

A compelling vision for
the target railway system

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1. Introduction

Transport should not be seen as an end in itself but as the means of delivering major policy objectives such as decarbonisation, economic growth, and social inclusion.

To achieve these objectives, reflection must be done on how railways can play a major role in the future transport system.

The following definitions will help in developing the vision for the target railway system as part of an integrated multimodal transport system.

- › Transport⁽¹⁾. The movement of people or goods from one place to another.
- › Mobility⁽²⁾. The ability to move freely or be easily moved.
- › Accessibility⁽³⁾. Ability of reaching desired services and activities.
- › Network⁽⁴⁾. A large system consisting of many similar parts that are connected together to allow movement or communication between or along the parts, or between the parts and a control centre.
- › System⁽⁵⁾. A set of connected things or devices that operate together.
- › Integrated. Two or more things combined in order to become more effective.

This document outlines the future paths towards the evolving target railway system. It has been compiled having taken account of inputs from sector stakeholders⁽⁶⁾. Regular updates are foreseen to integrate those.

Its purpose is to:

- › outline the rationale for specifying a target railway system as a framework;
- › describe the target railway system, linked to the Single European Railway Area (SERA) and its integration in the future multimodal transport system;
- › identify the actions needed to implement this target railway system; and
- › provide a basis for an ongoing dialogue with the stakeholders and for an ongoing monitoring.

The urgency to fight climate change in the transport sector calls for measures including transport avoidance, a modal shift to more sustainable modes, and improvement of the efficiency and resilience of the multimodal transport system. The Agency has completed an analysis⁽⁷⁾ of historic trends in modal share for both passenger and freight. This analysis provides an insight into the main drivers to focus on in order to achieve a modal shift towards rail.

This requires a structural transformation of the transport system by integrating the various modes to achieve the optimal end-to-end transport solution:

- › physically – hubs, nodes, networks, cross-border, new modes added on existing infrastructure or built in parallel;
- › on data – using artificial Intelligence (AI) where it adds value – asset knowledge and monitoring, interoperability, open access;

⁽¹⁾ <https://dictionary.cambridge.org/dictionary/english/transport>.

⁽²⁾ <https://dictionary.cambridge.org/dictionary/english/mobility>.

⁽³⁾ Evaluating Accessibility For Transport Planning (vtpi.org).

⁽⁴⁾ <https://dictionary.cambridge.org/dictionary/english/network>.

⁽⁵⁾ <https://dictionary.cambridge.org/dictionary/english/system>.

⁽⁶⁾ ERRAC 2050 vision.

⁽⁷⁾ [Modal shift analysis for the 2024 ERA Compelling Vision](#).

- › on ticketing and schedules, also using AI where it adds value – service or user-organised;
- › on organisation – stakeholders’ cooperation, Public Private Partnerships, and
- › on administrative matters and regulations.

The future multimodal transport system should be end-user focused, environmentally friendly, socially just, and integrated taking a top-down approach. Its definition should include:

- › its characteristics – integration of urban transports and other such as new modes, access to the integrated multimodal system, physical design and operations, regulatory basis;
- › automation;
- › the foreseeable technological and societal evolution;
- › free access to machine-readable data focusing, in particular on accuracy and reliability in order to place confidence in the information, based on the EC vision of open data⁽⁸⁾ and the deployment of semantic technology;
- › the sharing of technologies between transport modes such as use of batteries, or automation support the concepts of Interoperability in space and time, and economies of scale;
- › a design that allows easy implementation of enhancements from other fields, such as predictive maintenance, customer information, entertainment, and
- › IT (safety and non-safety) related applications compatible between different transport modes while ensuring appropriate interfaces between them, as necessary.

Innovation will cover all parts of the multimodal transport system: service, operation, vehicle, infrastructure, maintenance, ITC and marketing. In particular, good infrastructure is needed to deliver good services. This means a good physical network with good digital connectivity.

The following prerequisites for non-local innovation solutions should be required:

- › a full-scale demonstration at least in one EU Member State, proving the alignment of technical and industrial innovation with the business needs and regulatory acceptance;
- › a sound assessment of feasibility across EU endorsed by railway actors and regulatory authorities;
- › financial and economic aspects to consider for the prioritisation/selection of innovative solutions. Innovation costs (development, implementation, other); and
- › before developing/integrating a new application, answers to the following questions should be made clear.
 - Can the application, at least its generic part, be used all over the SERA?
 - Can the application contribute/provide information for other applications?
 - Can the application use information from existing applications?
 - Can the application use information from existing databases?
 - Which components are railway tailored made and why?

The implementation of the new solutions would require cooperation between the different stakeholders according to their defined roles.

The System Pillar (SP) of Europe’s Rail Joint Undertaking (Europe’s Rail) will develop a unified operational concept and a safe and secure system architecture. Such system architecture framework shall support the concepts of Interoperability in space and time, and economies of scale.

⁽⁸⁾ <https://digital-strategy.ec.europa.eu/en/policies/mobility-data>.

2. Why is a target railway system needed?

To have a more efficient and effective functioning of the railway system, including its evolution, a comprehensive inventory of the basic features of the framework is necessary.

A common single vision for the target railway system would serve as a generic guidance for the various initiatives under development to achieve a sustainable transport system.

This framework will allow to:

- › enhance technical and operational harmonisation (TSI);
- › ensure multimodal integration where progress needs to be made;
- › optimise railway transport system with regard to wider economy; and
- › accommodate and incorporate research and innovation.

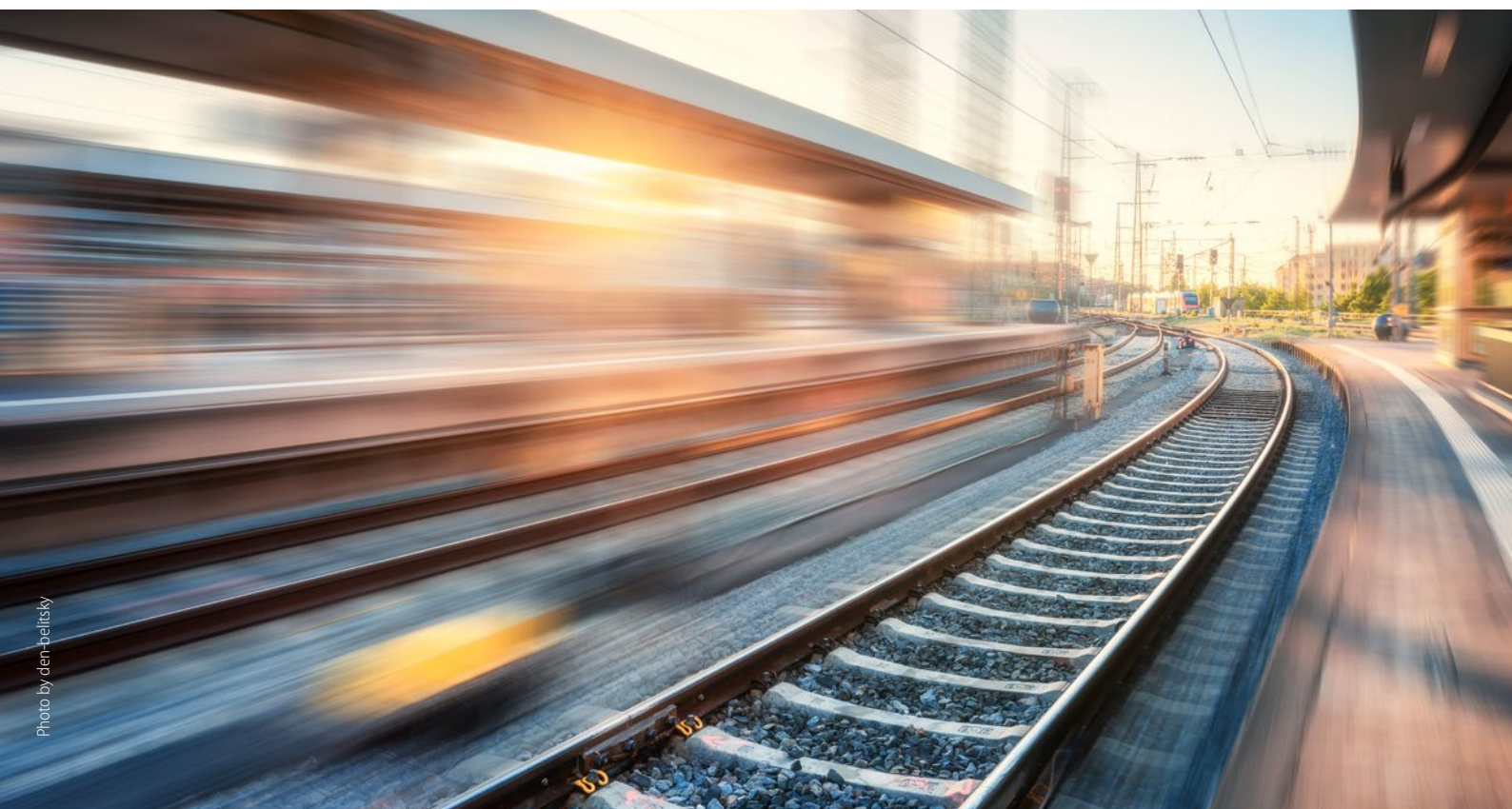
Each of these elements are developed below in more detail:

Technical and operational harmonisation

The four fundamental freedoms of the EU as set out in Article 26 (2) of the Treaty on the Functioning of the European Union⁽⁹⁾ states that ‘The internal market shall comprise an area without internal frontiers in which the free movement of goods, persons, services and capital is ensured’. The target railway system should support those fundamental freedoms.

As railways in Europe were originally set up as national systems, there is still a relative high level of fragmentation of operations and of governance, limiting the growth potential, especially concerning cross-border and international services. To overcome this fragmentation, further harmonisation is necessary.

⁽⁹⁾ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:12012E/TXT>.



Effectively, rail is competing with other modes which are far more advanced in terms of harmonisation. Progress on harmonisation is being developed through the Agency led work on TSIs and removal of national rules whenever justified.

In this context, specifying the target system provides a dynamic reference point for improvements. As part of this, the importance of incorporating modularity is a further impetus to reach a higher level of overall harmonisation.

Multimodal integration

A high performing railway system as backbone of the transport system is based around multimodal integration both within and between modes. This would cover both first and last miles as well as any other interfaces throughout the trip.

Optimised integration concerns regulatory, physical and information elements.

Overall, improved multimodal integration of the railway system will contribute towards enhancing return on investments of the transport system as well as reducing requirements for operational subsidies. The optimum multimodal integration will also enable achieving the best socio-economic value from the transport system.

Railway transport system and wider economy

Improved alignment with the wider economy is essential to ensure the long-term viability of the railway system. This brings into the core the extent to which the railway system satisfies user needs for passenger and freight transportation.

Increasingly, data and digitalisation play a key role to align service offer and customer requirements.

In turn, a high railway usage would potentially generate additional positive socio-economic impacts beyond the direct user benefits. This approach is being currently undertaken in Austria under its long-term strategy for the development of its Target network 2040⁽¹⁰⁾.

Research and innovation (R&I)

R&I is key for railways to become the backbone of the transport system of the future with rapidly changing user needs. These highly dynamic changes require not only strengthened R&I activities but also enhanced take-up and incorporation of R&I outputs into the existing railway system.

There are two elements slowing down innovation in rail:

- ▶ firstly, the elements of the railway system are closely interrelated, meaning that any change related to a subsystem might potentially impact all other subsystems, and,
- ▶ secondly, the investment decision is for the individual legal entities (IMs and RUs in particular) who will have to consider financial boundary conditions such as accounting rules. Replacement of any asset that potentially still have some useable years of life will lead to a financial loss.

The long-life cycle of railway assets coupled with high costs of asset ownership thus generates an economic obstacle in R&I take-up. In this context, R&I targeting:

- ▶ optimised application of the modularity principle, and
- ▶ more efficient asset utilisation,

is essential to overcome this long-lasting obstacle. The modularity principle based on harmonised interfaces will allow to reduce fixed cost stemming from R&I, and will help to avoid supplier lock-in.

These four elements are used in Annex 4 to justify the focus on moving towards a target railway system.

⁽¹⁰⁾ [Target network 2040 – The rail network of the future - ÖBB-Infrastruktur AG \(oebb.at\)](https://www.oebb.at).

3. What is the concept of target railway system?

For more than a century the railways were leading edge technology, transforming people's lives and the economy.

This compelling vision is intended to promote railways to become the backbone of an automated and integrated multimodal transport system. Such system should be based on the 'users first' principle.

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

Although overall harmonisation is necessary for the target rail system, for economic reasons, some of its elements may differ either on a permanent or on a temporary basis. This would be for instance the case for:

- › line electrification that would not be viable under certain conditions (low density area, low frequency lines which might require instead hybrid vehicles powered with alternative fuel); and
- › Automatic Operation (GoA3 and GoA4) that would not be viable for all operating patterns lines.

This requires a sound analysis and economic evaluation within a reasonable timescale (considering the environmental urgency) of the optimal level of technical and safety harmonisation for each element of the target railway system.

A specific focus should be given to the deployment of the following EU priority areas:

- › elimination of national specificities/national rules,
- › radio technology,
- › automation, and
- › digitalisation.

The optimal level of harmonisation might be reached with a mix of several sub-systems composed of various categories.

The technical solutions should support flexible possibilities of combining systems with different capability levels. To achieve the optimal level of harmonisation, there should be a limited number of capability categories.

The target railway system outlined in this document would be delivered incrementally (step by step) within a reasonable timescale. Technological progress, societal needs and new policy objectives may require subsequent reviews and updates.

It is not only necessary to describe the target railway system but also to describe how it shall be implemented. The Agency's communication material that is available on its [website](#) provides an illustrative example of the vision of the target railway system and its integration in the future multimodal transport system.

The implementation of the target railway system as part of the multimodal transport system will happen in several stages:

- › In the short term, the simplification of tariffs and ticketing at national level would help attracting more users/customers to rail;
- › In the medium-term, the extension of such system at EU level would help in realising the Single European Railway Area, and
- › In the long term, the implementation of a multimodal tariffs and ticketing system would allow to reach an optimal mobility service in terms of customer satisfaction, economic growth, and environmental footprint.



4. How to develop the target railway system

This would require to develop each element of the target railway system in a structured way, involving the main actors, taking account of constraints and opportunities.

The analysis of these elements will allow to identify what needs to be further developed (research and innovation) and what needs to be harmonised (regulation, standards).

The following principles should always apply where possible:

- ▶ 'users first',
- ▶ sharing information,
- ▶ sharing facilities, tools (e.g. testing facilities, training tools),
- ▶ 'plug and play' (e.g. Radio systems from 5G to 7G and beyond),
- ▶ cost-efficient solutions, and
- ▶ 'products from the shelf' including technologies developed from other sectors such as automotive and aerospace (e.g. localisation, communication, and passenger information); could also include components such as axles and bogies where scale effects could help lower costs.

Among the prerequisites, better access to data and involvement of specialists from different fields are needed.



5. High level outline of the challenges to reach the target

An analysis of the current railway system, the drivers for change, the opportunities and constraints affecting the potential for change is presented in Annex 3 of this document.

