RAIL 2030

RESEARCH & INNOVATION PRIORITIES

ERRAC
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RESEARCH & INNOVATION PRIORITIES

Glossary

ACS:	Adaptable Communication System
AI:	Artificial Intelligence
ATO:	Automated Train Operation
ATS:	Automated Train Supervision
BIM:	Building Information Modelling
B2B:	Business to Business
CAPEX:	Capital expenditure
CBTC:	Communications-based train control
CCA:	Cross Cutting Activity
CCS:	Control Command Systems
CCTV:	Closed-circuit television
CDAS:	Connected Driver Advisory System
CEF:	Connecting Europe Facility
CERT:	Cyber Emergency Response Team
COTS:	Commercial off-the-shelf
DAS:	Driver Advisory system
ESS:	Energy Storage System
ENISA:	European Union Agency for Network and Information Security
ERRAC:	European Rail Research Advisory Council
ERTMS:	European Rail Traffic Management System
ETCS:	European Train Control System
FRMCS:	Future Railway Mobile Communication System
GoA:	Grade of Automation
GNSS:	Global Navigation Satellite System
GSM-R:	Global System for Mobile Communications - Railway
HMI:	Human Machine Interface
HVAC:	Heating, ventilation, and air conditioning
I2I:	Infrastructure to Infrastructure
ICT:	Information and Communications Technology
IoT:	Internet of things
IP:	Innovation Programme
IPR:	Intellectual Property Right
ISO:	International Organisation for Standardisation
IT:	Information Technology
ITS:	Intelligent Transport System
LCC:	Life Cycle Cost
KIC:	Knowledge and Innovation Community
KPI:	Key Performance Indicator
MaaS:	Mobility as a service
MOCC:	Multimodal Operation Control Centre
NaaS:	Network as a service
NIS:	Security of network and information systems
OPEX:	Operating expense
RFI:	Request for Information
RFP:	Request for Proposal
SETA:	Single European Transport Area
SI:	Swarm Intelligence
SIL:	Safety Integrity Level
TCMS:	Train Control and Monitoring System
TMS:	Traffic Management System
TRL:	Technology Readiness Level
V2I:	Vehicle to Infrastructure
V2V:	Vehicle to Vehicle

Contents

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1. Rail 2050 Vision and the Contribution of Shift2Rail

RAIL 2050 Vision (ERRAC, Dec 2017) contributing to the development of the Single European Railway Area, presented a clear view of how Europe's railway system could maximise its contribution to mobility for Europe's citizens and logistics, based on technical innovation and the need for a supportive research environment to deliver this over the coming decades. Supported by the European Research Area, it advanced this in five points:

- the political goals of economic development, improved social cohesion and, at the same time protecting the natural environment, require a base of much improved mobility;
- only rail can provide the backbone of this mobility, within an integrated transport system;
- opportunities for radical systemic improvements exist – based on the deployment of emerging technical capability;
- delivering these improvements needs research and innovation;
- EU funding is needed for this research, to overcome fragmentation resulting from structural market failures - it represents a sound investment for Europe.

A key feature of the Vision and the methods being adopted to bring it about is the focus on ways to reduce the overall cost of the railway system, rendering it more affordable, with a reduced call on public funding support. This capability to deliver service at lower cost, founded on concepts such as modularity, standardisation and an efficient supply chain, will underpin strong business cases for the extension and integration of rail-based solutions within the overall transport mix to serve all the citizens and businesses of Europe.

The key activities of the Vision are customer-centric and market/demand driven. The benefits accrue only if there is market uptake of the new products and services. So, the vision places a strong emphasis not only on the technical developments within the research and innovation process but also on all the other related factors which need to align to ensure successful deployment and implementation. These include a continuing comprehension of changing transport market trends and their drivers, which affect demand for railway services, and the introduction of appropriate and timely authorisation, standardisation and regulatory processes, which affect the speed of delivery to the market.

The principal delivery mechanism for European rail research and innovation is currently the Shift2Rail Joint Undertaking, which operates within the framework of Horizon 2020. This has already made a very significant contribution to the sector, enabling it for the first time to federate its efforts in a way unparalleled in other sectors – bringing together a broad-based representation of train service and infrastructure operators, manufacturing industry and other suppliers, academia and research institutions in a unified research and innovation programme. This collective approach has allowed sensible risks to be accommodated for cutting edge research, which would not have been possible if left to individual actors operating alone. It has provided the scale and critical mass to justify engagement with technology developments external to the rail sector, such as silicon carbide electronics. Crucially for delivery timescales, Shift2Rail has approached standardisation processes in a coherent manner, challenging timing and assumptions, and developed new solutions that are interoperable by design. Both are making inroads in accelerating the time to market. These solutions are based on delivering identified capabilities for the railway system of the future. The solutions align with both the industrial and operational plans and the wider EU economic and social challenges mentioned above. Shift2Rail has created strong links with national and regional investment and R&I to meet EU objectives. Overall, it has made the sector much more innovative, investing increasing amounts in research and innovation, which will have multiplier effects. Externally this has encouraged SMEs, previously put off by the sector, to engage and prosper within rail. Ultimately it has placed the user – both passengers and shippers – properly at the centre of rail research and innovation.

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2. The Backbone of Mobility in 2030

Reaching the 2050 Vision requires consideration of the stages between today and then, particularly which aspects of the vision should be delivered by each stage, as a guide to formulating the priorities for research and innovation. The first such stage is the period to 2030, the focus of this document.

Enhancing the European transport sector, the railway system of 2030 will make wider social, economic and environmental contributions. It will produce significant value to the wider economy thanks to a variety of innovative technical and operational solutions which will have been developed. These will contribute to the creation of new added-value, green, EU based jobs and the reduction of negative externalities such as air pollution, greenhouse gas emission and noise. Taken together, the introduction of the new technologies will create a substantial increase in the productivity of various non-transport sectors. It will do this by reducing the transport costs of industry and other businesses, increasing their efficiency, and accelerating the availability of new options to meet the expectations of society and legislators, in particular for a more sustainable society and to maintain and improve European competitiveness as a whole.

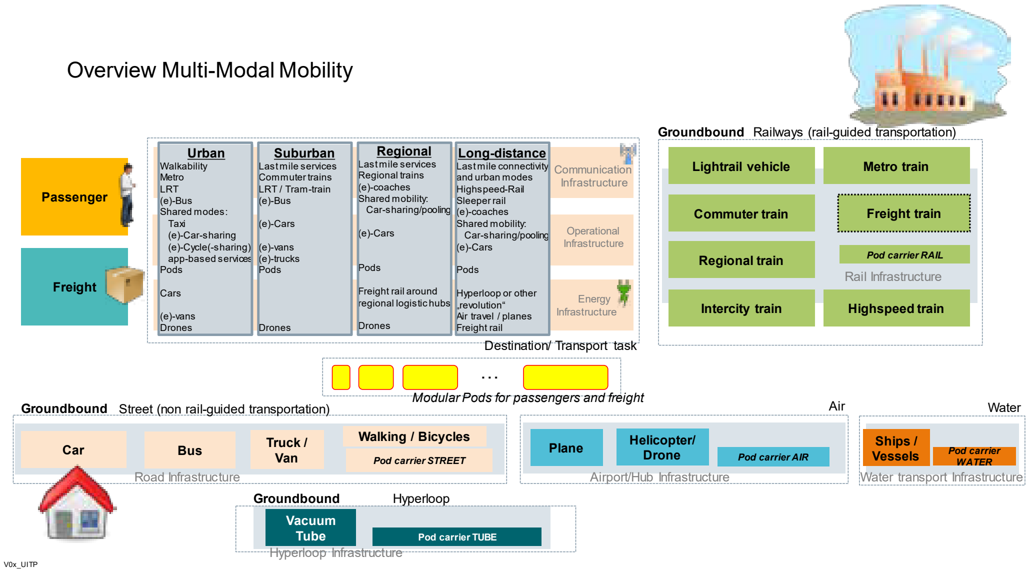
The 2030 rail system will interact with other transport modes and with local, regional, national and European economic activities in transformational societal changes and trends. Safe, reliable, comfortable and efficient rail services will influence and benefit many different areas, such as lifestyle,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

These priorities, which form the base for rail research and innovation, are described in more detail in section 3.

The objective of the sector is to offer end-users/citizens easy and seamless access to a portfolio of sustainable mobility options which have rail as their backbone.

Delivering this objective means we must improve current customer experience of transport services. Today the needs of passengers and freight shippers are covered by multiple modes of transport and different segments within each mode. These tend to operate in silos and have difficulty working together to meet the variety and complexity of their customers' overall needs in a simple, holistic and effective way. This often leaves customers dissatisfied with their daily travel experience.

Figure 1 below illustrates the complex multi-modal transport ecosystem, including recent and prospective market offers based on new technical innovation.



The current social/business context and the on-going technological developments open new opportunities to change the world of transport and enable the different modes and segments to work together for the benefit of the end-users/citizen. Railways are well placed to play a central role in this process. The long-term vision for rail transport as presented in the Rail 2050 Vision has rail transport **as the backbone of future mobility in a multi-modal context**. The sector proposes a set of time-focused concrete plans to transform this vision into reality. These will be based on the identification of the right questions to answer in each ten-year time period and setting meaningful and influential milestones in a logical, coherent chain.

