORA) initiatives and looking at EULYNX, railML, RTM, IFCRail and considering new initiatives (e.g. O&M - SensorML, TransducerML, MaaS API …).. The work is divided into two streams:

- Conceptual Data Model (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 same vision of the future.

In order to create a reference architecture for railways and ensure its wide adoption, IPx wills work in conjunction with all IPs and CCA and liaise with the S2R Programme Board to streamline the change management within the running projects.



This work can become the base for a 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 set the ground for multimodal collaboration, especially in area dealing with similar aspects such as air traffic management, smart mobility, etc. It will also provide a new set of business cases and potentially new services that implementing a new system of system architecture and a new approach in sharing data, will prove in S2R benefits and performance that would potentially override any concen on migration costs. The work would consider also the initial integraton one at European level, collaborating with the EuropeanUnion Agency for Railway, for example with the ERA registers (e.g. European Register of Authorised Types of railway Vehicles), national vehicle and infrastructure registers but also with sectorial General Contract of Use for Wagons (GCU) or government to business services.

As the innovation does not necessarily stem from the technical advances, the actions should also have a closer look at the business innovation based on (access to and exchange of) CDM-enabled data and the System of the Systems approach with 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 railway sector to get a better understanding of potential implications on the lifecycle cost of the infrastructure, especially in the context of reusing the existing (commercial) network and spectrum, and the implications on 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, C-ITS, M2M, that would need to be assessed.

While LinX4Rail project stays 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 deploymen of TDs, and contributing to the main S2R objectives. For example, the work would look into further application of Artificial Intelligence (for example for image detection on autonomous train operations) and Big Data tools in railway, explore the new approaches to deployment of IT services, such as 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 (e.g. low-power wide area network – LPWAN, LoRa, MESH…).