The table below outlines the conclusions deriving from this analysis and highlights the changes necessary for railway to play its role as the backbone of an integrated multimodal transport system.

| ELEMENTS | CHANGES | MAIN ACTORS |
|--|---|--|
| Users: freight and passengers Patterns (e.g. spontaneous/regular/planned) | Service tailored to the needs of end-users including health related needs – Mobility as a Service (MaaS) On-demand transport (e.g. on train or in station) | Industrial actors competing/ collaborating to put the first viable solution on the market Citizens, users and customers |
| Financial arrangements (funding/taxes/tolls/levies) for the implementation of the SERA (See Annex 1) | Support implementation of multimodal approach among others through EU/national regulation of financial instruments | Policymakers Citizens, users and customers |
| Regulation | New regulations for the future framework to cover areas such as level crossing, bridges, terminals, ports, automations, etc. <ul style="list-style-type: none"> › Minimum set of requirements for automated and interconnected transport systems (railways with other modes) › Multimodal user charging of external costs (level playing field) › Regulation dealing with disruptive technologies Safety and liability (e.g. algorithms) | Policymakers Citizens, users and customers Sector associations |
| Data management including telematics (See Annex 1) | Open access to shared system data (e.g. Platforms) necessary for providing MaaS (timetable, dynamic data with real-time ETA and combined fares, automated clearing processes, etc.) Real time travel information Functional public registers (with possibility to include data related to public health if legislation so permits) enable to feed business driven applications Use of behaviour analytics Asset monitoring using data collected: <ul style="list-style-type: none"> › common standards › semantics interoperability › trend analysis Proposing added value from processing data/big data using Artificial Intelligence | Policymakers Integrated transport planners Academics Industrial actors (manufacturers, IT solution providers, etc.) |

| ELEMENTS | CHANGES | MAIN ACTORS |
|--|---|---|
| Harmonised operations, vehicles and infrastructure within SERA (See Annex 1) | Political, legal, technical and commercial barriers removed (including language barriers) | <p>Polymakers</p> <p>Infrastructure managers (IMs)</p> |
| Cross border traffic with third countries (See Annex 1) | Political, legal, technical and commercial barriers removed | <p>Polymakers</p> <p>Sector associations</p> <p>Infrastructure managers</p> <p>Railway Undertakings</p> |
| Ticketing and information (See Annex 1) | <p>Open market for retailing to enable multimodal end to end (e)-ticket from one stop shops (registration, routing, booking and billing)</p> <p>Ticketing could be done through various systems (e.g. single journey ticketing, registration plus regular billings)</p> | <p>Industrial actors, not limited to train operators (e.g. Global Distribution Systems and ticket vendors), competing/collaborating to put the first viable solution on the market</p> <p>Citizens, users and customers</p> <p>Polymakers</p> |
| Traffic management including CCS (See Annex 1) | <p>End to end traffic management across modes vs solely train traffic management</p> <p>Automatic Train Operation (ATO) is a common practice in train operation</p> | <p>Integrated transport planners</p> <p>Integrated transport regulators</p> |
| Infrastructure (See Annex 1) | <p>Interconnected infrastructure with other transport modes (this might cover new modes such as autonomous vehicles/pods)</p> <p>To cover the need of increased capacity and mobility with the expansion of:</p> <ul style="list-style-type: none"> › high speed lines linking cities and airports (for passenger and/or freight) › other lines (regional, urban rail, metro, light rail) › other railway links to, and between airports › digitized railway network description available for customers, railway operators and for potential investors <p>To strengthen captive traffic:</p> <ul style="list-style-type: none"> › bulk transport › metro/tram systems <p>To reduce infrastructure costs by vehicle autonomy (energy, Control Command and Signalling (CCS))</p> <p>Automated terminals and interconnecting points</p> | <p>Integrated transport planners</p> <p>Integrated transport regulators</p> <p>Industrial actors competing/ collaborating</p> <p>Polymakers</p> |

| ELEMENTS | CHANGES | MAIN ACTORS |
|---|---|--|
| Energy (See Annex 1) | <p>Trial new developments from other industries (e.g. hydrogen fuels, solar cells, batteries, photovoltaic slab track, piezoelectric ballast to enable infrastructure to produce energy (it already exists for roads)) vs existing technology considering:</p> <ul style="list-style-type: none"> › total costs (fixed installation and energy consumption) › global environmental footprint <p>Open market for energy supply</p> <p>To maximise energy recovery with high efficient regenerative braking and to curb demand peaks:</p> <ul style="list-style-type: none"> › stations as active energy hubs linked to smart grids, › dynamic reallocation of energy to grids (in combination with speed profile of ATO), and › energy storage in local buffers for the benefit of e-vehicles | <p>Industrial actors</p> <p>Policymakers</p> |
| Vehicles (See Annex 1) | <p>More intelligent vehicles (e.g. autonomous driving, use of Artificial Intelligence (AI), predictive maintenance)</p> <p>Automated/virtual coupling</p> <p>More accessible customer friendly (e.g. People with Reduced Mobility), travel information, easy boarding, seats availability, public health protection measures)</p> <p>Enhanced on-board services (work and entertainment including connectivity)</p> | <p>Industrial actors competing/ collaborating to put the first viable intelligent, entertaining, accessible customer friendly vehicles on the market</p> |
| Personnel skills, competences and qualifications (See Annex 1) | <p>Changing proportion of categories of staff:</p> <ul style="list-style-type: none"> › less but highly competent staff (those who have the skills knowledge and experience to do the task in a safe way) › other staff who do not perform safety critical tasks <p>Impact of automation (including intelligent software)</p> <p>EU certification/qualification scheme for staff (considering human and organisational factors, safety culture)</p> <p>Training and maintenance of competence using Virtual and Augmented Reality (VR and AR)</p> | <p>Policymakers</p> <p>Industrial actors</p> <p>Social partners</p> <p>Academics</p> <p>Training centres</p> <p>Assessment bodies</p> |

6. Description of the target railway system

A fundamental characteristic of the railway system is that it is highly dependent on the infrastructure design and quality. Effectively, the specific design of the railway system infrastructure impacts key elements such as capacity, safety, reliability, resilience, and quality of service.

In addition to the purely financial aspects of CAPEX and OPEX, there are unavoidable fixed costs of the railway system which are due to the need to maintain different versions of assets, including signalling systems and IT applications.

Such redundancies are necessary to manage long transition periods while ensuring safe and continuous operations. This is described in Figure 1.



Figure 1

As such, the supply of rail transport services, passenger or freight, is essentially based on the provision and use of infrastructure. Usage of this rail infrastructure is in turn made possible through staff, rolling stock, as well as management systems, notably signalling systems.

The railway system is broader than just the physical network and rolling stock. It also includes institutional settings, regulatory frameworks, and IT related systems.

Passenger and freight customers will use the railway system depending on its characteristics and their user needs. In this context, price, travel time, and other service quality parameters, are key factors for use.

The railway system, as part of the transport system, will generate accessibility and mobility effects leading to a variety of socio-economic impacts. These impacts include productivity, the spatial pattern of economic development, and a range of externalities such as noise.

Figure 2 summarises these linkages stressing the important role that decisions on system costs (CAPEX and OPEX) play on quality of service, price, demand, and more broadly socio-economic impacts. These elements define the overall railway system performance.

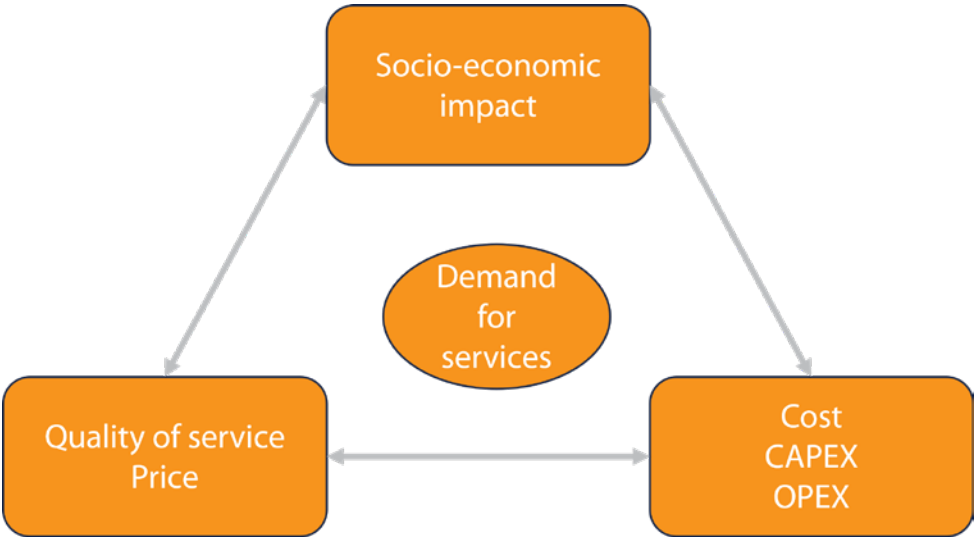
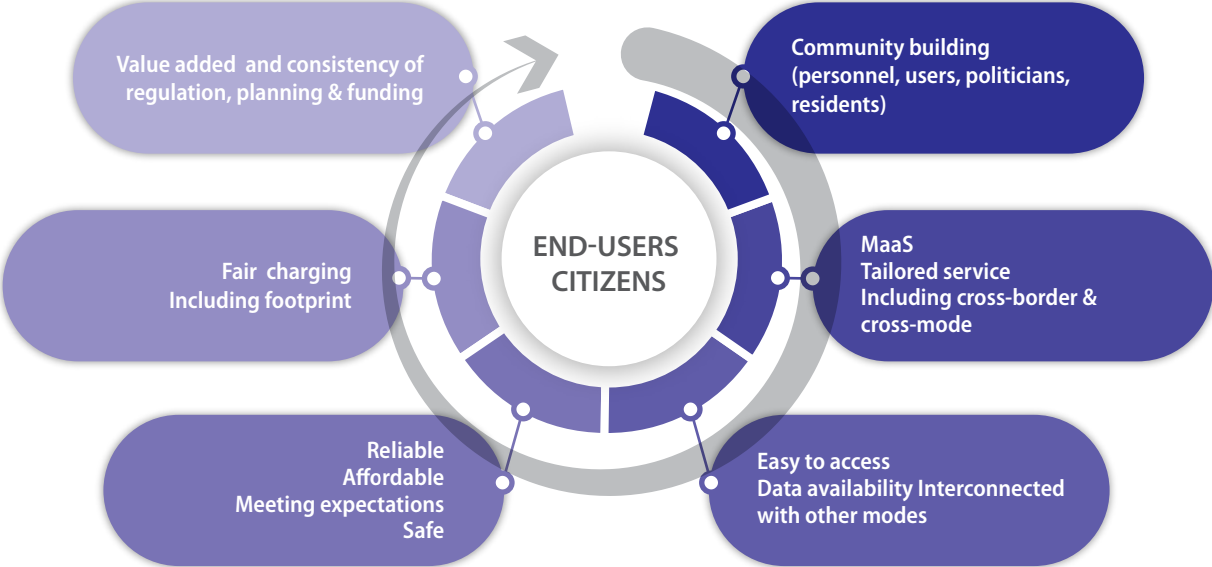


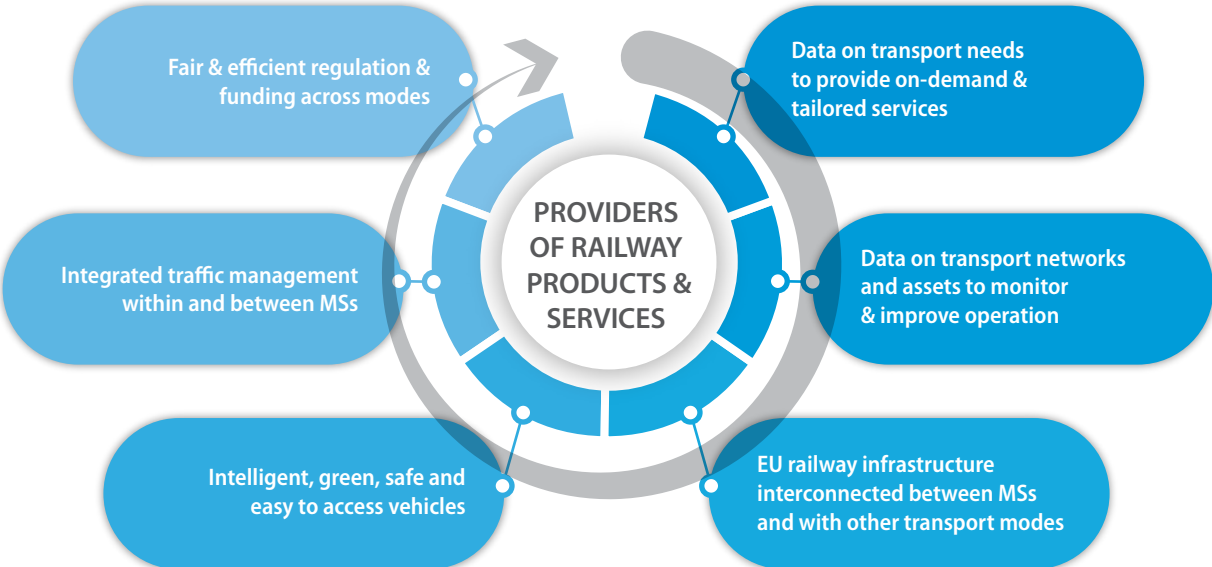
Figure 2

Considering the above high level outline of the changes to the current railway system, the description of the target railway system is given from three perspectives.

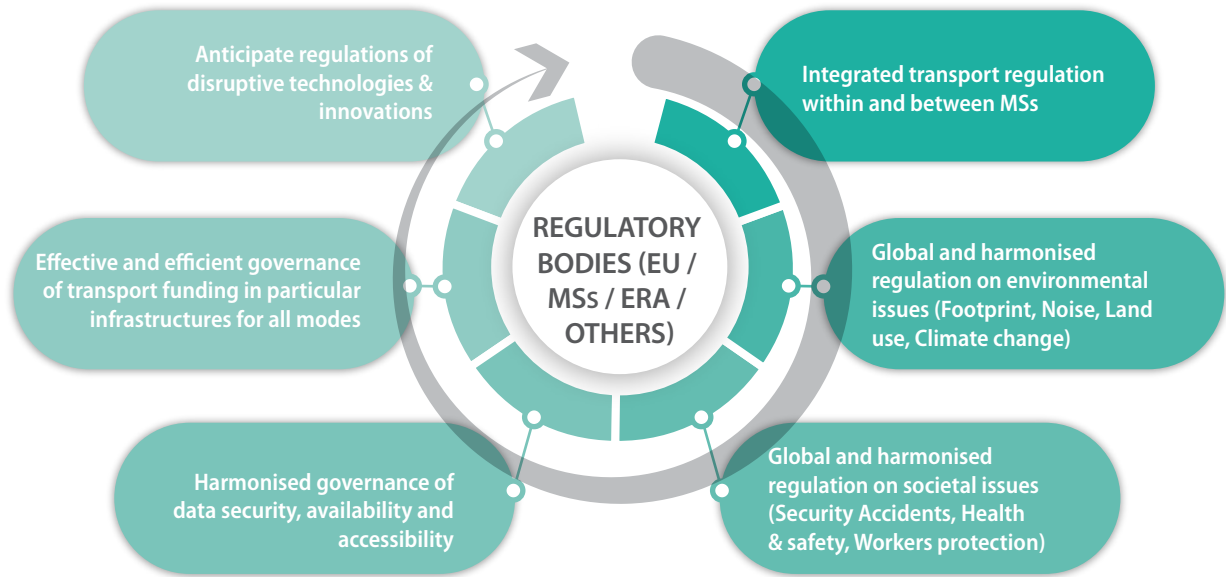
Target railway system from the perspective of the end-users and citizens



Target railway system from the perspective of providers of railway products and services



Target railway system from the perspective of the regulatory bodies



7. The way forward

To effectively emerge from the decline in rail modal share, an EU shift in approach is crucial. Learning from the Japanese approach ⁽¹¹⁾ that differs fundamentally with the EU approach is one way forward. European decisions are generally defined according to budgetary constraints whereas in Japan, it is predominantly the desired level of service which determines the necessary efforts to realise it within the budget.

On one hand, the frequent EU political short-term budget constraints have led to reduction of lines in operation, service frequency, and staff that in turn result in lower service quality and subsequent lower demand. On the other hand, the Japanese approach striving to deliver service answering customers'/users' needs results in increase of demand, and revenue that generate a higher farebox.

Several studies⁽¹²⁾ are converging on the need to change the EU approach to transport/mobility, business as usual will not suffice anymore. The following recommendations are broadly shared.

- ▶ Coupling transport planning and urban planning in order to save traffic and improve transport/mobility.
- ▶ Implementing digitalisation and shared data space that enable new business models while protecting private and sensitive information.
- ▶ Tailoring mobility/transport offers to people's needs, such as PRM, access to remote areas.
- ▶ Engaging people to adopt innovation, new sustainable consumer behaviour.

For the case of EU rail freight, disruptions during changes to the system should be avoided and operation continuity should be ensured. Consequently, incremental steps are essential in reaching the target system. The target to increase freight⁽¹³⁾ capacity could be reached through a combination of incremental measures such as:

- ▶ increasing wagon axle load from 22.5t equipped with cast iron brake blocks to 25t equipped with disc brakes;
- ▶ allowing operation of longer trains (>740m); and
- ▶ increasing freight trains speed.

The System Pillar introduced in Europe's Rail has the stated objective to accelerate innovation uptake. The Prerequisites for the successful outputs of the SP from the perspective of the Agency are developed in Annex 2.

Those prerequisites stress particularly the need to set the starting point, in order to provide the right direction for subsequent activities.

The starting point should cover the existing systems (Transport, Railway, EU railway, Control Command and Signalling and Traffic Management) and all the projects and initiatives at an advanced stage⁽¹⁴⁾ that would impact the transformation towards the target railway system.

This will require sound Key Performance Indicators (KPIs) using the Better Regulation⁽¹⁵⁾ S.M.A.R.T. criteria in the early phase of Europe's rail activities, their monitoring at appropriate periods, and consistent follow-up.

⁽¹¹⁾ <https://www.linkedin.com/pulse/learning-from-best-japanese-way-run-railways-joris-d-inc%C3%A0>.

⁽¹²⁾ <https://en.acatech.de/publication/acatech-horizons-transforming-mobility-english/>.

⁽¹³⁾ https://www.capacity4rail.eu/IMG/pdf/c4r-d2.4.2_catalogue_rail_freight_systems_of_the_future_final_.pdf.

⁽¹⁴⁾ Directive (EU) 2016/797.