This vision will target:

- automation of the railway system (Zero capacity waste for full reliability and flexibility and accessibility);
- intelligent assets lifecycle management (Zero failures for full asset availability)
- integration of the railways in a door to door mobility ecosystem (Zero service gaps for full user-convenience);
- environmental sustainability and carbon free mobility (Zero energy waste, zero carbon footprint and full green power);
- safety and security (Zero casualties).

EU funded research programmes, including Horizon Europe, are essential tools providing the framework to implement this vision. With their support, the rail sector can be positive about its role and ability to make a major contribution to addressing key social challenges from now until 2030, in ways described below. Taking account of the global and European trend of urbanisation, the challenges and opportunities faced by the rail system will increase. It is therefore the right time, from now to 2030, to set down the foundations of the solutions which will address them in a proper way.

The three key challenge areas are:

- with the mobility landscape changing quickly the 2030 railways sector will meet the evolving needs of end-users/citizens and businesses: **attractiveness and convenience** need to be provided in real-time, tailored within an end-users/citizens-centric environment, through an integrated door-to-door mobility system that provides a punctual, reliable, safe, secure and comfortable service;
- **maximised affordable** capacity of the system is key to reducing congestion and providing efficient and economical transport solutions for cities and regions. Part of this can be achieved through optimisation with little or no construction of infrastructure. However, if railways are to become the backbone of customer-centric mobility, bottlenecks in the most congested areas will also require new infrastructure. Rail is the only mode of transport that provides the capacity needed in future transport systems, at least with reasonable land use, especially in urban areas;
- **environment sustainability**: With a significant proportion of emissions coming from mobility, pursuing sustainable mobility is essential. As the railway is the cleanest mode of transport, promoting modal shift towards rail will support the reduction of emissions. But this is not enough, so rail will implement new technical solutions for non-electrified lines and further increase its energy efficiency. Improving the integration of transport systems in populated areas by reducing noise, vibration and carbon emissions will be essential to increase social acceptance in urban environments and beyond. Indeed, rail systems are contributing to mitigating the climate change challenge.

Addressing these key challenges, the railway has the potential to become the backbone of mobility by 2030. The current technological and social context offers specific opportunities to act in this direction. The rail sector will answer these challenges by promoting and implementing solutions in the following **key innovation areas**:

- **digitalisation:** a fully connected and integrated digital railway (system, sector and process) will be the basis of efficient asset management. For instance, digital control-command will raise the quality of the operation and support resiliency and capacity, while new end-users/citizens-centric services will raise the system's attractiveness. The digital railway will drive the integration of the overall mobility digital eco-system for all transport modes. Digital Asset Management will be the basis of digital end-to-end mobility for passengers and freight, supported by a resilient and powerful telecommunication network;
- **automation and Artificial Intelligence:** real time management of the operation, along with new concepts such as virtual coupling and platooning, will support the increase of flexibility in operations. Autonomous trains and automated freight operation will bring additional predictability and versatility. All these elements together will support an increase of the capacity and resiliency of the system without major infrastructure investments. It will also lead to more end-user/citizen satisfaction from improved traffic management enabling better punctuality and comfort and more flexibility for real-time demand fulfilment;

- **sustainable solutions:** globally connected energy management systems will be a step towards more sustainable mobility solutions. Holistic energy management systems will allow very efficient use of energy and the minimisation of energy losses. Societal demands will be covered by environmentally friendly solutions (e.g. alternatives to diesel, reducing noise, vibration and emissions) and developing pro-active security systems in rail. In addition, green synergies with other transport modes, such as electric road vehicles, will decrease the global transport sector's footprint by improving energy recovery and energy-shared optimisation. Additionally, the initial integration with other transport modes within this shared energy system may open the door to further opportunities beyond the transport sector for the following years (e.g. targeting smart grids by 2040-2050);
- **cost efficiency:** digitalisation of engineering, operations and maintenance activities will reduce the overall cost of the system. For example, the digital twin of railways and virtual authorisation techniques will optimise 'time to market' for railway solutions. Widespread use of the digital twin, with BIM as a prerequisite, will facilitate multi-stakeholder sharing and delivery speed and quality, as well as sustained asset management monitoring on a life-cycle basis. Digitalisation will benefit from existing and on-going developments related to maintenance activities, such as non-invasive inspection methodologies or predictive maintenance based on big data analysis and the internet of things and other smart devices (e.g. beacons). The digital twin will allow clever and timely interpretation of data into meaningful information, leading to a radical transformation of the business planning and therefore cost-efficient drivers;
- **fast track to the Market:** in the current context it is essential that innovation is quickly deployed and implemented. More efficient bottom-up standardisation mechanisms and simplified regulations will support the implementation of innovations. Standardisation will be defined in a holistic way so to fit into the whole transport sector's needs and in collaboration with other modes, e.g. when tackling digitalisation standards. This includes new thinking for the design of business models;
- **new mobility solutions:** as digitalisation and automation are developed and deployed, new opportunities for radical changes to the transport system will appear, easing its transition from being an asset business to becoming a service business where the end-users/citizens do not own their mobility assets but pick conveniently from a portfolio of services, called "Mobility as a Service", designed around the most sustainable options for each use case or need. These range from the development of railway systems based on shorter but more frequent trains that can couple together virtually, to multimodal shared-mobility solutions with full integration with other modes of transport and even totally new types of transport based on railways, such as personalised pods capable of being transferred to pod-carriers based on rail, road, water and even air. This level of modal integration will be matched and facilitated by developments in stations and terminals, which will act as 'mobility hubs' to meet the full range of user needs.

1 CHALLENGES FOR THE MOBILITY OF 2030

ATTRACTIVENESS & CONVENIENCE

- **End-user/citizen driven** services (passenger & logistics)
- Integrated **door-to-door** mobility
- Minimising Journey Time. No waiting times
- **Punctual, reliable & secure**
- **Comfortable** & quiet
- **Affordable and tailored** for all needs

MAXIMISED AFFORDABLE CAPACITY

- **Matching capacity with demand**
- **Affordable** and minimising infrastructure changes
- **Resilient** transport system and quick recovery
- **Customised & Flexible:** adaptable to changing needs

SUSTAINABILITY/SECURITY

- **Decarbonised mobility**
- **Energy efficiency**
- **Reducing congestion** in populated areas
- **Limiting noise, vibration and ground space**
- More secure and resilient

"The rail sector addresses these challenges as the backbone of integrated mobility"

2 THE RAIL SECTOR'S ANSWERS TO THESE CHALLENGES (Supported by Horizon Europe)

DIGITALISATION

- Connected & integrated railways
- Intelligent & cost efficient asset management
- Cyber-security solutions
- End-User/citizen-centric services
- Digital control command

AUTOMATION

- Real time operational management
- Trains running closer together: Platooning & virtual coupling
- Autonomous trains
- Automated freight operation
- AI & Robotics
- Extracting value from data

NEW MOBILITY SOLUTIONS

- Seamless integration between modes of transport
- Smaller and more frequent trains
- New types of rail transport solutions (pods & others)
- Stations and terminals as mobility hubs

SUSTAINABLE SOLUTIONS

- Green energy technologies
- Interconnection between Energy and mobility systems
- Apply digitalisation to energy
- Silent railways
- Pro-active security
- Non-invasive inspection solutions

3 COST SAVINGS AND DEPLOYMENT OF INNOVATION

Improved deployment, bottom-up transport-system standards solution, better adapted /regulation/certification (virtual), rapid deliveries…

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3. Research priorities

3.1 Automation of the Railway System including Automated Train Operation (ATO)

3.1.1 Context

To provide relevant solutions to mobility needs, railways will benefit from automated and autonomous systems. This has been widely demonstrated at urban level, where Communication Based Train Control (CBTC) supports advanced automation of many urban lines. While CBTC and new sensors will continue to improve and deliver maximum capacity on the most heavily patronised corridors for metros and some commuter railway lines, major investments are also being made in automated systems for conventional and high-speed rail. Today, the deployment of European Rail Traffic Management System (ERTMS) is the basis for a progressively more automated interconnected railway system. ERTMS combined with new technologies and sensors would allow "smarter" trains running more efficiently, closer together, more safely and at the same time overcoming the challenge of driver shortage.

Higher levels of grade of automation (GoA) can help rail to progress towards key ambitions:

- better sustainability through optimised energy management;
- more reliability of the system due to increased resilience;
- economic competitiveness by increased capacity;
- more flexibility by real-time adaptation to demand.

To move towards these ambitions, it is now crucial to integrate existing products, technical bricks delivered by R&I programs, in particular Shift2Rail, while facilitating the introduction of further innovations. This will enable the delivery of new solutions enhancing railway performance:

- advanced interoperable train control systems;
- advanced traffic management (TMS);
- towards Next Generation of Control-Command 4.0;
- intelligent and autonomous vehicles;
- automation of the logistics chain.

For these solutions to emerge, new connectivity and automation technologies for vehicles and infrastructure will have to be developed and integrated. Sensors, software, systems-of-systems, high performance computing and artificial intelligence will help the railway to deliver enhanced mobility.