⁽¹⁵⁾ Better regulation.

The following KPIs may form the basis for the starting point and the periodic monitoring measurements:

| KPI | FREIGHT | PASSENGER | NOTE |
|------------------------------------|---|---|---|
| Quality of service* | Punctuality rate in % | Punctuality rate in % | Customers/Users are keen to get up-to-date product information (including accurate and reliable rail transport event forecasts) |
| Transport service operating cost** | Cost per ton km | Cost per passenger km | For HS, CR |
| Energy consumption*** | Ton oil equivalent per Ton Km | Ton oil equivalent per passenger Km | |
| Greenhouse Gas emission**** | Total cost per Ton Km | Total cost per passenger Km | |
| Safety***** | Number of fatalities per billion ton km | Number of fatalities per billion passenger Km | |

* [RMMS Monitoring report](#).

** Time series (2005-2018) from MOVE study: New mobility patterns in European cities.

*** <https://ec.europa.eu/eurostat/> and Statistical Pocketbook on Transport.

**** Eurostat and EEA (time series are available in MOVE study: New mobility patterns in European cities).

***** [sdb_report_2021_public.pdf \(uic.org\) for freight, and Common Safety Indicators for passengers](#).

Additional KPIs would also be useful such as customer (passenger and freight) satisfaction rate, capacity, Member States' performance for supporting the necessary changes on safety management, Multi-modal integration, and in-depth economic performance. Currently, there is no EU-wide system in place for their definition, collection, and analysis. These should be given priority in order to have a comprehensive monitoring. In this context, the Agency has undertaken an analysis⁽¹⁶⁾ on the possible framework to define and apply KPIs regarding multimodal integration with focus on travel time comparisons.

For all identified target system elements, research and innovation activities are needed. The selection of the innovative solutions should prioritise those with:

- ▶ quick effects on achieving the climate change goals; and
- ▶ the less investments needs.

For the particular case of infrastructure developments, because of their high costs and long time period, they need a specific strategic and financial analysis.

Before deployment and implementation of innovative solutions, comparison of alternative options should be done to evaluate properly the costs of a change that includes all consequential costs (upstream and downstream).

The target system will probably be reached progressively through several migrations. It is therefore necessary to define securely the various stages of such migrations without unsettling the entire system. Those migrations should take into account the interactions between technical and operational elements of the target system.

The Agency provides its input on research needs relating to the realisation of the SERA for consideration by Europe's Rail in its Master Plan and work programmes.

⁽¹⁶⁾ https://www.era.europa.eu/system/files/2024-05/ERA_Multimodal_KPIs_2024_05_03.pdf?t=1714722975.

Annexes



ANNEX 1.

Target railway system

This annex contains the description of the elements of the target railway system.

1. Financial arrangements

1.1. Overview

A high ambition level is necessary in order to ensure the delivery of the policy goals regarding sustainability (climate change, social cohesion, economic prosperity). This would include a level playing field between modes regarding, for example, carbon footprint, environmental externalities and fair and efficient charging for use of infrastructure.

Under this section, financial arrangements cover transport related costs in the widest sense: financing infrastructure and assets, operating costs (i.e. costs accrued during the utilisation of assets), external costs, as well as the resulting financial and societal benefits. Key improvements are identified for each of these categories.

A better use of the EU financing instruments could be achieved by avoiding a silo approach to horizontal topics such as cybersecurity, safety, communication.

As such this component of the target system is by nature at a more generic level and it will rather concern identification of key improvements.

Financing infrastructure and assets

- ▶ Integrated approach between MSs, between modes and between the actors within each mode.
 - Harmonised principles for assessing infrastructure projects between modes.
 - Better utilisation of synergies in planning of multimodal projects.
 - Ensuring that vital connections between networks are included in investment projects' planning.
- ▶ Reduced upfront costs so as to reduce the payback time.
 - Lower upfront costs using new technologies such as AI.
- ▶ Improved management of Public Private Partnerships.
 - Optimise the allocation of risks and liabilities (e.g. by inclusion of incentives for private parties to take preventive action against risks).
 - Considering projects dependencies with land use planning/ urban planning (smart cities)/mobility planning.
- ▶ Coupling EU research and Infrastructure financing instruments.
 - Use EU-13 MSs as demonstrator(s) for EU research projects under the TEN-T corridors to ensure better geographical coverage and inclusive growth.

Operating costs

- › Understanding and improving the factors determining asset utilisation. Comprehensive use of efficiency analysis (e.g. efficiency analysis should be done by independent regulators).
 - Flexible use of competitive structures (e.g. facilitating cooperation between different stakeholders within the railway system: Coopetition).
- › Identifying the most cost effective balance between: make or buy, own or lease, human resources or automation.
 - Flexible approaches allowing for optimisation of operating costs.
 - Decisions driven primarily by optimisation of available resources and value creation.
- › Optimise economies of scale and scope.
 - Identifying and measuring scale and scope properties of railway operation (e.g. size of companies, complexity of companies, number of companies).

External costs

- › Integrated approach between the actors within each mode, between modes and between MSs/countries.
 - Full and complete implementation of the user's pay principle across modes and across MSs/countries.
 - Common standards for measuring external costs:
 - Safety,
 - Impact on environment and health (gas and particle emissions, noise, landscape, impact on biodiversity),
 - Land use,
 - Congestion, and
 - Social and geographical cohesion.

Financial and societal benefits

- › Integrated approach between MSs, between modes and between the actors within each mode.
 - Defined mechanism to balance the total costs (capital, operating, maintenance, renewal, external costs) against the total societal benefits (private and social). Consideration of both private and social costs/benefits would prevent decisions that may be optimal from a private perspective but are not optimal from a societal perspective.

1.2. Enablers

Enablers are factors which would allow the railway sector to respond/react optimally to the four areas highlighted above.

On the basis of the overview in section 1.1, key enablers would include:

- › multimodality integration;
- › system approach/stakeholders' cooperation (public/private) on a voluntary or mandatory basis;
- › accessibility;
- › cross-border coordination;
 - According to an ERA 2022⁽¹⁷⁾ study, EU cross-border traffic covers 50% of rail freight and 6% of rail passenger services. Tackling EU rail cross-border traffic issues will help to reach the target system.
 - Several recommendations were made in the ERA study to overcome the fragmentation of the Single European Railway Area. Sharing and harmonising data is part of those recommendations.
 - Collecting and processing data brings added value to the EU railway system. It provides information to users, supports planning of operations and maintenance, helps reducing equipment downtimes, can lead to automatic actions, and enable digital twins to support decision making process.
 - Per nature, data do not know borders, it is then important that the digital transformation of the EU railway system does not create any artificial border. Data sharing will be done via semantic technologies, connecting the various parts of the railway system based on standardised communication in line with the Telematics TSI.
- › societal considerations (including competent people) in order to facilitate optimisation; and
- › consideration of the linkages between transport and the wider economic context (transport avoidance, other).

⁽¹⁷⁾ https://www.era.europa.eu/system/files/2022-12/20225455_PDFA2A_TR0522377ENA_002.pdf.

1.3. Target system components and their link to the enablers

| TARGETS | ENABLERS | ACTORS |
|---|---|--|
| Implementation of multimodal approach through EU/national regulation of financial instruments for financing infrastructure and assets | <ul style="list-style-type: none"> › Harmonised principles for assessing infrastructure projects between modes › Better utilisation of synergies in planning of multimodal projects › Ensuring that vital connections between networks are included in investment projects' planning › Optimise the allocation of risks and liabilities (e.g. by inclusion of incentives for private parties to take preventive action against risks) › Considering projects dependencies with land use planning/urban planning (smart cities)/mobility planning | <p> Policymakers Regulators Citizens, users and customers Industrial actors Private investors</p> |
| Implementation of multimodal approach through EU/national regulation of financial instruments for financial and societal benefits | Defined mechanism to balance the total costs (capital, operating, maintenance, renewal, external costs) against the total societal benefits (private and social). | <p> Policymakers Industrial actors Academics Regulators Private investors Citizens, users and customers</p> |
| Implementation of multimodal approach through EU/national regulation of financial instruments for external costs | <ul style="list-style-type: none"> › Full and complete implementation of the users pay principle across modes and across countries. › Common standards for measuring external costs | <p> Policymakers Industrial actors Academics Regulators Citizens, users and customers</p> |
| Optimise operating costs | <ul style="list-style-type: none"> › Understanding and improving the factors determining asset utilisation (e.g. "UBER" models to fill trains) › Identifying the most cost effective balance between make or buy, own or lease, human resources or automation › Optimise economies of scale and scope | <p> Industrial actors Private investors Academics Regulators Policymakers</p> |

2. Data management including telematics

2.1. Overview

Global picture

Going for global performance requires to design and model the railway system as a whole and as part of the multimodal transport system. This is why an overall data system architecture is important with the integration of the various transport modes from a trip perspective.

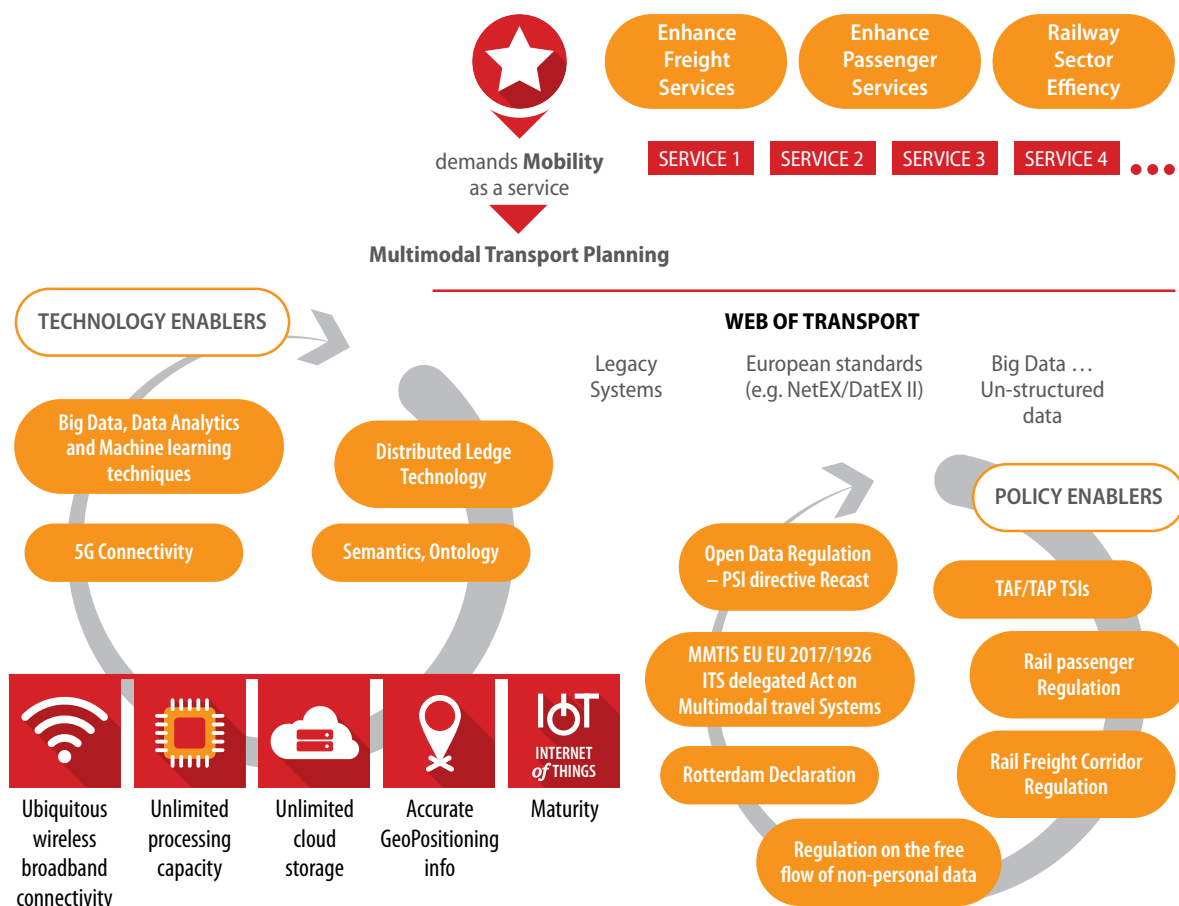
A major barrier today is the lack of effective and efficient information connectivity or data interoperability within and between various transport modes. Freight and Passenger customers want up-to-date product information in the pre-journey phase and precise goods tracking in the during-journey phase of transport.

The future is integration of services to provide smarter services to the user/customer (passenger or freight customer). The demand is evolving from an “always connected” status to an “always informed” status meaning able to access consistent and aggregated information on time and everywhere.

The user/customer (passenger, freight customer or railway stakeholder (including combined transport operators)) demands an end-to-end mobility service that might be multimodal.

Data are shared freely regardless of the transport mode and the provided service. At the same time, data are becoming a valuable good, and enriched mobility services is/can be achieved through enhanced Data. To support this there will be a need for a neutral authority at European level to support the sharing of data, ensuring the application of the wider EC policy of FAIR (Findable, Accessible, Interoperable and Reusable) data. National access points (NAP) shall host all rail related data (e.g. timetables, fare products).

Data management in the target railway system



A secure seamless data exchange between actors involved and systems (machine to machine) that will interlink without the need to change legacy systems.

New services supported by a multimodal transport system based on open standards, including appropriate data management and usage by the actors.

This system of multimodal transport relies on an architecture based on a canonical data model and a semantic dictionary of all used terms.

Target system description

The following needs cover the above target system.

For passenger and freight services:

- › promote railway data exchange specifications and their use, including RU-IM communications (such as path request, train positioning, etc.), to other transport modes customers/users;
- › robustness of telematics system deployment and change control baselining;
- › transparent data about all available train paths for timetable planning and ad hoc train routing.

Specific for passenger services:

- › enable open data on timetable (planned vs real-time) and on fare products (tariffs) accessible on the European mobility dataspace and based on European standards;
- › enable the creation of Railway passenger data information brokers and of Rail Meta Search Engines covering all timetables and fares for rail (also including other modes of transport);
- › enable the harmonised European e-ticket and ticket check (also including other modes of transport);
- › enable open data to store real-time information, for data processing and for data mining within the European mobility dataspace;
- › improve the passenger information during the trip (also including other modes of transport).

Specific for freight services:

- › take into account open source and open data architecture requirements;
- › revision of exchange of wagons and train composition and, where appropriate, simplification;
- › revision of messages in relation to combined or multimodal transport, and where they are not available, their development in order to facilitate logistics and operations;
- › further integration of safety related applications (e.g. Dangerous goods regulation) data;
- › harmonising the exchange of information between railway actors and customers (including soft compliance for protocols);
- › better access to tracking data and traffic forecasts for customers;
- › transparent and easy bookable freight services (e.g. book your container as a flight ticket);
- › loading and unloading points included in the digital railway network;
- › alternatives for the above bullet point:
 - service facilities and multimodal terminals form part of the digital railway network description,
 - the core railway infrastructure database (RINF) serves as reference data to digitize locations and infrastructure of service facilities and intermodal terminals.

2.2. Enablers

Policy enablers

- › Open Data Regulation – PSI Directive Recast.
- › MMTIS – ITS Delegated Act on Multimodal Travel Information Systems.
- › Rotterdam Declaration.
- › TSI TAF and TAP (Telematics).
- › Rail Freight Corridor Regulation.
- › Rail passenger rights Regulation.
- › Regulation on the free flow of non-personal data.
- › Agency Regulation.
- › RINF.

Technology enablers (scenario description and game changers)

Around 2030–2040, the technological scenario will allow unrestricted processing capacity, unlimited data storage, ubiquitous broadband wireless connectivity, wide implementation of accurate geopositioning information and highly sensorised railway through a mature IoT framework.

What is mainly covered here by IoT is about connecting sensors, actuators, and devices to a network and enabling the collection, exchange and analysis of generated information.

The following technology enablers might turn into game changers:

- › 5G;
- › semantics ontology;
- › big data platforms;
- › data analytics and machine learning techniques; artificial Intelligence used to enhance business analytics by:
 - providing the operating companies the means to adapt their offer to a real time multimodal demand,
 - optimising service planning, operation and capacity,
 - enhancing passenger services providing the user:
 - the tools to search for all travel options, and
 - a virtual companion from departure to arrival helping people get to the right station/gate/platform, to cope with service disruption and congestion; and
 - supporting investigations for safety purposes (incidents, accidents, public health).

Market enablers

- › European mobility dataspace legislation.
- › Multimodal digital mobility services.
- › Timetable and tariffs distribution systems.
- › Global distribution systems ticket vendors.
- › Monitoring of the train running.
- › Real time tracing and tracking of the wagon events.
- › Exchange of consignment notes.
- › Digital railway network description.

2.3. Target system components and their link to the enablers

| TARGET SYSTEM COMPONENT | ENABLER | ACTOR |
|---|---|---|
| General | | |
| Data is shared freely regardless of the mode and the provided service | <ul style="list-style-type: none"> › Open Data Regulation – PSI directive Recast › Multimodal digital mobility services › MMTIS EU – ITS Delegated Act on Multimodal travel information systems › Rotterdam Declaration › TSI TAF and TAP (Telematics) › Rail passenger rights Regulation › Timetable and tariffs distribution systems › Global distribution systems Ticket vendors › Monitoring of the train running › RINF › Compliance with public health requirements where applicable | <ul style="list-style-type: none"> › Infrastructure manager › Intermodal operator › Railway undertaking › European Commission |
| A secure seamless data exchange between actors involved and systems (machine to machine) that will interlink without the need to change legacy systems. | › Same as above | › Same as above |
| New services supported by an open system of multimodal transport. | › Same as above | › Same as above |
| Passenger and freight | | |
| Rail data exchange promoted to other transport modes | <ul style="list-style-type: none"> › Rotterdam Declaration › Monitoring of the train running › Real time tracing and tracking of the wagon events › Exchange of consignment | <ul style="list-style-type: none"> › Intermodal operator Intermodal Service Integrator › Agency › European Commission |
| Telematics system robust in deployment and control baseline | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) › Agency Regulation | <ul style="list-style-type: none"> › Agency › European Commission |
| Always available real time information on train paths | <ul style="list-style-type: none"> › Monitoring of the train running › RINF | <ul style="list-style-type: none"> › Infrastructure manager › Railway undertaking |
| Passenger | | |
| Always available timetable, tariff and train running information | <ul style="list-style-type: none"> › Timetable and tariffs distribution systems › Monitoring of the train running (i.e. RNE TIS) | <ul style="list-style-type: none"> › Infrastructure manager › Railway undertaking › Authorised public body › Ticket vendor |
| Achieved an harmonised European e-ticket and passenger control | <ul style="list-style-type: none"> › Timetable and tariffs distribution systems › Rail passenger rights Regulation TSI TAP (Telematics) | <ul style="list-style-type: none"> › Railway undertaking › Station manager › Ticket control organisation › Ticket vendor |
| Brokers and multimodal transport meta engines in place | <ul style="list-style-type: none"> › Harmonised European Standards › Semantics ontology › Big Data platforms › Data analytics and machine learning techniques. Artificial Intelligence used to enhance business analytics, › Timetable and tariffs distribution systems | <ul style="list-style-type: none"> › Ticket vendor |

| TARGET SYSTEM COMPONENT | ENABLER | ACTOR |
|--|--|---|
| Freight | | |
| Simplification of exchange information on train composition and wagons | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) › Monitoring of the train running (i.e. RNE TIS) | <ul style="list-style-type: none"> › Infrastructure manager › Railway undertaking |
| Data exchange for combined and multimodal transport | <ul style="list-style-type: none"> › Rotterdam Declaration › Monitoring of the train running › Real time tracing and tracking of the wagon events › Exchange of consignment notes › RINF | <ul style="list-style-type: none"> › Intermodal operator › Intermodal service integrator › Agency › European Commission |
| Harmonising dangerous goods data | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) › Exchange of consignment notes | <ul style="list-style-type: none"> › Consignee › Consignor › Railway undertaking › European commission |
| Harmonising the exchange of information between railway actors and customers (including soft compliance for protocols) | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) | <ul style="list-style-type: none"> › Agency › European Commission |
| Better access to tracking data and traffic forecasts for customers | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) › Rotterdam Declaration › Big Data platforms › Data analytics and machine learning techniques. Artificial Intelligence used to enhance business analytics › Monitoring of the train running › Real time tracing and tracking of the wagon events › RINF | <ul style="list-style-type: none"> › Infrastructure manager › Intermodal operator › Intermodal service integrator › Railway undertaking |
| Transparent and easy bookable freight services (book your container as a flight ticket) | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) | <ul style="list-style-type: none"> › Wagon keeper › Railway undertaking |
| Loading and unloading points digitally connected to the railway network | <ul style="list-style-type: none"> › TSI TAF and TAP (Telematics) › RINF › Rail Facility Portal | <ul style="list-style-type: none"> › Agency › European commission › Terminal operator |

3. Safe and Interoperable Operations

3.1. Overview

Description

The scope of the target system for Safe and Interoperable Operation is wider than the current scope of the OPE TSI. It covers cross-border operations within the EU and with third countries and also through ticketing.

Harmonisation of operations is needed not only for interoperability, but also to ensure that the Safety Directive principles are respected in each MS.

Another key objective of operational harmonisation (within and across MSs) is to standardise ERTMS technical implementation, allowing faster deployment, using validated and tested modular solutions, reducing the resources that would have been needed for the various tests and validations.

Target system components

The target system for safe and interoperable operations would include:

- › effective cross-border operations within the EU (within and across MSs);
- › effective cross-border operations with third countries; and
- › development of advanced ticketing.

3.2. Enablers

Effective cross-border operations within the EU

- › Adopt a comprehensive safety management system covering all operational situations and requirements, including the role of national safety rules and company rules in managing and controlling operational risks. Prerequisites:
 - elimination of Class B systems and deployment of ERTMS and ATO;
 - cleaning-up and removing unnecessary national safety rules for operation by Member States so that there is consistency across borders;
 - having a comprehensive European rulebook for ERTMS-only operations;
 - align the CCS systems across borders to the same principles and engineering rules; and
 - effective application and use of the TSI OPE, linked to the SMS including the use of the fundamental operational principles and common operational rules.
- › Clear links made by IM and RU between operational risks in the SMS and operational procedures required for safe operation both at the individual (RU/IM) and interface operational level. This means:
 - using the SMS to manage railway risks with anticipation and resilience;
 - understanding the reality of operations and the impact the organisation and its safety culture has on the operation;
 - effective and targeted communication and co-operation across all the sector players;
 - cultivating a continuous improvement environment (including proactive monitoring of the SMS procedures and rules, learning from accidents and how improvements should be made, changes implemented and their effectiveness reviewed); and
 - integrating safety and business throughout the operation, covering the top down senior management and the bottom up operational staff.

- › Develop a European Traffic Management Layer to harmonise traffic management at SERA level:
 - common traffic management rules (e.g. on dealing with disruptions), and
 - common capacity allocation rules.
- › Clear and risk based requirements on language skills/possible adoption of a common operating language.
- › Risk based and targeted supervision by the relevant authorities which focuses on areas for operational process improvement, rather than the introduction of national rules.

Effective cross-border operations with third countries

- › Establishing, maintaining, further developing:
 - equivalence between the EU and OTIF technical regulations, and
 - cooperation with other organisations (OSJD, Gulf Cooperation Council, etc.) on specific technical matters (e.g. standardisation).
- › Establishing, maintaining and further developing administrative cooperation, in particular those relating to customs, with 3rd countries authorities by:
 - facilitating networking, joint actions and training among customs personnel; and
 - using IT systems allowing real-time exchanges of information that takes also into account cybersecurity.
- › Coordinating funding instruments, for example CEF contributing to building EU railway network in a coordinated way.

Development of advanced ticketing

- › Dematerialisation.
- › Through-ticketing (Open market for retailing to enable multimodal end to end (e)-ticket from one stop shops (registration, routing, booking and billing).
- › Open access to information enabling the afore-mentioned dematerialised end to end ticketing (in particular timetable and tariffs and fares) and ticket exchange.

3.3. Target system components and their link to the enablers

| TARGET | ENABLER | ACTOR |
|--|--|---|
| Effective cross-border operations within the EU | | |
| Reduction of national rules | <ul style="list-style-type: none"> › Political will and agreement to reduce national rules in alignment with new legislation › Harmonisation of operational requirements (acceptable means of compliance as per TSI OPE) | <ul style="list-style-type: none"> › Policymakers › Sector associations › Industrial actors › Academics › Agency › Authorities |
| Risk based operation | <ul style="list-style-type: none"> › Effective implementation of SMS › Risk based supervision of the system › Training › NSA monitoring | <ul style="list-style-type: none"> › Sector associations › Authorities › Agency |
| ATO | <ul style="list-style-type: none"> › Integrate ATO into CCS and link it with traffic management system | |
| Development of advanced ticketing | | |
| Dematerialised through-ticketing | Politically and business driven: <ul style="list-style-type: none"> › Access to open data › Ticketing standard change control (including public key infrastructure) | <ul style="list-style-type: none"> › Policymakers › Sector associations › Industrial actors › Infrastructure managers › Railway undertakings › Ticket vendors › Standardisation bodies › Agency |

These are the key areas to consider for moving towards the target railway system:

- › development of risk based acceptable means of compliance under the TSI OPE;
- › implementation of European communication methods and tools;
- › planned reduction of national rules by MSs in line with the Agency framework;
- › implementation of the new SMS criteria;
- › driving improvements through NSA monitoring; and
- › strong stakeholders' cooperation on cross-border issues within rail freight corridors.

4. CCS covering traffic management as part of a multimodal transport system

4.1. Overview

Scope

The scope of the SERA target CCS is:

- › all the trackside and on-board equipment required to ensure security, safety and to command and control movements of trains authorised to travel on the network;
- › equipment carrying out other functions shall also be included where justified on the grounds of economic viability.

Description

The CCS part that covers traffic management has to be seen as part of the target railway system that is itself part of a multimodal transport system.

This means that it is crucial to establish:

- › harmonised interfacing with the non-ERTMS parts of the target railway system, with the other transport modes; and
- › secured communication system for the on-board (where safety and non-safety related components of the vehicle are connected to).

The key elements are as follows.

- › Standardised interchange of localisation data, for the railway system CCS and traffic management (as centre of trackside ERTMS gravity). This shall be based on a standardised Rail Data Model. Reliable localisation of trains is an important part of the data to be exchanged.
- › Communication system (where safety and non-safety related components of the vehicle are connected to) for the on-board.
- › Secured communication system on-board – trackside, based on FRMCS.

For the sake of upgradability, it is highly recommended to have:

- › separation of safety and non-safety related applications;
- › life cycle of the non-safety related part similar to IT components/software;
- › life cycle of the safety part aligned with the pace of innovation in the related domain;
- › euro traffic management for SERA; and
- › track – train and train – train communication system performant enough to serve the needs of ERTMS and other applications (e.g. ATO, Entertainment).

The CCS part is the basis for safe train movement. CCS components such as IL, LX, RBC are safety relevant applications. The quality and the safety level of the used data are in general much higher than for other applications. This leads to the situation that CCS applications need a specific environment (e.g. safe computing, secured data transmission). Such specific environment may be too costly for non-safety related application to connect to. For non-safety related applications, a stand-alone and tailored solution might be less expensive and closer to the technical evolution.

Applications

The current CCS applications such as IL, LX, signals, train detection systems, point machines, RBC, and train protection system (e.g. ETCS) were developed stepwise. It is mainly trackside based for:

- › route setting and securing,
- › train detection,
- › route release, and
- › computing and transmission of the movement authority for each train.

CCS on-board systems intend to stop the train before the danger point. The functionality of the existing legacy systems varies from simple driver warning systems to train protection systems, with a Safety Integrity Level varying from level 0 to level 4, taking into account track description (e.g. speed profiles, gradients) as well as train data (e.g. braking performance, train length) and signalling data.

In the future IL and RBC will be merged, signals will gradually disappear (ETCS L2 with or without train integrity) and train localisation will be done by other means (e.g. ETCS L2 with train integrity). With the implementation of ETCS moving block, train to train communication, and with ATO GoA3/4 more and more safety related applications will be transferred on-board.

It is not yet clear where this will get to:

- › independent and highly intelligent vehicles asking for route setting, controlling all their movements and with trackside providing only the physical route on vehicle's request;
- › a trackside European traffic management system and highly intelligent vehicles executing the orders received from the trackside; or
- › an intermediate solution.

However, the future looks like CCS applications will be merged together. Some of them will completely disappear. For some others the basic functionality will remain but the way to generate it will completely change.

4.2. Enablers

Clear migration policy

Migration and the ability to migrate (financial resources, life cycle of the existing assets) are the main challenges to reach the target system. The railway undertakings and infrastructure managers face different economic conditions. As long as there are actors (especially the IM) not able to migrate in synchronicity, the target system will be a patchwork and the full benefit of an interconnected system will not be reached.

It is therefore crucial to have a clear structured approach to make this happen.

Migration may cover a complete change from one application/system to another that may not allow backwards compatibility.

Platforms

Concept of platform

In the age of Big data and Internet of Things, access to appropriate information is key. Platforms could be the right instrument to collect information and to make it available for users. The benefits of having platforms are:

- › sharing and decreasing costs;
- › allowing sharing information as a transversal service for several applications;

- › increasing the sources of the same type of information; and
- › allowing exploitation of Big data for tailored/specific use.

In addition, storage of information could be de-centralised

The following section provides a list of possible platforms. Their relevance should be further analysed/developed.

Trackside localisation platform

It is the centralised provider of localisation data for railways. It allows other platforms/applications to access and share railway localisation data between them.

The trackside localisation platform is able to:

- › receive and provide information to:
 - movable assets/actors such as trains, cars, staff, mobiles;
 - fixed assets/applications/actors such as TMS, ATO, Shipper, Eurocontrol, maintenance applications and maintenance database
- › deal with the quality level of the localisation information (received/requested), for example SIL level, resolution.

On-board localisation platform

It is the centralised provider of localisation data of the train, based on multiple sensors (satellites positioning, wheels sensors, accelerometer, IMU, other.). It allows other platforms/applications (such as TCMS and ETCS) to access and share railway localisation data between them.

The on-board localisation platform is able to:

- › receive and provide information to:
 - on-board modules such as:
 - Train Control Monitoring System (TCMS)
 - European Train Control System (ETCS)
 - Passengers Information system (PIS)
 - trackside localisation platform such as:
 - TMS, ATO, Shipper, Eurocontrol, maintenance applications
 - maintenance database;
- › deal with the quality level of the localisation information (requested), for example SIL4 level for ETCS, better accuracy allowing to increase the capacity of the line and removing balise of relocation;
- › share information with the trackside localisation platform.

Rail Data Model platform

For ETCS, precise and reliable data of the track layout are key in order to engineer the ETCS trackside implementation (e.g. movement authorisation, speed profile, gradients). This 'Rail Data Model' could be interconnected with other railway assets providing information (e.g. to feed in the localisation database or to provide information for good tracking). This data model will provide services not only to ETCS but to other on-board or trackside applications, such as ATO and IL.

TMS platform for the transport system

Traffic management systems need knowledge, for example on actual train position, train data (e.g. train length, train type) in combination with route settings, planned train path, traffic conflicts. On the other hand they can provide information for shippers, and interact with the energy system.

Asset Management and Maintenance platform

Maintenance information for fixed and movable assets could be collected by on-board (through an Online Monitoring System) and trackside (through sensors). Feeding this in a database and share the information between on-board and trackside allows the concerned users to access maximum information via a single entry point.

Goods tracing platform

Goods tracing platforms for the railway part would allow , for example, the shipper or buyer to trace their good(s). Interconnecting with platforms from other transport modes would allow the goods tracing from door to door.

Energy management platform

The current railway energy infrastructure is a costly asset. Energy management platform supports intelligent train management in order to avoid energy peaks and drops.

On-board DMI platform

A DMI platform (also called Train Display System (TDS)) may:

- › provide independence between systems (ETCS, TCMS, Voice Radio) and DMIs;
- › allow other platform to access information introduced by the driver or display information to the driver without requiring an important effort of engineering;
- › reduce costs of integrations and validations.

4.3. Target system enablers

These are the key areas to consider for moving towards the target railway system.

- › Replace obsolescent core concepts and eliminate the diversity of operating concepts (see target system for operations), engineering rules and technical specifications;
- › Eliminate legacy systems.
- › Integrate ATO into CCS and link it with traffic management system.
- › Specify CCS architecture in a modular way with common interface specifications so that it delivers a viable migration strategy.
- › Open the market for CCS components based on a common approach to technical regulation and common standards.
- › Develop and adopt a risk-based approach to movement authority.
- › Define the optimal distribution of safety and non-safety related functionality and intelligence within and between on-board and trackside needs.
- › Interconnect CCS and other relevant information (e.g. localisation and odometry data base) in order to make it available for the multimodal transport actors.
- › Develop/use new generation of AI models able to cope with critical functions and that can be certified according to railway safety standards.
- › Ensure cybersecurity is met in all CCS system and components.

5. Fixed installations

5.1. Overview

Description

Key Interfaces:

- › energy supply characteristics (e.g. including overhead contact line geometry, non-electric energy supply),
- › CCS including ATO,
- › traffic management (intelligent infrastructure able to inform about residual capacity),
- › boarding and alighting (e.g. platform height),
- › autonomous charging/loading,
- › infrastructure support for driverless vehicles,
- › harmonised detection and monitoring of rolling stock (e.g. train detection, hot axle box detection).