3.1.2 Achievements in Shift2Rail

For passenger trains, Train Control and Monitoring System (TCMS) is a necessary development for an automated global rail system, for example by providing train-to-train communication. Safety in future autonomous door solutions, highly accurate brake systems and virtual coupling are prerequisites for automated rail systems allowing increased traffic capacity.

The activities undertaken in the "Railway network capacity increase (ATO up to GoA 4)" are also a key driver for automation and autonomy. ATO GoA2 operations will be demonstrated, supported by Traffic Management System (TMS) interface integrated with ATO. And relying on the future Adaptable Communication System (ACS) the proposal for the next generation of telecommunications.

Cybersecurity embedded by design in products and the use of scientific tools such as formal methods are also key outcomes. The introduction of moving block systems, positioning technologies and on-board train integrity features provide a more efficient approach towards the evolution of the Control Command Systems (CCS), contributing to increasing capacity and reducing trackside equipment.

Automated freight train & logistics operations are of importance for competitiveness. They are supported by the fast development of wagon intelligence (embedded sensors and telematics), automatic coupling for boosting operations and as an important enabler for reliable data connections through the train, automatic locomotive/wagon features such as, train preparation, train dispatch, train stabling and train parking.

3.1.3 Required for 2020-2030

ERTMS is the basis for building future mainline solutions. These developments will enable further innovations in the functional landscape, using emerging technologies. For the metro, CBTC and technologies derived from C-ITS will allow a smooth transition from Full automatics GoA4 towards Full automatic and autonomous train control.

Advanced Interoperable Train Control systems

Advanced interoperable train control systems will deliver more flexibility in operation therefore better real-time adaptation to the demand and economic competitiveness by increased capacity.

To achieve advanced interoperable train control systems, key technology enablers are identified. Their suitability for railway application and their integration in the railway system will be boosted by collective research and innovation actions:

- fast, safe, secure, reliable and high capacity connectivity in the railway system, supported by the latest telecommunication: this will require the implementation and full deployment of the ACS/FRMCS after the allocation of the adequate frequency bands;
- safe, reliable and accurate train positioning: for mainline and freight railways, Global Navigation Satellite Systems (GNSS), notably Galileo, are an essential part and supported by additional sensors to achieve the required performance;
- advanced train control and monitoring system, in particular traction, brakes and doors control aiming to better performance: Future solutions need enhanced safety features fulfilling additional automation requirements;
- a reliable environment perception: the identification of all external hazards (obstacle detection, environmental monitoring) is essential to enable on-board decision-making intelligence (before possible collisions and after collisions to speed up the recovery time);
- for urban rail, advanced train control systems will continue to be developed around CBTC solutions and new autonomy capabilities, especially useful to deal with degraded modes.

Advanced Traffic Management (TMS)

Advanced traffic management can help energy optimisation, support operational resilience and flexibility while increasing infrastructure capacity. Advanced traffic management solutions will emerge by integrating studies, tools and solutions developed in Shift2Rail, it will also benefit from new technologies:

- artificial intelligence to support operation and to optimise the management of resources. This will lead to better predictive capabilities, on demand solutions and smoother intermodal connections;
- data mining and management in order to facilitate the integration of various technical systems supporting mobility services. Scenario-based simulation will support decision-making while historical data can support machine learning, and therefore contribute to progressive decision automation;
- traffic management application will become independent from the physical system and leverage a common data lake for more efficient railway traffic management;
- new standards for remote control and drive functions will deliver enhanced levels of automation, helping to smoothen and maximise traffic on railway lines.

Towards Next Generation of Control-Command 4.0

The next generation of Control Command 4.0 will help to leverage the benefits of the combination of autonomous, intelligent and highly responsive vehicles able to communicate with each other and with the intelligent infrastructure.

Migration towards the new generation of control command needs global and innovative approaches:

- various levels for the control and management of the system (infrastructure and vehicles) in order to optimise capacity and avoid conflicts;
- cybersecurity will be managed by design and routed in the physical layer;
- trackside components dedicated to the control-command operations will have migrated from the ground to the cloud. The only essential field elements in the track that will remain will be "Smart radio-connected all-in-all wayside objects" for switches and level crossing. The controllers for these devices will have to be connected via an internet-based interface to route management;
- virtual train configurations composed of non-mechanically coupled vehicles (platooning) will maximise the benefits of automation;
- close collaboration with other mobility sectors will allow to integrate new technologies within railway systems while developing the necessary technical interfaces facilitating multimodal transport services.

Intelligent and Autonomous Vehicles

It is a natural development that vehicles will have to become more intelligent in a more automated system. For a smooth implementation, policy aspects, such as the competitiveness of the various stakeholders involved, will be included from an early stage.

Some key enablers for intelligent and autonomous vehicles still need to be developed:

- infrastructure and environment monitoring: through sensors, and artificial intelligence with long range abilities offering cooperative mechanisms and communication and a more global intelligence;
- self-healing/management of vehicles (e.g. door management, intelligent closed-circuit television (CCTV), smart subsystems in general) ready for remote control and supervision;
- vehicle to Vehicle (V2V) communication in order to decrease the costs of operations on low traffic lines, progressing towards a less centralised system of supervision and therefore facilitating the autonomous control-command of the train;
- lower and/or lighter vehicles such as a pod/pod carrier concept, being adapted to the traveller needs, are permitted by the greater flexibility of the control-command system. They are easily connected by virtual coupling (platooning) forming virtual trains to optimise the use of the infrastructure;
- advanced vehicle-to-vehicle communication and AI-technologies, which will enable Swarm Intelligence (SI) whereby autonomous units cooperate in aggregates (swarms), running as single car or as virtual train configuration;
- connection of railway vehicles to the road infrastructure by Intelligent Transport System (ITS), which should ease connection to other modes and thus permit more connections for a complete mobility system: for instance, the management of level crossings, passenger exchanges or smooth street-tram operation.

Automation of the Logistics Chain

Digitalisation will strengthen the end-users' communication and set up a direct link to the production process of the rail freight system and to other transport modes.

New solutions for the automation of the logistic chain will help expanding the initial developments at the layer of communication, production process, assets and services:

- the automation activities for freight trains, marshalling yards and intermodal terminals need to enter the next step of maturity in the direction of a fully automated rail freight system;
- intelligence of the assets especially on rail freight wagons need to be linked to the Internet of things (IoT).

Running trains on GoA 4 is the next step. Real time information provided by intelligent assets and IoT will increase the level of automation of the production process towards full automation.

3.1.4 How to Ensure Migration to 2030

The path towards more automation and autonomy at a system level will be eased by the development a common and shared architecture based on a modular framework as a reference. It should facilitate migration strategies and adaptations to specific business challenges while supporting the introduction of state-of-the-art technology (e.g. track and vehicles sensors, 5G, formal proofing, quantum computing, new human machine cooperation strategies).

Migration towards new solutions need also to be anticipated:

- trackside control line detection should only be considered as an intermediate step for automation on the non-ERTMS equipped part of the network;
- during the migration period, suitable driver Human Machine Interface (HMI) for remote train operations and automated train operation (GoA2 to GoA4) will be necessary to keep a high-level performing driver;
- the technical complexity arising from non-harmonised operational rules needs to be analysed in order to identify opportunities for simplified technology either emerging from newly harmonised rules or solving “by design” the diverging local constraints usually exported to the human factor;
- standards and interoperable systems and sub-systems (ATO on board, ETCS on board) should be sought as far as possible to preserve the competitiveness of the mode.

3.2 Integrate the Railways in a Door to Door Mobility Ecosystem

3.2.1 Context

End-users/citizens’ needs are changing with the introduction of digital technologies. People are always connected and expect mobility offers which are versatile, resilient, selected in one click, with fully transparent information, going more and more towards “on demand” door-to-door integrated mobility. The success of new “modes” of transport are today largely based on their capacity to answer these digital needs.

To remain the backbone of mobility, railways must respond to these challenges and improve the integration of rail in the new wider mobility ecosystem:

- propose to end-users/citizens (passengers and freight) seamless access to the services associated to the journey, in which rail is integrated with the other modes of transport and provide a continuous support during the journey;
- offer users/citizens and businesses a variety of transactional schemes for payment, settlement and accounting for mobility that integrate seamlessly with their digital identity and across providers of other personal and business services;
- improve integration of rail to the mobility ecosystem, by enhancing digital connections and accessibility with all the other modes, developing the means to manage properly the interfaces, allowing a combined reaction in case of events/disruption, and developing the elements of a multi-modal traffic management platform;
- develop enough versatility to adapt in real time the rail mode to the actual passengers/freight demand in to contribute to the door to door “on demand” mobility;
- facilitate physical interchanges of people and goods at mobility and logistics hubs.

The emergence of new transport modes allows cities and regions to propose multimodal mobility solutions (including shared and on demand) to address the traffic congestion issue and enhance the attractiveness of the public transport. For end-users/citizens (passenger and freight) it will provide a seamless, customised i.e. personalised, efficient and cost-effective end to end journeys, whatever the mode of transport. This means providing seamless information, but mostly improving the offer: connections between modes, accessibility, improved coverage and adaptability of the overall offer. For operators and transport administrators it will provide intelligent and adaptive multi-modal traffic management system to ensure seamless end to end journeys to rail end-users/citizens.

To meet the objective to foster the integration and the quality of service of the rail mode to remain the backbone of multimodality, new solutions must be developed:

- facilitate the emergence of MaaS platforms through technical standards, business models and regulatory frames, in particular use and sharing of data. Rail end-users/citizens need accurate and real-time information about the multi-modal offer, taking into account their preferences, and proposing a personalised support before, during and after the journey through an electronic travel assistant/companion. Emerging MaaS platforms are providing rail end-users/citizens with personalised service bundles offered through multiple delivery schemes, including through service contract and subscriptions, that deliver mobility solutions optimised to their specific circumstances, regardless of modal planning, booking and ticketing mechanisms. They automate contract execution, payment, settlement and accounting across the network of personal and business service providers involved in delivering tailored, end-to-end customer-centric mobility;
- facilitate the emergence of hub and multimodal control centres to improve coordination of the transport ecosystem, with the high capacity rail mode considered as the backbone, together with more adaptable and on-demand modes used as complementary resources. Integrating this multimodal offer, improving the interaction between modes through a multi-modal traffic management or a Multimodal Operation Control Centre (MOCC), will answer the increasing need for seamless mobility and will drastically reduce the waiting time for the users/citizens;
- develop new concept green railway stations and terminals designed as mobility and logistics hubs that are a seamless extension of smart cities for the seamless flow or people and goods in and out of smart cities;
- develop intelligence through digital technologies (big data and AI) to adapt in real time the multi-modal offer to the actual mobility demand, either using the existing connection with other transport modes or by developing more flexible approaches like the pod concept.

3.2.2 Achievements in Shift2Rail

Shift2Rail covers in the Innovation Programme "IT Solutions for Attractive Railway Services" most of the aspects related not only to the end-user/citizen but also from the Mobility Service providers perspective. It proposes a seamless approach to the mobility services required for a journey using different transport modes, including air, rail, bus, car-sharing, and easily extended to other modes.

It includes the pre-trip phase, with planning, booking and ticketing, support during the trip, with personalised information (including ancillary services), in-door navigation, re-allocation of the journey in case of disruption and after sales capabilities. To achieve this, passengers have access to the services through a travel companion, a personal application which collects the user/citizen preferences and stores the rights to travel in a protected wallet.

From the Mobility Service providers point of view, it provides a web-based interoperability mechanism that eases the integration into the ecosystem without changing the legacy systems, reducing the cost of adapting the interfaces of providers participating in service bundles offered as-a-service.

Moreover, thanks to the Business Analytics platform, the Mobility Service providers will better adapt their level of service to the passengers' demand and to optimise their operations.

This IP's developments are targeted to reach Technology Readiness Level (TRL) 6/7 (system prototype demonstration in operational environment) and are including different experimentations in the context of the Mobility as a System (MaaS) approach.

The extension in Horizon Europe should target a full deployment, with the extension to any other modes of transport and business models and should be extended to the freight context.

In the Future Stations design area, the development of tools for the crowd management is providing valuable information to optimise the station layout and to refine the procedures in case of crisis. The same approach can be used to improve the physical integration and the interfaces between the modes in large stations (hubs).

In the Cross-Cutting Activities, within the long-term needs and socio-economic research work area, travel chains and customer preferences are collected to assess how to enhance the attractiveness of travelling by train in a seamlessly integrated cross-modal transport chain. A KPI on attractiveness will be defined, taking into account main passenger comfort factors such as less vibration and noise inside the train and better IT services.

3.2.3 Required for 2020-2030

The technical scope will include:

- the deployment of interoperable mobility service platforms to support seamless end-to-end journeys (following Shift2Rail developments);
- the use of a comprehensive understanding of transport market trends and drivers to underpin the business cases for technical developments. This will be based on access to existing information sources, or the development of new information streams;
- the use of open data from third parties to create added value customised services (for passengers and freight). This will enable rail end-users/citizens to be provided with optimal connection offers based on sophisticated forecasts of service operation;
- solutions development, such as a train localisation platform, to anticipate and predict the status of different transport mode operations by sharing real-time information between modes, including last mile for passengers and freight. The usage of real time information will provide an accurate status report on the full transport system and will allow the overall optimisation of the transport offer;
- the use of integrated information which will be communicated through all types of support on a real time basis, both to rail end-users/citizens for customised services and to rail operators for efficient operations.

All these developments are based on real time distributed computing architectures operating on web-based open linked data, and will rely on big-data, business analytics and AI technologies.

This programme will have a large business impact by creating new competitive business models for suppliers, operators and end-users/citizens. Furthermore, the governance for the coordination of the multi modal traffic management system will have to be explored with different stakeholders across all transport modes.

3.2.4 How to Ensure Migration to 2030

The migration path is highly dependent on the maturity of the businesses. If no major disruption is expected in the go to market, we can easily correlate the migration with the TRLs of the solutions. But the problem becomes more complex when business disruptions can emerge, with new business models, different go to market, or when the migration requires prior agreements with stakeholders who are outside the railway ecosystem.

For the activities developed in Shift2Rail, which are already at TRL6/7, the migration is depending on the market uptake. A strong enabler will be the connection with other initiatives like the next Knowledge and Innovation Community (KIC) Urban Mobility program expected in early 2020, and the use of Connecting Europe Facility (CEF) funds to accelerate the deployment.

For rail freight, modular freight wagon designs allow a seamless and efficient horizontal change of goods and loading units. Intelligent freight wagons are connected to intermodal terminals, marshalling yards, end-users/citizens sidings and cross modal nodes to provide a high-performance access to the rail system.

Some of the new solutions, related to technical improvements (techno push), will be proposed incrementally to the market as soon as they reach adequate TRL, and will continue to use rather standard Request for Information/ Request for Proposal (RFI/RFP) processes. All solutions relying on improved communication (5G), cloud platform, big data, analytics and AI will progress at the speed of the use of these new technologies.

The migration of more disruptive solutions, in which the role of the stakeholders and the business models evolve, and which require coordination between different transport sectors (e.g. MOCCs or multimodal traffic management systems) is more difficult to predict. These new systems are modifying the existing businesses, giving a reinforced coordination role to the transport authorities, and requiring certainly more (European) political actions, regulatory environment, and potentially new standards. As an example, regulations for open data are certainly instrumental to foster the deployment of some of the proposed systems. For these solutions, watching the emerging trends, for instance around MaaS paradigm, and using them as business enabler, is essential.

3.3 Intelligent Assets Lifecycle Management: Whole-Life Asset Approach

3.3.1 Context

One of the main potentials of the digital transformation is the possibility of increasing the (cost) efficiency of the asset management process and profitability of assets themselves through decision support systems based on the comprehensive digital monitoring of railway systems – "smart data". Analysing the huge volumes of Big Data provides the basis for efficient and risk-based decision-making. The focus lies in ensuring maximum railway network availability and reliability and reducing life cycle costs (LCC); the knowledge will also feed back into the design and construction or manufacturing loop.

Furthermore, to maximise the possible impact of this potential, railways need to be understood as a single system where moving and fixed elements work together, replacing the conventional approach of addressing each subsystem separately.

The major challenge in this context is to adopt a holistic view involving every subsystem in the infrastructure and vehicles and considering their interfaces. Such a global approach to assets and their management will result in increased and enhanced operational flexibility and contribute to a more robust, resilient, and reliable service as well as faster recovery from service disruption, along with a reduction in the cost.

Intelligent asset management will reduce costs and improve the reliability of the rail system. Better technology and developments in maintenance will support rail's progress towards achieving key ambitions:

- higher reliability and availability of the system due to fewer failures;
- economic competitiveness by lower CAPEX and OPEX;
- better sustainability due to lean construction and maintenance.

To move towards these ambitions, it is now crucial to integrate existing infrastructure construction and maintenance methods, technical bricks delivered by R&I programs, in particular Shift2Rail, thus facilitating the introduction of further innovations. This will enable the delivery of new solutions enhancing railway performance:

- digitalisation of the maintenance system;
- prognosis and Health Assessment at System Level;
- specific Technologies for Maintenance Execution;
- new construction methods;
- new calculation methods and more powerful computers allow studying in further depth classical and/or basic problems for example related to wheel-rail contact.

A whole life asset approach will deliver two key benefits. First, it should reduce the overall cost to maintain the asset over its life cycle. Then it should also release constraints for migration at subsystem level, by a better alignment between asset and technology life cycles.

Starting from the achievements of Shift2Rail, the proposed concept that will bring asset management to the next level requires progress in the *digitalisation of the whole system and its components*, with a special focus on integration aspects that will enable its holistic management. Then, the *opportunities brought by advanced technologies* should be developed into specific solutions to the key problems in the design, building operation and maintenance of the whole rail system.