Optimising life cycle cost to meet new priorities:

- › new and renewable energy sources such as Fuel cell and hydrogen units,
- › different lifetimes for different components,
- › distinguish between safety and non-safety related products (including software),
- › full recyclability,
- › higher climate resilience.

Converging towards a multimodal approach to:

- › safety management system,
- › security (including cybersecurity),
- › infrastructure planning (e.g. land use, freight terminals), and
- › novel terminals, hubs, marshalling yards, sidings, connection.

To migrate towards multimodal terminals for both freight and passenger will require ability of policymakers at local/regional/global level to design transportation planning that considers evolutive:

- › mobility options,
- › mobility demand, and
- › their short term and long-term impacts (land-use, economic development, traffic impact).

Transport consumes space and this is particularly the case for road transport. The more space used for transport, the less space available for other activities (housing, industrial installation, or farming).

New rapid loading/unloading procedures.

The possible use of big data for infrastructure management (e.g. powering sections of OCL only when scheduled).

5.2. Enablers

Policy

- › ENE and INF TSI.
- › EC policies (especially for the energy market).

When interoperable solutions are implemented through SERA, the negative impact of national rules should be reduced.

Performance requirements needs to be determined.

Migration strategy

The role of IMs in clearly expressing the needs for a proper migration strategy is essential to reach the target system and to exploit its benefits.

However, as investments are considerably high, the importance of regulators/MSs shall be also considered.

Platforms

Platforms (especially with the use of big data) are the right instruments to collect information and to make it available for users. They may bring a valuable benefit to receive and to provide information from/to fixed applications:

- › converging towards a multimodal approach (e.g. freight terminals, automatised self-positioning platforms that will avoid interoperability problems linked to platform height and can address last-mile mobility issues);
- › reducing life cycle cost (e.g. maintenance for different components);
- › avoiding energy peaks and drops using intelligent train management; and
- › identifying clearly the processes (e.g. installation and exploitation of energy counters).

5.3. Target system components and their link to the enablers

The table below is a first attempt to specify the link between the identified target system components and their enablers.

| TARGET | ENABLER | ACTOR |
|---|---|---|
| Optimisation of infrastructure management | <ul style="list-style-type: none"> › Big data › Multimodal approach › Use of platforms | <ul style="list-style-type: none"> › Policymakers › Infrastructure managers › Research bodies › Industrial actors |
| Replace obsolescent core concepts and eliminate the diversity of engineering rules and technical specifications | <ul style="list-style-type: none"> › Robust migration strategy | <ul style="list-style-type: none"> › Policymakers › Infrastructure managers |

These are the key areas to consider for moving towards the target railway system:

- › reduce or eliminate NTRs that are redundant with TSIs and ENs; and
- › complete ENE and INF TSIs' technical aspects incorporating the above-listed targets.

6. Vehicles

6.1. Overview

On-board intelligence

All vehicles:

- › intelligent maintenance (vehicle condition monitoring, predictive maintenance based on real time data);
- › infrastructure condition monitoring from vehicles;
- › optimised speed profile according to route, timetable, weather conditions, local restrictions;
- › vehicle to vehicle communication (e.g. virtual coupling);
- › driverless vehicles where feasible;
- › fully implemented interface functionalities between vehicles and traffic management (information on accidents, works, environmental conditions, etc.);
- › train protection based on a single harmonised system (ETCS);
- › communication system enabling safe and secure wireless communications;
- › other non-safety related communications for added value services (e.g. on-board multimedia and telematics services, use the train as sensor for data such as air quality, geospatial, etc.).

Wagons

- › digital freight wagon including couplers;
- › wagons for 'Trucks on trains';
- › derailment prevention measures and detection.

Locomotives and steering cabs:

- › information platforms (e.g. localisation platform) to be accessible for all on-board and trackside applications;
- › ATO (for CCS functions).

A sustainable system

New power sources:

- › migration away from diesel;
- › develop solutions for energy storage and reuse.

Vehicle performance for a better energy efficiency:

- › enhanced acceleration and braking,
- › reduced weight and energy consumption,
- › improved aerodynamics,
- › noise reduction,
- › full recyclability,
- › higher climate resilience.

A system taking into account of the users expectations

Specific for passenger vehicles:

- › accessibility:
 - for all categories of passengers for multiple platforms,
 - wheelchairs, prams, suitcases, cycle,

- for luggage handling services,
- part of a multimodal approach to end-to-end accessibility (seats, escalators, big lifts, not stairs).
- › capacity:
 - flexible train capacity,
 - train design enabling its adaptation to the timetable/influx,
 - modular interior to adapt the configuration to the passenger needs (e.g. temporary public health protection measures).

Specific for freight vehicles:

- › capacity:
 - longer trains,
 - increased payload.
- › flexibility:
 - end of train devices,
 - automatic coupling,
 - electrification,
 - tracing.

A system with an optimised life cycle cost

Different lifetimes for different components:

- › distinguish between safety and non-safety related products (including software).

Developing new business models:

- › standardised vehicles and vehicle components to increase the market/improve the price;
- › improved fleet and operations management.

A system truly engaged in the development of multimodality

Integrated approach with other modes:

- › freight: improvement of containers transport, freight terminals adapted to multimodality;
- › train trip as the backbone of a fully accessible and seamless multimodal end-to-end journey;
- › urban rail and public transport: seamless urban multimodal journeys/freight;
- › geographical information tracking shared with other modes of transport.

Converging towards a multimodal approach to:

- › safety management system,
- › rules (crashworthiness, fire resistance, etc.).

6.2. Enablers

Innovations are rapidly placed on the market

Good communication between stakeholders improves the definition of technical interfaces. Cooperation between manufacturers, railway undertakings, infrastructure managers and the regulator enables the market intake for promising railway innovations.

Innovations are taken into account with an interoperability perspective

New solutions are developed from a system perspective and interoperability is addressed early in the regulation. TSIs are continuously updated to take innovation into consideration. Research projects are monitored so that technical regulations do not hinder the development of innovative solutions.

The authorisation process takes an early consideration of the virtual testing reducing the testing on site

Innovative technologies can be tested and their reliability and safety demonstrated at equipment level, and then at subsystem level with simulations, before being experienced in service.

Affordable solutions are made suitable for authorisation in railway environment

Technologies deployed in other sectors are made suitable for railway use with the minimum adaptations, for example energy storage technologies, fuel cells, composite materials, lighting technologies, etc.

6.3. Target system components and their link to the enablers

| | TARGET SYSTEM COMPONENT | ENABLER | ACTOR |
|---|--|---|---|
| 1 | On-board intelligence for all vehicles | <ul style="list-style-type: none"> › Interoperability perspective › Virtual testing › Innovations are rapidly placed on the market | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Railway undertakings › Infrastructure managers |
| 2 | New power sources | <ul style="list-style-type: none"> › Interoperability perspective › Virtual testing › Affordable solutions | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Railway undertakings › Infrastructure managers |
| 3 | Accessibility and modularity | <ul style="list-style-type: none"> › Interoperability Perspective › Affordable solutions | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Railway undertakings › Infrastructure managers › Citizens, users and customers |
| 4 | Integrated approach with other modes | <ul style="list-style-type: none"> › Interoperability Perspective › Innovations are rapidly placed on the market | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Railway undertakings › Infrastructure managers › Citizens, users and customers |

7. Personnel skills, competences and qualifications

7.1. Overview

As this area is heavily influenced by factors external to rail, the analysis below focuses on identifying major societal and technology trends having impact on staff competency framework. For each dimension, the potential to optimise within the railway/transport sector building on broad trends are highlighted.

- ▶ Harmonisation will lead to the possibility to have training sessions and education/qualifications which are valid across different countries. This will impact the training and education market that will become more and more international.
 - In this context it would be possible to establish international and multimodal education/training entities for new and existing staff within the railway sector.
 - This may stimulate the introduction of exchange programs such that persons can package their education/training from providers in different countries while still having a valid certificate.
 - Overall, this could contribute to enhance human capital within the railway sector and in particular address the longstanding problem of an aging labour force.
- ▶ Modularisation will also apply to education. People will be able to select the modules that are relevant for their tasks instead of getting a wide education profile.
 - This trend may concern:
 - general education prior to employment (e.g. persons packaging different single modules to form a complete diploma/certificate),
 - specific education and/or training during employment.
 - Staff in the railway sector could benefit from this trend through better targeted training in relation to their tasks.
 - For the railway sector this would contribute towards more efficient and effective training that could support general improvement of productivity, as well as fostering the implementation of safety culture.
- ▶ Regarding skills, there will be a huge shift from practical skills to digital and automation skills. There will be a need for more skilled staff:
 - to maintain communication networks, IT equipment and automated tools (including Artificial Intelligence and robots), and
 - to analyse big sets of data (data analysts).

In addition, relevant education/training in non-technical skills would need to be addressed.

This general societal trend can be utilised by the railway sector in at least two ways:

- promote initiatives towards increased digitalisation and automation such that the railway sector can attract persons with IT skills;
 - in turn, increased automation may help to reduce the risks associated with human and organisation factors (even new risks can arise).
- ▶ In order to ensure that staff can undertake their tasks, consideration also needs to be given to ensuring that non-technical skills (NTS) in education and training is given equal attention as technical skills. NTS, for example, resilience, ensures that staff are competent to carry out their tasks in all situations (normal, degraded and emergencies)
 - ▶ For highly competent staff, NTS, in addition to the technical competencies, ensures that staff mitigate against risk and errors. NTS has a broader scope, including all staff, from the train driver to the staff who operate automated systems.
 - ▶ Language issue will lessen because of education and new techniques in communication (e.g. new generation of simultaneous translation engines). Consequently, mobility of staff will increase.
 - Building on this trend railway actors may identify business opportunities in terms of providing services in different countries including cross-border services.
 - Furthermore, cooperation between actors located in different countries could be facilitated.
 - ▶ All the new techniques will change the learning and training techniques and opportunities (e.g. learning with VR and AR at home).

- These innovative techniques will allow easier access to training/learning for staff in the railway sector which could ensure continuous adjustment of skill sets in a changing environment.
- This trend would also facilitate faster take-up of new technologies.
- There could also be positive implications for the railway sector in terms of reduced resources (including costs) involved in training and/more interactive training techniques.
- › Because of the rapid evolution of society and technology, there will be a shorter validity of knowledge as compared to now. This will be reflected in the education. For example the needs for ongoing training and development will significantly increase and adaptability will be a key NTS for staff.
 - Other trends listed above may accommodate the increase in training needs, for example the introduction of innovative training methods (see above).
 - The railway sector would need to accommodate for the rapid evolution of society and technology in order to provide services of relevance to users.
- › Ensure that there will be sufficient competent railway staff.
 - Taking into account the age profile within the railway sector, priority should be given towards attracting new talented staff.
 - This could be facilitated if the railway sector takes a proactive approach regarding innovation and implementation of new technologies which could encourage talented staff to consider career paths in this sector.
 - Important elements for the railway sector to attract new staff would be:
 - experience gained can be easily transferred to other (transport) sectors and other locations;
 - autonomy in terms of ability to choose where and when to work;
 - enhanced and up-to-date collaboration tools and applications;
 - compatible and sufficient infrastructures to support the collaboration tools; and
 - adjusted workplaces and organisational structures to accommodate trends.
- › In turn, this will also involve changes regarding the provision of training to staff working in the railway sector.

7.2. Enablers

Enablers are factors which would allow the railway sector to respond/react optimally to the trends highlighted above.

A useful schematic approach is shown below to highlight that the trends will influence the entities in the railway sector including staff. Depending on enablers, the influence from trends may result in changes in the performance of the railway sector.



Key aspects for the railway sector to address in order to respond sufficiently to the trends would concern:

- › perform task analysis to understand the new required competencies which will determine the training strategy;
- › implement state-of-the-art training approaches;
- › promote continuous improvement in terms of staff competences and training; and
- › adopt organisational wide measures to ensure introduction of digitalisation across activities.

7.3. Target system components and their link to the enablers

| TARGET | ENABLER | ACTOR |
|--|--|--|
| 1 Attract and retain staff trained and competent for the job | <ul style="list-style-type: none"> › Positive organisational environment › Task design › Training programmes (TS and NTS) › Coaching › Continuous professional development › Targeted technical and engineering skills | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Social partners › Training centres › Educational systems |
| 2 Integration of automation (including intelligent software) | <ul style="list-style-type: none"> › Effective and planned transition from existing to target system › Human and organisation factors are considered from design to user, i.e. for all life cycle | <ul style="list-style-type: none"> › Policymakers › Industrial actors › Social partners › Assessment bodies |
| 3 Training using new technologies such as Virtual and Augmented Reality (VR and AR) | <ul style="list-style-type: none"> › Inventory of new technologies that could be used for railway › Inventory of tasks that could benefit from new technologies such as VR and AR › Training the trainers › Deployment plan | <ul style="list-style-type: none"> › Industrial actors › Training centres › Academics › Ergonomists › Psychologists |
| 4 EU certification qualification of staff (human and organisational factors, safety culture) | <ul style="list-style-type: none"> › Inventory of qualifications needing harmonised certification › Establish/define the certification scheme(s) › Legal framework where needed | <ul style="list-style-type: none"> › Policymakers › Social partners › Industrial actors › Accreditation/certification bodies › Training centres |

ANNEX 2.

Europe's Rail System Pillar – prerequisites from the perspective of the Agency

1. Background

The ambitions of Europe's Rail Joint Undertaking (Europe's Rail) are to make the most environmentally friendly mode of transport, rail, more efficient and more customer-oriented through:

- › Europeanisation of the Railway System,
- › Efficiency through organisational improvements, and
- › Innovation.

The proposal for Europe's Rail includes a novel element, the System Pillar which is intended to accelerate innovation uptake.

As network-wide innovation in a shared network such as the European railway system can only work through regulation, the System Pillar shall also significantly accelerate the development of those regulation, including:

- › the assessment of cost/benefits;
- › the appropriate changes to operational procedures; and
- › a well-conceived migration plan.

In order to function properly, a number of prerequisites are necessary for the System Pillar, both regarding organisation and governance, and in terms of a reference framework for the architecture of the European railway system.

2. The Relevance of a System Architecture Framework

A System Architecture Framework is essential for both Europe's Rail and the Agency. Such framework shall help to align the sector to focus the activities and to evaluate concrete achievements. To align with the ambition mentioned above, the system architecture framework shall support the concepts of:

- › interoperability in space and time, and
- › economies of scale.

In order to allow for the proper definition of the scope of the System Pillar, the System Architecture Framework should be established with priority and cover at least the functional aspect of railways as a socio-technical system.

3. Definition of the European Railway System

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

The vision of the European railway system is:

- › freedom of movement, i.e., no technical and operational boundaries, standardisation (economies of scale), safety (including learning from information sharing) and resilience;
- › synchronised deployment; and
- › no misalignment with the target.

4. Prerequisites

4.1. Starting point

As the European railway system already exists, the right balance needs to be found between the emerging architecture and a target architecture. The starting point needs to be set correctly in order to give the right direction for subsequent activities.

4.2. Consistency

The System Architecture Framework used by the System Pillar needs to be structurally and logically consistent.

The System Architecture Framework needs to reflect the structural reality that, currently, there is no single European railway system. However, the aspiration of technical and service integration into a seamless European system needs to be maintained and high-level interfaces need to be defined accordingly.

4.3. Consistency with European rail regulations

Consistency with the definitions in the Interoperability Directive, in particular the various Subsystems and Interoperability Constituents, need to be maintained. However, these definitions may evolve based on the results delivered by Europe's Rail.

4.4. Specificities of rail

The System Architecture Framework needs to be fundamentally linked with the specificities of rail.

- › Low friction at the wheel-rail interface, leading to low energy consumption and the ability to carry high loads, but conversely to long braking distance, specific safety requirements.
- › Guided transport system, leading to the necessity to avoid derailment, either by too high speed or by moving switches under the running train, and to avoid collision.
 - As per Appendix B1 of the TSI OPE, for safety reasons, a secured train path is required at three length scales: movement authority for a single train, route (in station) and train path (end-to-end).
 - The physical reality is relevant. The secured train path is the interface between the infrastructure and the train/vehicles.

4.5. Layers of control

In the System Architecture Framework, appropriate layers of control need to be distinguished, i.e., at individual train level, at collective level and at network-wide level with the necessity to also define lower-level interfaces.

4.6. The time dimension

The System Architecture Framework needs to appropriately consider the different scales of lifetime for the various types of assets in the railway system (bridges, rail vehicles, propulsion systems, passenger information systems, other) and consider the management of obsolescence.

4.7. Complexity and transparency

The railway system needs to operate safely; therefore, the System Architecture Framework needs to be transparent and avoid unnecessary complexity.

5. Technical Decision-Making

The governance of the System Pillar needs to establish adequate technical decision making, aligned with the role of the Agency as System Authority.

To ensure efficient alignment between the System Pillar outputs and the inputs for the Agency's regulation drafting, TSIs, other EU rail regulations, an agreed and shared calendar planning is crucial.

ANNEX 3.