3.3.2 Achievements in Shift2Rail

The Shift2Rail research activities and the deliverables and prototypes achieved the following:

- within the Passenger Trains Programme major subsystems such as traction and running gear are developing sophisticated sensors for diagnosis and specific condition-based maintenance approaches focused on these subsystems. A significant step is being taken at communications level by developing standard wireless communication systems within the vehicle and train-to-ground, which will facilitate the flow of data necessary to implement advanced maintenance;
- within the Traffic Management Programme the TMS evolution accounts for the direct connection with the result of the asset management nowcasting and forecasting to optimise the traffic decision and the possession management;
- within Cost Efficient and Reliable High Capacity Infrastructure the Asset Maintenance Pillar has been a driver to deliver innovative Asset Management in the railway sector, meeting the best practice set out in ISO55000, creating optimised data measuring, monitoring, processing & maintenance strategies, processes and methodologies, for the implementation of a step change in risk based, prescriptive analytics and holistic Asset Management in the rail sector. Deep new knowledge of the critical assets of rail infrastructure and their deformation mechanisms is developed, while innovative measuring techniques that are based on state-of-the-art technologies (such as robotics, satellite & drones) are tested on the field. This can feed directly into a new program. The function and optimisation of the mechanical infrastructure has been developed for reducing the environmental impact and costs;
- technologies for Sustainable & Attractive European Rail Freight are focusing on digitisation of rolling stock, which leads to smart, connected assets for improved services, and especially from a maintenance perspective, addressing condition-based and predictive-based maintenance;
- in the Cross-Cutting Activities, a common smart maintenance concept is being developed across the Shift2Rail IPs. In addition, standardisation of data transfer protocols, formats and structures for rolling stock and infrastructure condition based maintenance is ongoing.

3.3.3 Required for 2020-2030

The following interlinked steps have been started in Shift2Rail and shall be continued and developed into system solutions:

- collaborative design of on-board and infrastructure systems/subsystems based on cutting-edge innovative technologies and bring it to approaches for integrated measuring and monitoring the root causes of degradation/failure of critical assets integrated with IoT based paradigm and minimising the cost and impact of the solution (based on Vehicle to Infrastructure (V2I), Infrastructure to Infrastructure (I2I) and V2V communication solutions);
- the completion of the standardisation phase for the Shift2Rail Conceptual Data Model, the seamless interface with existing railway-related information in the different EU contexts;
- the integration of the present and newly developed heterogeneous sources of information to be shared between stakeholders. Develop the analysis of big data for the nowcasting and forecasting of assets' condition, diagnosis and prescriptive maintenance.

Furthermore, it will be necessary to progress in the following areas: **Digitalisation of the maintenance system, Prognosis and Health Assessment at System Level, Specific Technologies for Maintenance Execution, and New construction methods.**

Digitalisation of the maintenance system

Rail maintenance is based on manual knowledge and established practises. With evolving digitalisation, maintenance can be based on smart components and smart decisions. The rail system can have a digital copy on-line and in real-time:

- self-diagnostic, self-repairing and self-adjusting assets, through the development of Internet of Things IoT, making it possible for assets to update their own records and 'self-heal' to be applied on modular components;
- artificial Intelligence will bring real-time maintenance forecasting and servicing assets (maintenance execution). With large amounts of data available — such as maintenance history, actual usage of the assets and monitoring, AI can identify the correct time for the required interventions to avoid failures and disruption of the operation;
- concepts, procedures and regulations for the introduction of safety relevant AI based tools and methods;
- integration of 'Digital twins' in the asset management process supporting the operational process including the logistics for the execution of maintenance by simulating complex interventions and supporting the multi-disciplinary teams;
- Data Digital Market for the integration of heterogeneous data coming from different organisations defining the process for exchanging data, ownership and revenues;
- Block Chain and Smart Contracts: Block chain platforms, established in the financial sector, are becoming applicable platforms also in industrial contexts and the market for such platforms and smart contracts are growing rapidly. Such platforms need to be considered in future railway applications.

Prognosis and Health Assessment at System Level

Asset management is developing in all sectors. By applying the best knowledge into the rail sector, a substantial reduction in costs can be achieved. Inspections and checks can be made without personnel on the tracks, reducing risks and costs, while it can be done more frequently. AI will collect and store a vast amount of human knowledge:

- LCC automated models able to evaluate how to prevent a failure will influence the operational costs of maintenance and how much an asset management decision will affect the overall LCC;
- reliability and criticality models of system / Sub-system behaviour able to automatically assess how an asset failure affects the entire system performance;

- transfer available human expert knowledge about legacy assets into AI expert systems / sub-systems and self-learning AI expert systems / sub-systems based on cognitive computing providing interpretable diagnosis, prediction and maintenance planning information;
- development of Human Machine Interfaces based on augmented reality and natural language processing for interaction of human operators with AI expert systems / sub-systems for diagnosis, prognosis and maintenance planning;
- increased automated inspection from a robotic perspective, towards a final execution from an automated robotic platform.

Specific Technologies for Maintenance Execution

Maintenance is quite manual today, executed with the support of machines. In a future digital system, the machines will be more and more able to do the maintenance themselves, reducing the costs, risks and the lead time before the actual repair. The works can be done by mobile units or by the components themselves; further reducing down time, especially at odd hours:

- automated identification and automatic assets recognition and monitoring as the basis of precise service operation;
- increased automated maintenance execution from a robotic perspective, towards a final maintenance execution from an automated robotic platform;
- advanced augmented reality technologies (e.g. computer vision and object recognition) applied to remote maintenance operations;
- robotics using principles like swarm robotics and biomimicry creating small and easy to use tools making the physical work easier avoiding unhealthy and heavy work including development of Human Machine Interfaces;
- modular components that can be easily exchanged by automated plug-and-play solutions avoiding on-site repair.

New construction methods

The components and structures in the rail system are based on traditional systems. New construction methods will adapt the systems to the novel concepts of design, construction and maintenance; thus reducing costs and environmental impact, while building-in a low failure rate. It will also adapt the system to fast, cost efficient automated maintenance by:

- design reducing the number of components, and their linked dependency;
- moving critical functions away from the trackside to an environment where access is safer and easier, with more backups, e.g. the cloud;
- building-in smart components that can be much better tailored and suitable for on-line supervision;
- developing smart and lean components, track and structures;
- modular components that can be easily exchanged by automated plug-and-play solutions avoiding on-site repair.

Overall, the proposed activity will result in increased and enhanced operational flexibility and will contribute to a more safe, robust, resilient, and reliable service as well as faster recovery from service disruption, along with a reduction of LCC.

This will happen due to the following specific impacts achieved by the proposed activities:

- 24/24 and 7/7 system availability: Optimised interface maintenance keeps the railway continuously open, fostering minimal disruption to train services improving system reliability;
- a significant reduction of the life cycle cost of the rail system, supported by an improved management of the interfaces between subsystems;

- optimising network capacity: Intelligent maintenance increases train and track availability and reduces perturbations and delays;
- minimising the need of on-side activities: Reduction of downtime by using autonomous systems monitoring themselves and sending information and alarms on their status can achieve the capability for remote and just-in-time maintenance. Digital Twins support the maintenance logistics resulting in minimum impact and in first-time-right interventions;
- increased economically and environmentally sustainability using principles as self-maintenance incorporating retrofitting, in the design of new components and as a part of the system methodology.

3.3.4 How to Ensure Migration to 2030

Horizon Europe is expected to support an integrated approach to maintenance based on digital and automated solutions, and to take the most valuable new technologies to a high maturity level for implementation in railways.

This requires:

- standardisation of critical aspects of the digital system (such as interfaces, protocols, communications, data structures) required to integrate the different subsystems;
- development of an open framework that enables use of data and information by different stakeholders involved in operation and maintenance;
- deployment analysis of new maintenance concepts; within each project these aspects must be considered, and their feasibility proven;
- facilitation of and investments in remote maintenance and zero on site intervention;
- automation of maintenance adoption in procedures and rules/regulation;
- promotion of effective integration into existing information systems.

3.4 Environmental Sustainability and Carbon Free Mobility

3.4.1 Context

Achieving sustainable, environmentally friendly transport is a major societal need and a strong demand coming from institutions at all levels. Decarbonisation is a key topic in the short and long term political and institutional agendas. Railways have always been considered the cleanest mode of transport and have the potential to be the cornerstone of the decarbonisation of mobility by offering increasingly efficient transport that reduces the environmental footprint with clear benefits over other modes.

- Additional research and innovation actions would improve the current situation from the environmental perspective, providing the following **benefits**:
- *eliminating fossil fuels propulsion*: Even though a large part of the rail infrastructure is already electrified, a significant part of the network is not, or is only partially electrified and relies on diesel trains to provide the transport service;
- *carbon-free mobility*: Railways are the most environmentally friendly transport mode providing cleaner and sustainable transport with a low carbon footprint. As fundamental technologies evolve, new opportunities arise to reduce the consumption of energy which need to be adapted and implemented;
- *integration of mobility in populated areas*: The reduction of noise emissions and vibrations can make rail transport more attractive for users/citizens and benefit the surrounding environment.

To address these challenges new **solutions** should be provided:

- alternative affordable propulsion for non-electrified lines;
- holistic energy management approach for railways;
- simulation tools and procedures to accurately predict noise emissions and vibrations;
- procedures and techniques for recycling vehicles and eliminating polluting substances.