Analysis

1. The Context

The European Union is founded on the values of respect for human dignity, freedom, democracy, equality, the rule of law and respect for human right⁽¹⁸⁾. The world is facing acute global challenges that are transnational and require collective actions.

Three recent challenges have brought significant uncertainties that need decisive actions from governments, private sector, and citizens. These are global warming, COVID-19 pandemic and political instability over Europe, and in other parts of the world.

Those challenges affect different areas unequally. West vs East, North vs South and Urban vs Rural, as well as different populations: high and low-income.

On global warming. An IPCC (Intergovernmental Panel on Climate Change) press release of February 2022 noted the increasing difficulty to manage cascading impacts of weather extremes and the increasing gaps between action needed and action taken that are larger among lower-income populations.

On the COVID-19 pandemic. Asymmetries in National responses and lack of coordination between countries were notorious. A June 2021 IMF (International Monetary Fund) paper foresees rising gaps within countries that may persist for more than a generation and a plausible growth of inequality between countries with the unequal spread of vaccination that allows developed countries to recover much more rapidly than developing countries.

On political instability. The EU was shaken by the Brexit in 2020. In addition, Nationalism in many EU Member States was constantly on the rise. Most EU countries now have a significant far-right party that sits in the European Parliament with hostility to immigration, cultural conservatism, ultranationalism, and dislike of the EU.

United Nations (UN) and EU objectives in fighting global warming, adapting to the impacts of COVID-19, and bringing stability over the world are converging and specifically on transport related matters.

The Beijing Statement⁽¹⁹⁾ invited the UN General Assembly to declare 2022-2032 a UN Decade of Sustainable Transport to increase global awareness and action on sustainable transport. It identified additional actions required from all stakeholders to urgently accelerate the transformation towards sustainable transport by:

- ▶ promoting a people-centred approach;
- ▶ expanding access of remote rural communities through the development and implementation of sustainable transport systems and infrastructure;
- ▶ addressing the needs of countries in special situations by expanding sustainable transport systems and infrastructure and improving their links with international markets;
- ▶ strengthening regional and interregional connectivity;
- ▶ prioritizing inclusive, reliable, safe, accessible, and affordable public transport, non-motorized transport (walking and cycling) and multi-modal transport options in urban areas as essential components of sustainable transport solutions;

⁽¹⁸⁾ Lisbon treaty - The treaty on EU and the treaty on the functioning of the EU (2016/C 202/01).

⁽¹⁹⁾ https://www.un.org/sites/un2.un.org/files/2021/10/gstc2_beijing_statement_16_oct_2021.pdf.

- ▶ significantly increasing road safety , including using safety performance standards;
- ▶ accelerating the mobilisation of the transport sector toward climate action through increased international cooperation, policies, regulations, standards and incentives across all transport modes;
- ▶ strengthening resilience of transport systems, including as part of climate change adaptation;
- ▶ increasing the coverage, timeliness, and quality of data, and establishing a harmonised data collection, management and sharing system related to sustainable transport to allow for better monitoring and reporting on transport-related goals.

The quality of transport services has a major impact on people's quality of life. On average 13.2 % of every EU household's budget is spent on transport goods and services. Transport also depends heavily on oil resources and represents an important source of CO₂ emissions. The strategy outlined in the Transport 2050 Roadmap to a Single European Transport Area aims to introduce profound structural changes to transform the transport sector.

The main objectives of EU transport policy related to the economy and competitiveness, as well as on the decarbonisation of transport, are as follows.

- ▶ Increasing efficiency of the whole transport system – techno-economic analysis of emerging technologies, analysis of impacts on transport demand, costs, emissions, congestion, accessibility and economic impacts.
- ▶ Strengthening the competitiveness of European industry – analysis of the contribution of transport to economic competitiveness, both as a main element of economic activity (transport of people and goods) and as an industrial sector itself.
- ▶ Pioneering the transport of the future (long-term perspective) – technology watch and foresight activities, techno-economic characterisation, innovation in transport.
- ▶ Decarbonising and “greening” the transport system – analysis of technologies and measures to reduce transport Greenhouse Gas (GHG) emissions and other externalities, development of methodologies for the estimation of external costs.

The EU Sustainable and Smart Mobility Strategy sets out a roadmap with ten flagship areas supporting the 2030 climate target plan. In 2021, the European Commission (EC) put forward several legislative proposals and reviews in the field of transport: intelligent Transport Systems, Trans-European Networks (TEN-T), and the revision of the Regulation on a European rail network for competitive freight.

Railway is foreseen to play a critical role in an integrated multimodal transport system delivering end to end passenger journeys and logistics transport. This also means that each mode does what it does most efficiently.

This constitutes a profound change at the heart of EU transport policy for railways. Along with other political, societal, economic, technological, and legal changes, highlighted below, it drives the need for a new strategic direction for the future target railway system and the associated research and innovation needed to define complete and deliver it.

Railways are evolving under current policy to be an open system shared between many actors, each responsible for their part of the system. Rules and tools such as TSIs, Common Safety Methods (CSM), and a common regulatory framework have all been developed to manage the shared railway system. These distribute responsibilities between Infrastructure Managers, Operators of mobile assets and regulatory bodies.

For the future shared transport system in areas like telematics, cybersecurity, operations planning, tracking and tracing, ticketing and revenue settlement, these rules and tools will need to be expanded to cover or to be seamlessly interfaced with rules and tools to be used to manage other transport modes.

To optimise the end-to-end journey from an economic, environmental and safety point of view, a common understanding to issues like safety thresholds, risk assessment, will be necessary across the modes. It follows that for optimum performance of the integrated multimodal transport system a consistent approach to all the essential requirements that currently apply to the railway system (Safety, reliability and availability, environmental protection, health, technical compatibility, access) will need to be applied across all modes.

With increasing digitalisation, the needs of the sectors are converging. For example, the issues surrounding the regulation, separation of responsibilities and safety management of autonomous road vehicles and their infrastructure are very similar to those involved in automatic train operation.

Railways should focus on developing and improving their performance and capability in areas of inherent strengths (e.g. bulk freight, mass transit, high capacity, high speed inter-city). It should understand emerging business models, trends (e.g. growing parcel deliveries, automation of freight terminals, urban freight) and user experience expected by future users/customers.

There are different levels of technological developments and rail market demands within the EU. In some areas, investments in infrastructure upgrade and renewal may be more beneficial than research to meet the users/customers' needs.

2. PESTEL analysis

Political

- ▶ Climate change has become a real challenge for the United Nations, and the European Union. Both institutions have made it a policy priority, in particular GHG reduction.
- ▶ Geopolitical⁽²⁰⁾ risks of Climate change were flagged for the first time as an emerging threat by United States (US) authorities in 2021.
- ▶ Political stability around the world was shaken by various conflicts: Brexit in 2020 for the EU, the US leaving Afghanistan in 2021, constant rise of ultranationalism in many European countries, high increase of people displaced forcibly around the world (82.4 million in 2020), in 2022 the Russian invasion of Ukraine, the rising number of coups in Africa (Mali, Niger, Burkina Faso, Gabon, Guinea, Chad, and Sudan), the Israël/Hamas war. Holding a long-term vision is complicated.
- ▶ Military mobility is one key EU defence area. Under its Strategic compass for security and defence⁽²¹⁾, the EU Committed to enhance and invest in military mobility by the end of 2022. This includes the strengthening of dual use transport infrastructure across the trans-European transport network.
- ▶ The Russian-Ukrainian conflict has shifted EU Member States⁽²²⁾ politics in EU enlargement, defence, and asylum.
- ▶ Globalisation is a growing phenomenon with worldwide consequences. Aligning policies at local/regional/national level is not sufficient anymore. A wider approach is necessary for efficiency and coherence. Political polarisation⁽²³⁾ is on the rise in the world. Populism has exploded.

⁽²⁰⁾ NY Times Morning briefing 22 October 2021.

⁽²¹⁾ https://www.eeas.europa.eu/sites/default/files/documents/strategic_compass_en3_web.pdf.

⁽²²⁾ <https://foreignpolicy.com/2023/05/25/europes-losers-have-become-its-winners-again/#:~:text=Europe%E2%80%99s%20Losers%20Have%20Become%20Its%20Winners%20Again%20The,Europe%20correspondent%20for%20the%20Dutch%20newspaper%20NRC%20Handelsblad>.

⁽²³⁾ <https://hdr.undp.org/system/files/documents/global-report-document/hdr2023-24snapshoten.pdf>.

- ▶ The EU circular economy action plan⁽²⁴⁾ is part of the building blocks of the European Green Deal. It will reduce pressure on natural resources and is a prerequisite to achieve the EU's 2050 climate neutrality target. It contains initiatives along the entire life cycle of products.
- ▶ Many silo approaches in tackling societal/environmental/economic issues failed to deliver efficiently. This was also the case for EU railways where major projects did not bring fully the expected results.
- ▶ As an example, under the revision of the Regulation on a European rail network for competitive freight⁽²⁵⁾, the EP concluded that because of insufficient coordination on traffic management and infrastructure works, the rail freight corridors did not lead to an increase in rail freight transport along the corridors.
- ▶ Massive EU funds have been and will be made available for transport including railways under the various EU initiatives: InvestEU programme, EU recovery fund, Next EU generation, Green Rail investment platform, Connecting Europe Facility, Horizon Europe. These are signs of EU goodwill in making efforts to reach the Green deal and Fit for 55 objectives.
- ▶ The EU 2023 strategic⁽²⁶⁾ foresight identified the following trends:
 - the rise of geopolitics and reconfiguration of globalisation;
 - the increasing pressure to ensure sufficient private and public funding for sustainability;
 - growing demand for skills and competencies for the sustainable future;
 - increasing cracks in social cohesion;
 - threats to democracy and existing social contract.
- ▶ 2021 was the European year of rail⁽²⁷⁾. Initiatives emphasised the essential role of rail in 'door-to-door' transport. The following feasibility studies are foreseen by the EC:
 - european label to promote goods and products transported by rail to encourage businesses to switch their transport to rail; and
 - rail connectivity index, categorising the level of integration achieved with services on the rail network and showing the potential of rail to compete with other modes.
- ▶ The social and political⁽²⁸⁾ significance of migration has increased. Migration flows and dynamics have become more mixed in an interconnected world.
- ▶ Immigration is becoming more and more a political topic that the EU struggles to deal with. Far-right parties are on the rise. The results of the 2024 EU parliament elections in France illustrates the drift of voters from mainstream parties.

Economic

- ▶ The shift⁽²⁹⁾ of economic power from the established Western economies and Japan towards the emerging economies in the East and South is set to continue.
- ▶ By 2030⁽³⁰⁾, the consumer class is expected to reach 5 billion people. This means 2 billion more people with increased purchasing power than today.
- ▶ After a Gross domestic product (GDP) fall of 6 % in 2020 due to the COVID-19 crisis, the EU economy showed a rebound with a 5 %⁽³¹⁾ GDP growth in 2021.

⁽²⁴⁾ https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF.

⁽²⁵⁾ [https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/694246/EPRS_BRI\(2021\)694246_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/694246/EPRS_BRI(2021)694246_EN.pdf).

⁽²⁶⁾ https://commission.europa.eu/system/files/2023-07/SFR-23-beautified-version_en_0.pdf.

⁽²⁷⁾ Decision (EU) 2020/2228 on a European Year of Rail (2021).

⁽²⁸⁾ https://knowledge4policy.ec.europa.eu/increasing-significance-migration_en.

⁽²⁹⁾ https://knowledge4policy.ec.europa.eu/expanding-influence-east-south_en.

⁽³⁰⁾ https://knowledge4policy.ec.europa.eu/growing-consumerism_en.

⁽³¹⁾ <https://www.oecd.org/economy/euro-area-and-european-union-economic-snapshot/>.

- › Considering the National and European recovery plans, the Organisation for Economic Co-operation and Development (OECD) foresees further EU GDP growths of respectively 4.3 % in 2022 and 2.5 % in 2023. Unfortunately, the current Ukraine/Russia conflict is likely to negatively impact the world and EU economy, at least in the short and medium term.
- › The high EU energy dependency rate (60.7 % in 2019) with none of its EU Member State self-sufficient to its energy needs, requires bold EU actions to improve its energy efficiency, and to develop renewable energy sources.
- › A modal shift to rail will not only help reducing energy consumption at global level but will also limit energy dependency within the geopolitical context (oil dependency). The current heavy impact of EU dependency on foreign fossil fuel calls for an urgent effective modal shift to rail.
- › The pandemic has highlighted countries' dependence on global value chains for strategic resources. Major players have modified their approach and have started to change their supply chain structure (extending their own production capacity, cooperating with local suppliers)
- › Transport plays a major role in the economy: moving people and goods, linking territories, providing employment but also contributing to global warming from an environmental point of view. Transport in EU accounts for around 10 million people directly employed and for about 5 % of GDP. Logistics, such as transport and storage, account for 10–15 % of the cost of a finished product for European companies.
- › Although rail is environmentally friendly compared to road, its market share is still very low. In 2019, rail accounted for 17.6 % of the EU inland freight transport and road accounted for 76.3 %.
- › As energy prices will continue to rise, mobility will continue to cost more, mass transport, public transport and shared mobility are means to decrease mobility costs.
- › After its refusal of the Siemens and Alstom merger in 2019, the Commission approved the merger of Alstom and Bombardier in 2021 making it the second rail manufacturer after China Railway Construction Corporation.
- › The main findings of World Rail Market Study⁽³²⁾ 2020 were that at the end of 2019, rail industry reached a market volume of EUR 177 billion (from urban metro to commercial freight). The market is expected to develop positively in the medium and long-term, with an average annual growth rate of 2.3 % until 2025. The total market volume is expected to reach EUR 204 billion by 2025.
- › Business model innovation⁽³³⁾ consists in questioning the habits of a sector. Innovation often involves a radical modification of attributes or their level. Most of the recent innovative business models are either based on new pricing systems (free, premium, forfeit, usage, participation) or on platforms allowing partners to exchange/communicate or both.
- › Railway transport is inherently economically complex with:
 - a mix of:
 - public and private assets,
 - commercial and public service functions, and
 - public and private operations;
 - a changing balance of technical, operational and commercial functionality divided between fixed, mobile and intangible assets;
 - long fixed asset life, medium-long mobile asset life, intangible assets with short life; and
 - complex financial flows.

It needs a stable, growing economic environment to function and grow efficiently.

⁽³²⁾ UNIFE 2020 Annual report.

⁽³³⁾ <https://www.odyssey314.com/business-model.html>.

- ▶ To minimise the ‘innovation valley of death’ an optimised choice among innovative railway projects is necessary. This means, the economic viability for each selected project must cover not only the technological risks but also the financial risks resulting from the complexity of the railway system.
- ▶ Economic globalisation should make it easier to introduce new railway routes and networks (provided that global standardisation takes place).
- ▶ In comparison with fixed assets, it is easier to attract finance for mobile railway assets. This is an incentive in some cases to use innovation to reduce infrastructure costs by transferring functionality to mobile assets (e.g. on-board localisation to avoid track circuits/axle counters, discontinuous electrification plus on-board energy storage to avoid rebuilding bridges and tunnels).

Social

- ▶ Under its Goal 11 “Make cities inclusive, safe, resilient and sustainable”, the UN presented the following facts and figures:⁽³⁴⁾
 - Half of humanity – 3.5 billion people – lives in cities today and 5 billion people are projected to live in cities by 2030.
 - By 2050, 70 % of the world population is predicted to live in urban settlements.
 - 90 % of urban growth is forecasted to happen in Asia and Africa in the next 30 years.
 - The world’s cities occupy 3 % of the Earth’s land, but account for 60–80 % of energy consumption and 75 % of carbon emissions.
 - Rapid urbanisation is exerting pressure on fresh water supplies, sewage, the living environment, and public health.
- ▶ By 2050,⁽³⁵⁾ the urban population could reach 9 billion. Cities are increasingly functioning autonomously, setting new social and economic standards.
- ▶ Cities of tomorrow will need more public transports, more active travel, more alternative mode, and less travelling time.
- ▶ With more people living in dense areas, road capacity and parking constraints are likely to discourage driving and it also becomes easier to improve access to, and frequency of, public transport.
- ▶ It is clear that the increasing sensitivity among EU citizens for environmental issues, including land use, combined with increasing traffic congestion leads to a move away from the late 20th century view that the private car was the solution to almost all transport needs.
- ▶ During the 2021 Grand Paris summit, up to 40 % of employment were considered as prone to telework with two to three days teleworking per week. This was perceived as a probable cause of fall in ridership for public transport.
- ▶ Mobility patterns are under transformation with:
 - virtual mobility (online shopping, social media) impacting particularly urban logistics;
 - active travel redesigning cities and urban planning, for example secured cycle lanes (making corona lanes sustainable), secured bike storage;
 - new offers for shared mobility and alternative modes.
- ▶ The tendency is to rethink our relation to time, freedom to choose how to move from A to B, reducing the need to travel (space reallocation and planning). Most travellers are seeking value in the use of travel time that would be browsing on internet, reading, listening to music, sleeping, working, talking to other passengers, looking at the view.