3.4.2 Achievements in Shift2Rail

Different aspects of sustainability have been the subject of recent EU projects (OSIRIS, MERLIN, RIVAS) and are further developed in *Shift2Rail.* Some of these developments are useful building blocks which will enable a more integrated coverage in the future:

- the Passenger Trains Programme focuses on new subsystems technologies to develop lighter and more energy efficient vehicles, such as new power electronic technology for traction, new composite materials for carbody structures, reduced noise and friction brakes, lighter bogies, door insulation, new heating, ventilation, and air conditioning (HVAC) generation;
- the traffic Management Programme focuses on new algorithms for computation of optimum speed profile with coasting and cruising optimisation, avoiding the unplanned train stop, with impact on the enhancement of punctuality and reduction of energy consumption, based on real time timetable information from TMS;
- the Cost Efficient and Reliable High Capacity Infrastructure programme has worked on modelling tools to map and optimise the energy flow and has undertaken the initial development steps of smart energy management solutions. In addition, it worked on optimising the Rail Traction Power Supply system towards the reduction of energy losses & investment costs. It started to look at concept of integrating the rail power supply grid with public grid & renewable energy sources;
- in the Technologies for Sustainable & Attractive European Rail Freight programme new eco-efficient propulsion concepts for freight locomotives have been developed, including diesel hybrid engines for legacy shunters and dual power propulsion concepts for last mile transports on non-electrified lines.
- In the Cross Cutting Activities, the Energy and Noise work areas developed methods to facilitate effective noise/vibration and energy management by applying a system approach including all different parts of the rolling stock, the infrastructure and its close environment.

The proposed approach is focused on the following topics:

- *new propulsion systems*: Technologies to progress towards full electrification without catenary;
- *digitalisation*: With a wide amount of new data and analysis tools under development, there are new opportunities to address the energy consumption and efficiency problems in a holistic way.

Future work will also develop further some fundamental activities already started in Shift2Rail, which are:

- *energy efficiency in general*: New lighter materials, design concepts or new technologies for subsystems;
- *noise & vibration reduction with better prediction techniques and mitigation measures*, which are key for the integration of rail in populated areas.

3.4.3 Required for 2020-2030

To achieve the goal of having a full decarbonised, silent and eco-friendly railway system in 2030, the following scope of work is suggested for Horizon Europe.

Development of affordable alternative propulsion for non-electrified lines

Different technologies that may provide an alternative to diesel propulsion for freight and passenger transport in non-electrified lines are already under development. They need to be evolved to the point that technical and economic feasibility can be shown before they are fully recognised as legitimate substitutes of diesel traction. It is likely that different technologies may end up being successful in niche markets/applications with different requirements. Specific enablers to be developed are:

- **development of Future On-board Energy Storage Systems** (ESS) and charging technologies will facilitate the conservation of energy by reducing the average energy consumption and may also provide with a technological alternative to diesel propulsion;
- **identification and demonstration of suitable alternative propulsion systems.** The generic development of technologies with the potential to provide viable alternatives to diesel (e.g. fuel cells or batteries) and the adaptation to the specificities of railways needs to be considered. To cover the case of partially electrified lines, hybrid operation should also be studied;
- **study and develop new energy supply infrastructure in a full society context, i.e. combined systems for rail, road usage.** Production of energy could be undertaken centrally and distributed or locally depending on the electrical grid and production methods. Finally, the source of energy must be studied, in a real well-to-wheel concept.

Holistic energy management approach for railways

The energy consumption of trains in regular operation is influenced by many different factors, and therefore complementary technological developments should be undertaken to reduce it. Specific technological enablers to be developed are:

- **energy efficient operation based on digitalisation**. The availability of real-time information on the status of the system will lead to the possibility to minimise energy demand while complying with operational constraints. Energy efficiency will be improved through optimised driving modes performed by Automated Train Operation and Supervision (ATO and ATS) and real time fully Connected Driver Advisory System (CDAS);
- **holistic energy efficiency / management approach for rolling stock**. The efficiency of individual subsystems may be optimised with the adoption of suitable technologies. With more efficient propulsion systems and a holistic approach including non-traction functions, such as heating, lighting, air conditioning and air production, a significant global reduction of the energy consumption can be achieved. Additional optimisation of the energy consumption is achieved through new rolling stock concepts, full-electric service brakes and smart sub-systems, materials and technologies aiming also at reducing weight;

- **develop smart energy infrastructure**. On board and line-side energy storage technologies and charging technologies will make possible to recover a big amount of the braking energy and will support balancing the flow of energy. Electricity supply using SMART Grid technologies coupled with increasing the residence and variety of supply resources (e.g. main grid, local renewable, recovered, etc.), not only for rail traction systems but also for road usage and stations.

Simulation tools and procedures to accurately predict noise emissions and vibrations
As social sensitivity to noise levels grow, the incentive to reduce noise and vibration levels both inside and outside vehicles increases. Specific technological enablers to be developed are:

- **analysis methods for structure borne noise and for airborne train interior noise propagation**. Because noise is a complex technical issue, there is an increasing need of improving prediction. These will support the identification of the most suitable noise and vibration mitigation measures, and in many cases enable accurate performance prediction during the early design phase, reducing overall costs. Sound quality aspects are also important to include, for the future competitiveness of rail versus other modes of transport and hence as a support for the modal shift required for decarbonisation;
- **virtual authorisation of vehicles**. This will progress due to the increase in reliability of the simulations carried out and the procedures for allowing this to be installed and tested. Accuracy of the exterior noise propagation prediction will also be improved (including barriers, etc.).

Procedures and techniques for recycling vehicles and eliminating polluting substances
Ensuring eco-friendliness will require the recycling/dismantling aspects of new technology components implemented in Shift2Rail, such as new generation batteries, composite components, etc. to be addressed. Also, the reduction or elimination of emissions of dust, especially particulate matter, environment polluting substances such as oil is essential to the railway being the backbone of environment friendly mobility.

The impacts and values of these activities will be:

- support carbon-free freight and passenger railway transport by developing cost-effective and widely applicable alternative propulsion for non-electrified railway lines, also facilitating multi-modal production and storage systems;
- storage and use of excess electricity from renewable sources;
- reduce the cost of the railway system by reducing the need for building and maintaining electrification infrastructure in low density lines due to clean alternative propulsion systems;
- reduce the total carbon footprint of railways by reducing the total energy consumption, as a result of the increased efficiency;
- reduce the total LCC of railways by reducing the total energy consumption, resulting from the increased efficiency;
- noise and vibration levels to be reduced to facilitate increased rail traffic without increased disturbance, increased comfort and use of rail transport in comparison to other transport means and reduce costs by improving simulation techniques allowing optimisation in early design phases and a development towards virtual authorisation.
- In general, support the achievement of institutional objectives and long-term policies through the reduction of all types of emissions.

3.4.4 How to Ensure Migration to 2030

Horizon Europe is expected to support a new integrated approach to energy based on digital solutions, and to tackle the specific issue of full electrification through alternative propulsion systems. It will also push several key technologies to a high maturity level for implementation in railways. In this context, requirements to ensure migration are found in two main lines: **introduction of new propulsion systems and deployment of digitalisation**.

Introduction of new propulsion systems
Requirements to push for migration are:

- clear and wide demonstration of technical and economic feasibility, including different use cases in the regional / intercity segment and possibly in the urban segment;
- assurance of acceptance by standardisation and regulation: It will be necessary to work from an early phase on the adaption of regulation and standards to consider (and even favour) the use of the cleanest technology being developed;
- dual power concepts developed in Shift2Rail are implemented and enable electrified last mile transports on non-electrified lines.

Deployment of digitalisation
A precondition to ensure the migration to the new technologies developed is to ensure the widespread deployment of digital systems across the railway system and mobility in general. This requires:

- standardisation of critical aspects of the digital system (interfaces, protocols, communications, data structures) to be able to integrate the different subsystems;
- develop a clear and sufficiently open business and legal framework at business level that allows fruitful use of data and information by different stakeholders involved in operation and asset management, which often have conflicting requirements;
- promote the effective integration of existing information systems: Many individual information systems are currently available in the EU railways, thus not exploiting the potentiality of big data analysis.

Concerning the reduction of noise emissions and vibrations, the new predictive techniques and analysis methods developed within Shift2Rail should form the basis for developing new silent components and for deploying noise and vibration mitigation measures. Predicting the behaviour of vehicles and their components during the design phase will allow the concentration of effort from the start on noise and vibration sources and propagation channels, including infrastructure, and be more effective and cost efficient in their mitigation. Only approaching the noise and vibration issue from a holistic point of view will provide the expected results in terms of reduced emissions and increased friendliness towards rail transport.

3.5 Transversal Enablers

Rail sector engineering, logistics, manufacturing and maintenance will benefit from some transversal enablers, in particular digital technologies. This has been confirmed in pilot projects and other sectors where value was added to the whole supply chain of the sector, by reducing lead-time to delivery, manufacturing on demand, reducing storage, reducing goods transport cost and enabling stronger collaboration between supplier, manufacturer and railway operator/infrastructure manager.

Further investigating digital opportunities can help rail to progress towards key ambition:

- more competitive solutions for the full benefit of the end users/citizens;
- rapid deployment of new solutions;
- energy savings and environment sustainability;
- robustness and resilience against security threats.