⁽³⁴⁾ <https://www.un.org/sustainabledevelopment/wp-content/uploads/2018/09/Goal-11.pdf>.

⁽³⁵⁾ https://knowledge4policy.ec.europa.eu/continuing-urbanisation_en.

- ▶ The successive COVID-19 lockdowns have accelerated society digitalisation. Internet usage became an integral part of most people's lives, changing the way people study, work, communicate, and enjoy their free time.
- ▶ Another consequence of COVID-19 was the exodus of some urban population to less densely populated areas. This phenomenon will impact housing, and travel patterns.
- ▶ Three years after COVID-19, many downtowns have yet to recover with some cities suffering more than others (cf. telework and commuting patterns). In addition, the pandemic triggered revisions to regulations⁽³⁶⁾ to address challenges and uncertainties around telework.
- ▶ Population ageing has been observed across EU in recent decades. Changes in population structure can have serious implications on pension funds, government revenues and the provision of services such as health and social care.
- ▶ According to Eurostat projections, the old-age dependency ratio⁽³⁷⁾ is to increase from 33.0 % in 2022 to 59.7 % in 2100. While in 2022 there was one elderly person for every three people of working age, in 2100 there will be two elderly persons for the same number of people of working age.
- ▶ Ageing societies means:
 - more later life travel,
 - more health and social care, and
 - retirement of a comparatively rich generation vs less wealthy working ones.
- ▶ This situation may lead to different specific transport needs for:
 - relatively rich old travellers, and
 - relatively poor young workers.
- ▶ New generations⁽³⁸⁾ entering the workforce and older generations working longer are changing employment, career models, and organisational structures.
- ▶ Remote and low populated areas suffer from transport accessibility. Governments have different approaches⁽³⁹⁾ for decision making on transport provision for remote areas. An International Transport Forum (ITF) study recommends amongst other to:
 - develop integrated accessibility plans to link transport and basic services; and
 - support innovations that could reduce costs or improve service quality.
- ▶ The diversification⁽⁴⁰⁾ of threats, and the people behind them, are generating new challenges for the defence and security communities, and to society as a whole. This is a ticking bomb as illustrated by the 2023 street protests⁽⁴¹⁾ in France against President Emmanuel Macron's overhaul of the pension system and extension of the retirement age from 62 to 64.
- ▶ New approaches to redesign cities/places for people are developed to overcome the numerous challenging social issues. One of them is Place making⁽⁴²⁾. It is based on a hands-on approach to improve neighbourhood, city, region. The starting point is a common vision for the place with an implementation strategy with small scale, lighter, quicker, cheaper improvements that brings immediate benefits both to the spaces and the people who use them.

⁽³⁶⁾ <https://www.eurofound.europa.eu/en/publications/2021/future-telework-and-hybrid-work>.

⁽³⁷⁾ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_projections_in_the_EU#Ageing_society.

⁽³⁸⁾ https://knowledge4policy.ec.europa.eu/diversifying-inequalities_en.

⁽³⁹⁾ <https://www.itf-oecd.org/sites/default/files/docs/connecting-remote-communities.pdf>.

⁽⁴⁰⁾ https://knowledge4policy.ec.europa.eu/changing-security-paradigm_en.

⁽⁴¹⁾ <https://www.nytimes.com/2023/01/21/business/dealbook/demographic-crisis.html>.

⁽⁴²⁾ <https://www.pps.org/article/what-is-placemaking>.

Technological

- ▶ The 2021 UNESCO Science Report⁽⁴³⁾ 'The race against time for smarter development' reached the following conclusions.
 - Countries of all income levels are prioritizing their transition to digital and 'green' economies, in parallel.
 - Countries will need to invest more in research and innovation, if they are to succeed in their dual digital and green transition. More than 30 countries have already raised their research spending since 2014.
 - Since the private sector will drive much of this dual green and digital transition, governments have been striving to make it easier for the private sector to innovate through novel policy instruments such as digital innovation hubs where companies can 'test before they invest' in digital technologies.
 - The COVID-19 pandemic has brought greater international scientific collaboration.
- ▶ The EU Gross domestic⁽⁴⁴⁾ expenditure on Research and Development for 2022 was of 2.24 % compared to 2.41 % for China, 3.34 % for Japan, 3.46 % for US and 4.93 % for Korea. It shows that EU needs to maintain its position in the global technological race.
- ▶ The industry landscape is changing with more software and electronics in many products and/or processes. Transport and rail transport experience the same evolution.
- ▶ The continuous digital transformation with clouds, multiple clouds, the metaverse, and data analytics requires new frameworks, mindsets and talents.
- ▶ With increasing connectivity, the volume of data being available is becoming a highly valuable tool for many actors: manufacturers, operators, insurers, tech companies, mobility service providers, authorities, and more.
- ▶ There are cross-industry issues where both conventional companies and start-ups invest massively to overcome technology lag, captive market, and shortage of supplies. This is the case for battery and battery storage, process automation, and Software as a service (Saas).
- ▶ A 2021 McKinsey study⁽⁴⁵⁾ forecasts amongst other the following trends:
 - 50 % of today's work activity could be automated by 2025;
 - up to 80 % of the world population could be reached by 5G coverage by 2030;
 - more than 75 % of enterprise-generated data will be processed by edge or cloud computing by 2025; and
 - more than 75 % of the global energy will be produced by renewables in 2050.
- ▶ A 2021 ITF report⁽⁴⁶⁾ recommended Mobility as a service (MaaS) to be integrated into a broader vision for transport and urban development.
- ▶ In its article "The world ahead 2022", The Economist highlighted the following technologies:
 - eVTOL vehicles to be tested in 2022 for commercial use in 2023;
 - space tourism that started in 2021 is expected to increase in 2022;
 - delivery drones started in 2021 in Ireland and Bulgaria;
 - quieter supersonic aircrafts with a first test flight in 2022;
 - the metaverse that extends the scope of virtual experience; and
 - quantum computing development which scalability needs to be proved.

⁽⁴³⁾ <https://unesdoc.unesco.org/ark:/48223/pf0000377433.locale=en>.

⁽⁴⁴⁾ <https://www.oecd.org/en/data/indicators/gross-domestic-spending-on-r-d.html>.

⁽⁴⁵⁾ <https://www.mckinsey.com/~/media/mckinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/The%20top%20trends%20in%20tech%20final/Top-trends-in-tech-executive-summary-6-24-21>.

⁽⁴⁶⁾ <https://www.itf-oecd.org/sites/default/files/docs/innovative-mobility-landscape-maas.pdf>.

- ▶ The following technology trends are foreseen to shape the mobility sector according to a McKinsey article of 4 February 2024⁽⁴⁷⁾:
 - advanced connectivity,
 - applied AI,
 - cloud and edge computing,
 - generative AI,
 - immersive-reality tech,
 - industrialization of machine learning,
 - next-generation software development,
 - quantum tech,
 - trust architecture and digital-identity tools,
 - Web3.
- ▶ Although rail is environmentally friendly, improvements on its energy efficiency and carbon footprint are still needed.
- ▶ The total length of the EU-27 rail network in 2018 was around 201 000-line km, about 56 % of which was electrified while around 80 % of the whole traffic is running on those electrified lines. The electrification of the European rail network is expected to continue.
- ▶ Hydrogen powered trains operation are starting to emerge in the EU (Germany, France). An EU funded study concludes that hydrogen powered trains make economic sense when they are used on non-electrified routes of over 100 km and with low electricity costs of less than EUR 50/MWh and high utilisation of the hydrogen infrastructure (hydrogen refuelling station, electrolyser).
- ▶ The JRC 2021 report on Rail transport research and innovation in Europe reached the following conclusions⁽⁴⁸⁾.
 - Out of the 526 projects under rail transport mode in TRIMIS, the highest number of projects is related to the Strategic Transport Research and Innovation Agenda (STRIA) roadmaps. Organisations from the five most active countries (Germany, Spain, France, Italy, and the UK) attract almost 75 % of total EU contribution directed to rail R&I projects. Among the top-20 researched rail technologies, eight are linked only to rail while seven are linked also to road, five to multimodal transport, three to aviation, and one to waterborne transport.
 - The top-5 funded technologies (funding > EUR 50 million) are: collaborative logistics ecosystem; self-diagnosis smart sensors and smart running gear; decision support tools for infrastructure management; more efficient wagons; education and research in the rail sector.
 - Research and innovation projects in rail transport field were categorised under six sub-themes.
 - Efficient stock design and manufacturing – lightweight materials and lighter smarter designs hold promising results, along with new alloys which allow for reduced energy consumption and maintenance needs.
 - Emissions and noise reduction – main railway noise sources and scenarios have been investigated, as well as improved efficiency and performance of engines.
 - Track and stock maintenance – condition monitoring for track maintenance and axle bearing have been researched, using temperature and vibration-based methods.
 - Efficient rail operations – covers research ranging from railway signalling and automation systems, intelligent power supply systems, obstacle detection, and realistic testing of European Traffic Control System (ETCS) components.

⁽⁴⁷⁾ <https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/what-technology-trends-are-shaping-the-mobility-sector>.

⁽⁴⁸⁾ <https://trimis.ec.europa.eu/documents/rail-transport-research-and-innovation-europe>.

- Infrastructure management – improved energy management solutions were researched and applied, along with infrastructure protection against electromagnetic attacks.
 - Information and Communications Technologies (ICT) solutions to enhance the rail travel experience – includes research on interoperability between booking and ticketing systems, mobile application development and crowd flow analysis tools.
- The number of academic publications related to rail is increasing. Among all the sub-themes, ICT solutions to enhance the rail travel experience presented the highest increase in publications in the last decade. As a general remark, in the last years China seems to dominate scientific outputs in rail transport research. However, Europe's performance is strong: combining the publication record of all the 27 member countries (EU-27) of the EU, for most of the sub-themes the EU is the leading entity. For rail related patent applications, the highest number of patents belongs to the efficient stock design and manufacturing sub-theme, followed by emissions and noise reduction. The remaining sub-themes have a similar share of patents. The increase in number of patents is relatively linear until at least 2016, taking into consideration existing delays in granting patents.
- Some final considerations can be made regarding the way forward in rail Research and Innovation (R&I). A number of Shift2Rail R&I projects from the 2020 annual work plan and budget have commenced in December 2020, with findings expected in 2021 and beyond. It is expected that Europe's Rail will focus on digital innovation and automation to achieve the radical transformation of the rail system needed to deliver on the European Green Deal objectives.
- The EU Flex-Rail project investigated the following areas.
- Enabling technologies and general innovations – innovative materials, nanomaterials, artificial intelligence, sensors, 5G mobile networks, data protection (privacy and cybersecurity).
 - Energy related technologies – battery, fuel cell, power units (alternative propulsion systems), aerodynamics.
 - Automation of the transport system – autonomous trains, automatic gauge change, automated maintenance, connected vehicles, platooning, collision avoidance, event data recorders, port automation.
 - New modes and transport concepts – new transport concepts, new air modes, new rail modes, hyperloop, personalised rapid transit, higher speed freight trains.

Flex-Rail reached the following conclusions.

- The following technologies will have a strong impact on railways:
 - some enabling technologies and automation, when they will reach maturity and will be technically and operationally feasible for railways;
 - digital technologies and new societal and economic settings.
- Infrastructural innovations will be relatively slower and more conservative, due to the long life cycle of railway assets.
- Energy-related technologies will have less impact as substantial developments have already occurred over the past years.
- Most of the technologies considered could improve the performance of railways but at the same time also of other transport sectors.
- Regarding the relative speed of innovation, enabling technologies are seen to converge and accelerate further innovations, for example for Artificial Intelligence (AI) which is strongly linked to many R&I developments such as innovative digital services enabling new business models.

- As rail transport will operate within an increasingly broad and inter-linked mobility and logistics market, it will be influenced by the relative speed of uptake of innovations from other transport modes. For instance, for the automation of the rail sector, it will need major adaptations and investments across the whole (highly interconnected) network; a limitation compared to the road sector where a more gradual adaptation is viable⁽⁴⁹⁾.
- ▶ Several ongoing EU innovations/initiatives are particularly envisaged to boost the EU rail freight.
 - The 2022 Digital Rail and Green Freight TSI Revision Pack⁽⁵⁰⁾ is to work less by ‘silo/ individual TSIs’ and instead move to discuss overarching topics and discuss changes to several TSIs in one specific Topical Working Group. This aims to find the right balance between TSI stability and timely uptake of innovation and new standards, as well as to avoid extra delays in the application of the TSIs.
 - The Digital Automatic Coupler (DAC) is a key technology that is expected to revitalise European rail freight. Introducing the DAC will only be possible through an EU-wide, coordinated effort based on a technical interoperable solution and with the necessary investments. The involved railway actors through a Memorandum of Understanding committed to an EU-wide deployment until 2030.
 - The development⁽⁵¹⁾ of the transport of standardised maritime containers on-board the train indicates a strong need to transform the railway fleet by investing more on intermodal wagons. In addition, only a small fraction of trailers used in Europe is craneable. This means that special technologies such as Modalohr, Cargobeamer or RoadRailLink R2L from Vega are necessary for putting such trailers on trains.
 - Currently, most of the freight trains circulating in the EU are less than 600 m long. 740 m long freight trains, can increase the capacity by up to 25–30 % on most of the networks. Supporting the investment in new rolling stock or in their refurbishment together with the adaptation of the infrastructure, especially with longer railway sidings and transhipments facilities, is essential to achieve the modal shift.
- ▶ The ERTMS Work Plan⁽⁵²⁾ highlights that ERTMS deployment, both trackside and on-board, must be sped up with strong support from EU MSs throughout the entire European rail network by 2030, not only on the Core Network Corridors (CNC). The EC final Report on ERTMS Retrofitting strategy Funding and Financing, shows that it is more difficult for Railway Undertakings to prove a positive business case, creating a bottleneck to the overall deployment.
- ▶ The following developing technologies may impact transport and railways:
 - connected things:
 - monitoring, controlling, automating (industrial) processes,
 - AI that is considered as accelerator of the 4th industrial revolution⁽⁵³⁾;
 - satellites:
 - increasing role for automated cars, which will be better connected due to more consistent coverage,
 - tracking mobile assets – A 2024 report⁽⁵⁴⁾ from McKinsey foresees that industries like supply chain and transportation are going to become more dependent on satellite and other space technologies;

⁽⁴⁹⁾ <https://projects.shift2rail.org/download.aspx?id=58598759-3e85-41c8-a08f-bdbe85fe3bf5>.

⁽⁵⁰⁾ UIP Annual report 2019.

⁽⁵¹⁾ <https://www.era.europa.eu/system/files/2022-09/Fostering%20the%20railway%20sector%20through%20the%20European%20Green%20Deal%20%E2%80%93%20Part%202%20Freight.pdf?t=1721921989>.

⁽⁵²⁾ First Work Plan of the European Coordinator Matthias Ruete.

⁽⁵³⁾ <https://www.mckinsey.com/capabilities/operations/our-insights/adopting-ai-at-speed-and-scale-the-4ir-push-to-stay-competitive>.

⁽⁵⁴⁾ <https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth>.

- innovative transport solutions, for example self-driving vehicles, Hyperloop, Vertical Take Off and Landing, Urban cable, and Platooning (a showcase of platooning operation with autonomous battery-electric rail vehicles took place in the US in December 2023);
- enabling technologies promising new or better capabilities and/or reduced costs:
 - energy (e.g. hydrogen, solar),
 - materials (e.g. lightweight composites),
 - manufacturing (e.g. Train zero type concept (reduction of development time, maximised simulation), digital twins),
 - maintenance (predictive maintenance, 3D printing for some components/spare parts),
 - big data,
 - semantic technologies;
- cross-modal integration:
 - automotive is more flexible whereas railway has higher capacity and is greener, cross-modal integration may combine what is best from the two main land transport modes;
 - facilitate mobile to mobile communication between the railways and other modes.

The current technological environment is evolving into a series of shared systems with network effects needing to be taken account of and managed using where necessary standards and regulation.

Environmental

- ▶ According to the 2021 IPCC report, Climate change is already affecting every inhabited region across the globe. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO₂ and other GHG emissions occur in the coming decades.
- ▶ Some recent examples of climate-change which occurred within the EU in February 2022:
 - DB stopped⁽⁵⁵⁾ long-distance trains in many states after storm Ylenia;
 - The train⁽⁵⁶⁾ network in the Netherlands was paralysed, with no Eurostar and Thalys international services after storm Eunice.
- ▶ Demand⁽⁵⁷⁾ for water, food, energy, land and minerals is rising substantially, making natural resources increasingly scarce and more expensive.
- ▶ In 2018, GHG emissions in the EU had been cut by 20.7 % compared with their 1990 levels. The only source of GHG emissions to increase between 1990 and 2018 was transport (up to 31.8 %)
- ▶ Carbon reduction policy need alignment with land use planning (e.g. interaction of freight logistics with clean air zones), and social inequality reduction (inclusive growth) to succeed.
- ▶ Transport decarbonisation is inseparable from developments in other sectors. Specifically, sustainable mobility goes hand in hand with clean energy production.
- ▶ Although, modal shift has a particular role in the short term to combat carbon emission, public transport decarbonisation is also needed with bus fleet decarbonisation, taxi fleet decarbonisation, new service offers, and investment in rail.
- ▶ Environmental taxes can be used to try to influence the behaviour of economic operators, both producers and consumers. In 2019, EU environmental tax revenues were valued at EUR 330.6 billion, equivalent to 2.4 % of GDP.