To move towards achieving these ambitions, it is now crucial to integrate existing products, the technical bricks delivered by R&I programs, in particular Shift2Rail, while facilitating the introduction of further innovations.

This will enable the delivery of new means of enhancing railway performance:

- new materials and manufacturing techniques;
- reasonable security measures;
- cyber security protection;
- telecommunication;
- digital technologies (e.g. Big Data, AI, General Intelligence).

3.5.1 New Materials and Manufacturing Techniques

Context
It is now of great importance to integrate new materials and manufacturing techniques, benefiting from developments in other sectors (Aerospace, Defence, etc) and undertaking the required adjustments for the railway ecosystem.

New materials and manufacturing techniques will contribute to better products and new maintenance concepts. They will also contribute to a 'circular economy' while supporting performance improvements (e.g. energy saving with less weight).

Required for 2020-2030
To develop new materials and manufacturing techniques, some key enablers are identified:

- new material validation;
- additive manufacturing;
- new manufacturing technical for maintenance.

New Materials Validation
Today, metals, thermoplastics and photopolymers are the most frequently used materials for additive manufacture. New materials are arriving, with quite unknown but multiple properties. Evaluating these materials and driving the relevant material validation is key in the railway domain, while recognising that these steps are expensive and time consuming. It will allow the sector to define what is suitable from a technical and economical perspective for the stakeholders.

Additive Manufacturing
The challenge is in the part design coupled with low volume series production (today's cost impact vs traditional manufacturing processes) and associated railway sector requirements (reduced weight, mechanical resistance, …). However, the focus should also integrate the potential higher complexity of parts that can be manufactured by optimising the functionalities offered by these parts. Additive manufacture also reduces the need for post-process quality control as digitalisation offers more opportunities for on-line quality control. The additive manufacturing process should be optimised in terms of surface finishing and part design (topology). Evaluation should be undertaken on which manufacturing technologies are relevant for the rail industry from economic, quality and technical perspectives.

Manufacturing Techniques for Maintenance
Manufacturing techniques in the context of maintenance will benefit from robotics. The introduction of robotics in the rail sector can benefit from principles like swarm robotics. Avoiding the need for an autonomous vehicle to occupy whole sections of a track, robots should be able to access and leave the track near the location where the work is needed. A whole set of light and small robots could enter the track based on the theory based on swarm behaviour seen in ant and bee colonies. The idea is that small individual robots working towards a larger goal by distributing the work. The idea of swarm robotics is commonplace is the research of the application of robotics across various sectors. Using biomimicry will also help to find solutions to make light and small robots be fit for task were power and strength is required.

Focus is required in the life cycle of new materials and closed cycle waste management systems towards 100% level of recycling. This needs also attention for all legacy components.

3.5.2 Reasonable security measures

Context

Rail services are an easily accessible form of transport with reasonable security measures. Security is managed by specific human resources working closely with public police, supported by some specific systems (scan, etc.) and railways are rather secure. However, terrorism is a permanent threat and the rail mode with the high density of people using it is a potential target. Another issue for attractiveness is the *subjective feeling* of insecurity. Violence and vandalism (e.g. graffiti) in the public transport environment is creating stress among passengers and staff. Criminals, whatever the degree of severity of their wrong-doings, are damaging the image of the services and are a threat to passengers, staff, goods and assets. Any successful security policy is a mix of people (awareness, preparedness, training…), processes and products/technologies.

Research and innovation on reasonable security measures will deliver benefit in the perception of society related to transport insecurity and in the efficiency of security threat resolution.

Required for 2020-2030

To achieve advanced interoperable train control systems, key enablers are identified and should be supported by collaborative RDI activities:

- open access to stations and trains being the leading principle, security measures are non-invasive, not interfering with the travel experience;
- precautions against external threats, aggression and vandalism, supported by technologies are in place;
- new concepts aim at verifying access rights to rail services and infrastructure using intelligent wireless technologies, ticket detection systems and biometrics to prevent and limit terrorism or aggression from other passengers by monitoring, detecting and informing (the driver, staff and authorities) about possible imminent or ongoing actions. The following functionalities can be considered for railways applications: detection of abandoned objects, explosives and weapons detection;
- for freight, track-and-trace solutions support security issues efficiently. Points of vulnerability are places at which freight loads are transferred from one transport mode to another;
- tools supporting cooperation between the different modes will be developed in order to deliver practical and efficient solutions.

3.5.3 Cyber Security

Context

In the digital era, the protection of every sub-system against cyber-attacks is becoming critical, as most of the systems are now connected. The rail sector will not develop specific cyber protection but will use the best of the existing technologies. The Directive on security of network and information systems (NIS Directive) has initiated regulations that enforce cybersecurity system accreditation.

The objective is to ensure that every European rail transport network is secured properly and can detect efficiently security incidents. To achieve this, a precondition is to enhance European collaboration.

One of the main difficulties is that deployed systems have a long lifespan that make them particularly difficult to maintain at the right security level. New vulnerabilities are discovered continuously and patching may take time for Safety Integrity Level 4 (SIL4) systems. The new architectures and protocols should take this into account.

Research and innovation on cyber security will deliver benefit when easing the identification and resolution of vulnerabilities and accelerating the introduction in the rail system of state of the art cybersecure technology.

Required for 2020-2030

To improve cyber security, key enablers are identified and should be supported by collaborative RDI activities:

- standards must be revisited to simplify interoperability and European certification of secured solutions: Keys, certificates, train identities infrastructure and services should leverage on cloud and distributed technologies such as blockchain, providing pan-European services, highly scalable and resilient;
- european CERT (Cyber Emergency Response Team) for rail domain should be established including threat Intelligence, to build trusted source of information for security incidents affecting the rail domain. Cybersecurity operation of critical transport infrastructures and systems will leverage on it;
- rail protocols for end to end security need to be upgraded and must be independent from the security of the network layers. The current protocols which are used for signalling are missing mutual authentication and data encryption;
- european cybersecurity certification profiles need to be developed to establish harmonised cybersecurity practices in Europe (in collaboration with the European Union Agency for Network and Information Security (ENISA) and National security agencies);
- a clear methodology about cybersecurity for safety is required, making the link between cybersecurity risk analysis and safety analysis, also accounting for emerging new technologies, such as quantum computing which is a real challenge for the cryptographic based approaches.

3.5.4 Telecommunication

Context

Several major trends have been transforming the Information Technology (IT) and communications world in the recent years: virtualisation of functions, cloud-based infrastructures and services, the rise of Everything-as-a-Service, the growing use of the IoT, data becoming the new oil, and the constant need for cybersecurity.

The impact on the rail industry is the irreversible migration from closed legacy systems to “Digital Railways” calling for cheaper, open, and interoperable solutions, with a true integration of technologies to cater for end-to-end service delivery, including more mobile broadband radio for operations and passengers, IoT connectivity and data monetisation, whilst ensuring cybersecurity by design.

Fast changing communication technologies need to be reconciled with the longer lifecycles of rail-specific standards such as ETCS and Communications-based train control (CBTC). The suitability of the various telecom options has been extensively analysed by the FP7 European NGTC project and clear strategic pathways have been defined for future bearer neutral, scalable and fail-safe data transmission.

However, prior to any developments and deployment in data transmission, railways need to ensure availability of and access to bandwidth resource for fail-safe operation. In the context of road ITS developments the existing exclusivity of bandwidth resources for railway and metro applications is no longer guaranteed and solutions needs to be developed avoid third-party interference in both mainline AND urban applications. This requires continuous action at regulatory and technical levels. Failing to obtain this pre-requisite will jeopardise all efforts to increase rail capacity and quality of service.

Research and innovation on telecommunication for railway will bring benefit by reducing asset cost and facilitating successive migration to state of the art connectivity standard. Solutions will become modular, systems integration will consistently address all needs, in a future-proof, cost-effective, and secure manner.

Achievements in Shift2Rail

Telecommunication is addressed in Shift2Rail (via the wireless TCMS and Train to Ground Communications). An important achievement is the delivery of requirements for Train to Ground Communications.

They do not only provide a foundation for the telecommunication architectural specification, they also support business model development, and requirements for applications interfacing with the telecommunications (e.g. train integrity and communications with remote maintenance vehicles) avoiding as far as possible any specific railway solution to reduce LCC.

New telecommunications technologies and capabilities such as those being developed under the '5G' umbrella are emerging. The focus is put on shifting from a network as an asset to a network as a service (NaaS) model.

Required for 2020-2030

The main targets for future proof telecommunication are:

- cost effective, vendor independent, modular and future-proof solutions;
- adaptability to available networks, including hybrid operation across multiple infrastructures;
- availability and reliability levels for '5G' networks;
- robustness in mobility and in aggressive environments;
- interoperability and ease of migration of critical applications to the new technologies;
- validation of the future rail communication system by Pilot Lines to prove the ACS/FRMCS specifications.

Advanced telecommunication for railway requires to solve some key enablers:

- migrate from siloed proprietary solutions to a set of Commercial off-the-shelf (COTS) orchestrated by an overarching integration intelligence, ensuring the seamless delivery of virtualised rail-specific services across all links in the communication chain, as well as comprehensive real-time monitoring and consistent application of cybersecurity policies;
- develop and validate multiple-bearer integrated board-to-ground communication devices allowing simultaneous, or opportunistic, use of any available technology with mobility, for uninterrupted services and operation of a same train on different types of networks;
- ensure interference-free and fail-safe data transmission for railway applications despite growing appetite for bandwidth resource from other stakeholders, especially from the transport road sector and the numerous future "connected cars and trucks";
- build and integrated resilient IoT versatile communications architecture, secured from the sensor through to the cloud, to feed Analytics and Insight generation tools with accurate and integer data.

3.5.5 Digital Technologies (e.g. Big Data, AI, General Intelligence)

Context

The development of Digital Technologies, such as Data Science, Data Services, Artificial Intelligence, Machine Learning, Deep Learning, Neuronal Networks, Blockchain, Self -learning systems, Cognitive Computing and Cloud Computing, already had a big impact in railway field and they will become increasingly important.

The usage of Digital Technologies in railways aims to deliver various benefits:

- fast and efficient decision-making: based on data analysis results, making decisions on traffic management or route planning optimally in different situations;
- increasing reliability: based on analytic models, predict failures and program targeted interventions;
- reducing costs: improve maintenance schedules based on the results of predictive analysis.

Achievements in Shift2Rail

Shift2Rail contributes to the development of Big Data Analytics in the railway field. The large amount of heterogeneous information requires a lot of attention in data management. Shift2Rail provides an open, standardised, seamless and secure access to data, covering aspects such as transaction of Intellectual Property Right (IPR) -protected Business to Business data, management of data with safety-critical impact, strict information assurance and related quality control procedures on data and quality gates.

Data processing through analytics techniques, such as anomaly detection, asset decay prediction, process mining and prescriptive maintenance, contribute to the improvement of interventions and activities related to railways:

- increase of asset status monitoring capabilities through anomaly detection;
- more targeted maintenance interventions based on railway asset decay prediction, increasing operational reliability (less service disruption);
- maintenance activities optimisation through predictive maintenance, guaranteeing a cost reduction both in terms of spare parts and in terms of effort;
- LCC reduction based on condition-based maintenance of railway assets and continuous improvement of components/maintenance schedules.

In its Programme on IT Solutions for Attractive Railway Services Shift2Rail proposes Business Analytics developments to improve the interaction between the passengers and the operator's networks: assessing the best offer for a passenger accounting for their preferences and previous journeys, and the real time knowledge of the multi-modal transport offer and constraints. Business Analytics is also used to provide the operators an accurate feedback of the passenger's needs, and to adapt their offer accordingly.

Required for 2020-2030

In order to get the best benefit from digital technologies, some enablers will be worked out:

- the Railway Information and Communications Technology (ICT) ecosystem should focus on the application of digital techniques to automate and accelerate the decision process at every level (from maintenance to traffic management) so to decrease human intervention and the corresponding variability due to the uncertainty introduced by the human factor;
- knowledge management technologies should be used to encode the human decision process so that optimal decision procedures could be distilled, based on the experience of human operators and supervisors;
- artificial Intelligence and knowledge processing methodologies should be developed to apply and extend those procedures to achieve optimal decisions with respect to well defined Key Performance Indicators;
- the human supervision of the decision process should be taken in account by evolving the current human-computer interface between operators or decision makers and the digital ecosystem;

- data, information and knowledge should be encoded and standardised to allow the interoperability of the several knowledge processing entities in the railway ecosystems and eventually develop a digital market;
- the Railway ICT ecosystem should be designed to be "secure by design" moving from an "intrusion detection" paradigm to an "intrusion resilient" one to anticipate, mitigate and, in any case, detect security threats to the railway digital ecosystem. As the complexity of this ecosystem increases, new approaches and techniques should be developed or adapted from other applications fields to achieve secure and trusted operation inside and between each information system;
- Block Chain and Smart Contracts: Block chain platforms, established in the financial sector, are becoming applicable platforms also in industrial contexts and the market for such platforms and smart contracts are growing rapidly. Such platforms need to be considered in future railway applications.


4

4. Cost Efficiency and Rapid-Deployment of Innovations

4.1 Modular Design and Platform Architecture

The railway market in Europe is fragmented due to its historic heritage. That does not favour a quick breakthrough in overall railway performance and cost. As with the European aeronautic sector, a reference system architecture for rail should increase the capacity of the existing network, improve deployment speed and reduce life cycle costs, improving the agility of the rail system.

The main characteristics of such an architecture are: low LCC, a single modular framework, ability to migrate, adaptability procuring safe investment. Innovation will be facilitated and the time to market of innovations accelerated. From a simple and single reference architecture, some specifications relative to open and standardised interfaces have been defined.

The work will be dedicated to enlarging the basis of the system architecture. Developed using formalised methods, the definition of the architecture will set clear and unambiguous interface definitions aiming at providing generic safety approvals (plug & play), a modular split of work, independent development of components (allowing for technical evolution), an important quality step in the specification of operators' needs towards the manufacturers and the strengthening of this manufacturing industry.

4.2 Regulation & Standardisation

The rail sector calls for strategic support through well-aligned policies both at European Union and national level and a strong commitment to its ongoing requirement to invest in research development and innovation using all necessary resources.

In order to deploy the planned innovations strong cooperation between rail stakeholders is required. It needs to be underpinned by an appropriate, efficient and effective policy and regulatory framework involving public authorities. Regulation and standardisation should be dynamic allowing innovative technologies to be adopted more quickly by streamlining European-wide, systems engineering, design, manufacturing, testing /authorisation and upgrade processes to keep up with the pace of innovation, address complexity and minimise development costs. Much will depend on organisations such as the European Union Agency for Railways ability to update the relevant railway regulation in a flexible and speedy manner allowing the sector to benefit from regulatory stability while at the same time being able to apply state-of-the-art standards. At the same time, it should not negatively impact the performance, safety and / or interoperability of the railway system.

4.3 Efficient Supply Chain

The whole supply chain is impacted by digitalisation in the following way: the traditional supply chain is a sequential process. With additive manufacturing, the supply chain becomes collaborative with end-users/citizens & suppliers interacting at various points by data exchange and the co-creation of parts (for example). New challenges are appearing, such as master-data use and sharing, make or buy strategies, and easier split between engineering & manufacturing centres. It could also bring newcomers who will challenge the current railway supplier/manufacturer base. Defining the standards & interfaces and connecting data systems will protect the sector from a competitiveness point of view.

The new digital supply chain is also a major contributor to the cost efficient and agile generation of railway products.

Additionally, completely new potential applications based on the new information available may be unlocked, creating the conditions to develop new businesses. Opportunities exist for vertical and horizontal service development, linking people goods and services to the transport system and increased co-operation and efficiency with the supply chain.

In the context of maintenance in the rail sector, with components having a lifetime expectation of several decades, complex and high-tech components and a multitude of players in the supply chain, requires continuous attention and the introduction of new and advanced technologies. This can be solved using tools facilitating more collaboration: Extending the supply chain requires new solutions supporting collaboration-enabled maintenance, service and support from the various partners involved. Collaboration solutions should support maintenance training, field inspections, maintenance actions and repairs, on-site or and in the field. Mobile video collaboration solutions and advanced augmented reality technologies (e.g. adding computer vision and object recognition) can support all this involving people from various organisations at the same time. Together with the introduction and diffusion of multimodal transport services, is the need to study a generalised support system able to account for the needs of reliability and safety along the entire transport/logistic chain, increasing the co-operation and co-ordination between the different parties involved.

For this, strategic global collaborations are beneficial and can easily be supported by innovations. For example, the use of augmented reality to train maintenance and service mechanics in repair practices. In this way partnerships can pool the expertise and workforce throughout the supply chain and even reduce risk.

When working with strategic partners, the main suppliers need to stay informed and be responsive to use the knowledge within the supply chain and share it for an efficient operation of their assets at different client sites and use it for future designs.

4.4 New Business Models

The digital transformation of the rail sector is not only impacting the solutions and sub-systems. Ubiquitous connectivity and real time data sharing are transforming the role of the stakeholders along the whole value chain, and the way they provide, consume and monetise their transactions.

One of the consequences is that the transport sector is already moving towards new models, most of them being “customer” oriented.

This is true for the passengers, who see that owning a car is not required if their smartphone can provide a seamless multi-modal transport service which satisfies their needs. But it is also true for the railway undertakings, which can develop their operations in procuring services instead of assets, changing the economic model with a different balance between CAPEX and OPEX.

Another big disruption which has already transformed many sectors is the creation of platforms. The exponential growth of the platform companies, based on an ecosystem of well-chosen stakeholders, which have a mutual interest to create business value, can rapidly disrupt the established market, with some of the participants losing direct contact with, and the interest of their end-users/citizens, and then the capacity to control their destiny.

Work will be dedicated to analyse the impact of the legislation on the evolution of the market and the associated business models, looking at how to ensure that the rail sector remains the backbone of the mobility ecosystem, in order to bring the necessary elements of a resource efficient transport system, as requested by the White Paper 2011 on the Roadmap to a Single European Transport Area (SETA).

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