⁽⁵⁵⁾ <https://www.dw.com/en/storm-ylenia-causes-transport-chaos-in-germany/a-60807818>.

⁽⁵⁶⁾ <https://phys.org/news/2022-02-dead-storm-eunice-power-weurope.html>.

⁽⁵⁷⁾ https://knowledge4policy.ec.europa.eu/aggravating-resource-scarcity_en.

- › From EU-28 figures of 2016, road transport is the largest contributor to external costs (83 % of the total costs, EUR 820 billion while it is only EUR 18 billion for rail transport)⁽⁵⁸⁾.
- › It is necessary to shift transport to a whole-life-cycle approach. This needs system thinking, not silo thinking, covering the whole life cycle and engaging the supply chain in every project.
 - Energy – how do we obtain that energy, is it green?
 - Materials that we are using – are they the best? The greenest? Will we be re-using materials more intelligently?

Legal

- › A trend observed by the EU knowledge hub is that non-State⁽⁵⁹⁾ actors, global conscientiousness, social media and the internationalisation of decision-making are forming new, multi-layered governing systems.
- › Out of the 138 EU legislative priorities for 2022, only one has direct link to railway which is the proposal for a Regulation on Union guidelines for the development of the Trans-European Transport Network.
- › The European climate law⁽⁶⁰⁾ of July 2021 forms the core basis for EU policy to reach the 2050 climate neutrality with the intermediate step of 2030 where GHG emissions should be reduced of at least 55 % compared to 1990 levels. Transport has a major role in achieving the EU targets as it is expected to deliver a 90 % reduction in emissions by 2050.
- › The EU sustainable and smart mobility strategy⁽⁶¹⁾ set specific objectives for rail such as:
 - doubling high speed traffic by 2030,
 - tripling high speed traffic by 2050,
 - doubling freight traffic by 2050,
 - further electrifying rail transport,
 - opening rail market,
 - through-ticketing,
 - boosting long distance and cross-border passenger rail services, and
 - internalisation of the external costs of transport by 2050.
- › Many of the EU railway sector representatives pleads for more consistent policy actions regarding railways which includes creating a level-playing field, having a good infrastructure network on which to operate, and capacity management considered from an international perspective⁽⁶²⁾.
- › UIRR asked for⁽⁶³⁾ horizontal aspects such as digitalisation or infrastructure, as well as legal topics such as rules for safety, environment, or customer protection to be addressed in mode-neutral horizontal legislation.
- › A 2022 research paper⁽⁶⁴⁾ concluded that many shared micromobility companies have expanded around the globe offering their services in metropolises and recommends that given their rapid diffusion, effective regulation and integrated transport planning of vehicles and services is pertinent.

⁽⁵⁸⁾ http://publications.europa.eu/resource/cellar/0efedf2c-a386-11e9-9d01-01aa75ed71a1.0001.01/DOC_1.

⁽⁵⁹⁾ https://knowledge4policy.ec.europa.eu/increasing-influence-new-governing-systems_en.

⁽⁶⁰⁾ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN>.

⁽⁶¹⁾ https://eur-lex.europa.eu/resource.html?uri=cellar:5e601657-3b06-11eb-b27b-01aa75ed71a1.0001.02/DOC_1&format=PDF.

⁽⁶²⁾ ERFA 2020 Annual report.

⁽⁶³⁾ UIRR Report 2019–2020.

⁽⁶⁴⁾ <https://www.sciencedirect.com/science/article/pii/S1361920921004296>.

- ▶ A 2023 UIC study⁽⁶⁵⁾ of the EU railway regulatory framework concluded that there are four major challenges for the completion of the Single European Railway Area:
 - divergences in the implementation of the existing EU rules, on access to infrastructure and pricing;
 - obstacles to cross-border services;
 - management of congestion;
 - lack of incentives for investments in Infrastructure and thereby extremely long deployment times for reaching a compliant state.
- ▶ A 2024 study⁽⁶⁶⁾ on the impacts of the Proposed Amendments to the Weights and Dimensions Directive on Combined Transport and Rail Freight Transport raised the risk that it might not support intermodal transport. It would contrarily reverse modal shift in the range of 16–20 % for CT and rail freight transport for the benefit of road transport.

3. SWOT analysis

Strengths

Europe's strong role in the rail industry needs to be protected against unfair competition from the rest of the world. Rail industry and in particular its future technologies are strategic assets of the European Union.

Railways will essentially be the backbone⁽⁶⁷⁾ of a climate-compatible European transport system but are today often limited to individual countries. Investments to extend and reactivate rail routes within and across borders are necessary.

Rail is the safest land transport with the fatality risk for a train passenger being one fourth of the risk for a bus/coach passenger and car occupants having almost a 50 times higher likelihood of dying compared to train passenger travelling over the same distance⁽⁶⁸⁾.

Rail is the greenest mass transport accounting for 0.26 % of the total annual climate change costs associated to land-based modes⁽⁶⁹⁾.

Rail is the most energy efficient mode of transport carrying 8 % of the world's passengers and 7 % of global freight transport but representing only 2 % of total transport energy demand⁽⁷⁰⁾.

Rail is the fastest door-to-door long-haul transport. In most cases, between 150 km and 800 km rail is faster (door-to-door) compared to other modes notably air, although beyond 400 km this would be valid for high-speed only⁽⁷¹⁾.

Rail has low externalities⁽⁷²⁾ and better variable-cost coverage than other motorised transport modes, both for passengers and freight.

Railways deliver an order of magnitude of more capacity per unit of land space than road transport (Rodrigue, 2020)⁽⁷³⁾.

Railways are more efficient compared to road when considering congestion. Overall, it is estimated that road congestion (passenger and freight) represents annual costs for the EU countries of around 1 % of GDP (Christidis, 2012).

⁽⁶⁵⁾ <https://fsr.europa.eu/wp-content/uploads/2023/04/UIC-study-on-the-regulatory-framework-FINAL.pdf>.

⁽⁶⁶⁾ https://www.cer.be/images/publications/reports/240111_Study_WeightsDimensions.pdf.

⁽⁶⁷⁾ [EUMobilityatlas2021_FINAL_WEB.pdf](https://www.boell.org/en/publications/2021/04/eu-mobility-atlas-2021-final-web) (boell.org).

⁽⁶⁸⁾ <https://www.era.europa.eu/system/files/2024-06/Report%20on%20Railway%20Safety%20and%20Interoperability%20in%20the%20EU%202024.pdf?t=1721919229>.

⁽⁶⁹⁾ Handbook on the external costs of transport - Publications Office of the EU (europa.eu).

⁽⁷⁰⁾ The Future of Rail – Analysis – IEA.

⁽⁷¹⁾ Steer Davies Gleave (2004) High Speed Rail: International Comparisons.

⁽⁷²⁾ The Commission study «Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities».

⁽⁷³⁾ [Spatial Performance of Rail and Road Transportation | The Geography of Transport Systems](https://transportgeography.org/) (transportgeography.org).

A 2020 research paper⁽⁷⁴⁾ identified the following advantages of rail for passenger transport compared to concurrent transport modes:

- › the train as a space for social interaction;
- › the view;
- › transportation without worry;
- › do not have to pay attention or control the actual process of travelling;
- › ability to move around in the train; and
- › the comfort during the journey.

Rail creates value for Europe in terms of:

- › employment (direct and indirect employment – 1 million persons were directly employed in the rail sector and 1.2 million indirectly)⁽⁷⁵⁾;
- › connecting people (8.2 billion passenger trips in 2019)⁽⁷⁶⁾;
- › industry/manufacturing rail products and services; in terms of economic size, the direct gross value added of the European rail sector is EUR 66 billion and the indirect value amounted to EUR 77 billion⁽⁷⁷⁾;
- › contribution to the Single European Transport Area (SETA) and representing a fundamental element of the Union long term sustainable development strategy policy.

The COVID-19 pandemic has also shown that when rail freight has access to a good quantity and quality of capacity, it can provide an attractive service. During the height of the pandemic, the punctuality of international freight trains increased from around 60 % up to 80–90 %. Issues related to low punctuality are not a systematic problem but rather a question of capacity management which must be addressed⁽⁷⁸⁾.

Weaknesses

Rail do not have a problem with decarbonisation but with attractiveness⁽⁷⁹⁾. To be attractive, rail needs to improve its costs, reliability, punctuality, service offer and product tracing.

EU railways are still not competitive in terms of price and reliability compared to:

- › Road for short journeys outside urban areas and inter-urban journeys not well served by rail (CE Delft, 2018)⁽⁸⁰⁾, and
- › Air for low-cost flights for long-distance journeys not served by High Speed Rail (Akgüç et al., 2018)⁽⁸¹⁾.
- › EU railways have service lag compared to other transport modes in terms of their:
 - ticketing system (as it is based on multi actor and multi country approach), and
 - on-board services, although they are improving gradually.

⁽⁷⁴⁾ Transactions on Transport Sciences | Peer-Reviewed Open Access Journal DOI: 10.5507/tots.2020.014.

⁽⁷⁵⁾ Rail supply industry (europa.eu).

⁽⁷⁶⁾ Railway passenger transport statistics - quarterly and annual data - Statistics Explained (europa.eu).

⁽⁷⁷⁾ https://cer.be/images/publications/positions/The_Economic_Footprint_-_web_-_final_final_30_Sept_0.pdf (cer.be).

⁽⁷⁸⁾ ERFA Annual report 2020.

⁽⁷⁹⁾ https://institutdelors.eu/wp-content/uploads/2021/03/PP261_210329_Rail-europeen_Ruete_FR.pdf.

⁽⁸⁰⁾ CE_Delft_4S52_Modal_choice_criteria_in_rail-transport_Def.pdf.

⁽⁸¹⁾ LowCost Airlines Bringing the EU closer together.pdf (ceps.eu).

A 2020 research paper⁽⁸²⁾ identified the following disadvantages of rail for passenger transport compared to concurrent transport modes:

- › delay,
- › transfers between modes of travel,
- › poor accessibility of some destinations, and
- › the fact that the train does not go where travellers need.

EU rail international travel is still poor, and passenger services are mostly limited to national travel.

On the other hand, more than 50 % of the railway freight transport is international but it suffers from the lack of a truly Single European Rail Area. For example, the various language requirements across EU are a burden and add additional costs for international freight operations.

Competition is still rather limited despite the successive regulations on market opening. Most of the competition takes place between incumbent operators (e.g. SNCF entered Italian high-speed market with NTV and vice versa Trenitalia entered the French high-speed market with Thello). Open access operators emerge in the following countries: Germany, Sweden, Czechia, Poland, Hungary, Switzerland, Slovakia, Spain, Italy and Austria.

Public Service Obligation may also limit market opening. The complexity of the EU railway system, with its numerous interdependent elements/components/subsystems and numerous actors having different roles/interests/cultures, makes the introduction of a new solution with a clear view of the added customer value difficult.

The railway sector maintains a culture of silo management, leading to fragmentation:

- › with each technical discipline having its own approach to common issues (e.g. acceptable levels of risk);
- › each country/national railway company/infrastructure manager defining its own system architecture; and
- › the emerging importance of data and digitalisation has the potential to also create new barriers to the Single European Railway Area.

Compared to road/automotive industry, the following differences are apparent.

- › Rail is of a more complex architecture. For rail, it is at the level of the system (system of systems) whereas for road/car it is simply at vehicle level. This makes innovation in rail more difficult to implement.
- › Renewal cycles for railway assets (infrastructure and rolling material) are longer and more capital intensive than for road assets (CE Delft, 2019)⁽⁸³⁾ making difficult the entry of new players (investors and outsiders).
- › Road is available in most of all EU countries for short haul whereas rail is not always.
- › Railways are a matter of National and European policies. Railways cannot be competitive if they maintain a National focus. A common operational language is necessary to ensure full interoperability of cross-border and international traffic.
- › Road has more and quicker up-to-date product information in the pre-journey phase and more precise goods tracking in transit phase.

Opportunities

The 2021 ITF Outlook foresees a continuing economic development and a growing world population with an overall transport demand that is estimated to more than double by 2050.⁽⁸⁴⁾

⁽⁸²⁾ Transactions on Transport Sciences | Peer-Reviewed Open Access Journal DOI: 10.5507/tots.2020.014.

⁽⁸³⁾ CE_Delft_4K83_Overview_transport_infrastructure_expenditures_costs_Final.pdf (cedelft.eu).

⁽⁸⁴⁾ <https://www.itf-oecd.org/sites/default/files/transport-outlook-executive-summary-2021-english.pdf>.

Considering growing ESG (Environmental, Social and Governance) requirements, rail is globally sustainable and eligible for green bonds and green financing.

Rail has political and social support as green transport mode enabling to achieve climate change objectives.

Rail industry is considered by EC as a potential contributor to the reduction of transport emissions. A substantial part of the 75 % of inland freight carried currently by road should shift onto rail and inland waterways.

The EU rail network infrastructure is amongst the densest at world level⁽⁸⁵⁾. It could be either upgraded and/or extended to improve capacity.

Under the 2021 European year of rail, the EC has been invited by the EP to examine the possibility of creating a rail connectivity index to assess the consistency, quality and diversity of the EU rail network, and its accessibility as regards the options it provides for intermodal travel. This, with a view to identify areas where investment in rail infrastructure is particularly needed.

The Swiss example⁽⁸⁶⁾ shows that a successful modal shift policy in favour of rail is possible and requires rail infrastructure and capacity on one hand and a fairer competition between transport modes on the other.

New technologies are gradually implemented in rail provided there are financial support from investors (private and public).

The recent Europe's Rail Joint Undertaking with its significant budget of EUR 1.2 billion offers a possibility to develop a unified operational concept and a railway system architecture that would help removing technical and operational barriers within the SERA.

Railways have already proven experience in ATO. It may scale up ATO earlier than other land transport modes.

The EU framework for railway regulation and standards is a global reference that forms the basis for ISO and IEC standardisation.

In the passenger sector EU suppliers are among the technological leaders (ECORYS 2019)⁽⁸⁷⁾.

The will to place the railways as the backbone of EU mobility gives a strong incentive to EU railways to:

- ▶ clean up their inefficiencies and inconsistencies by importing best practice so that they are no longer perceived as the weakest link in the chain; and
- ▶ make available their expertise and framework (rules and tools) for shared system management.

The introduction of new technologies in railways (ATO, Big data, AI) makes them attractive for young personnel and counterbalances their perception as a mature/older industry.

Research should be prioritised to exploit these opportunities.

Threats

Fragmentation of EU rail network still hampers EU rail competitiveness and capacity.

Enforcement of EU regulation in rail needs to be strengthened to achieve the policy objectives.

With increasing globalisation and railway development outside the EU, it is necessary to ensure the framework, rules and standards remain 'best in class'. This is to mitigate the risks that the EU might lose its global reference status. However, where better practice exists outside the EU, this needs to be imported into the EU framework.

⁽⁸⁵⁾ <https://blogs.worldbank.org/en/transport/climate-action-how-can-eu-countries-unlock-potential-railways>.

⁽⁸⁶⁾ https://www.cer.be/images/publications/positions/CER_Essay_SBB_FINAL.pdf.

⁽⁸⁷⁾ <https://data.europa.eu/doi/10.2873/592269>.

The COVID-19 pandemic still has a negative effect in rail ridership, and trust from customers needs to be regained.

When railways are slow at adapting to customers' needs, this creates a risk of trust deficit.

Other modes have achieved or are perceived to have achieved more rapid rates of greening. They are more responsive to greening. This may, in time, tilt the balance away from railways.

Ageing workforce and non-attractive image of rail may lead to shortage of workers with the required skills.

Autonomous vehicles may be scaled up first in road transport (train of trucks).

Whereas the automotive industry is shifting towards services industry with a more horizontal approach (car ownership tends to be replaced by leasing, and other forms of service such as pay as you drive,) rail remains more conventional at least for the passenger market where trains are purchased by investors, mostly incumbent railway companies, and operated by them at national level. Thus, new business models are less numerous for rail.

When rail competes with air and road (minimising costs per passenger-kilometre or tonne-kilometre moved under a fair level playing field), the need for speed and flexibility tend to favour air and road. Rail's future will depend on how it responds to increasing demand and increasing competition.

In addition, the increased quality of road infrastructure and increased speed with motorways may increase the gap between average speed of rail and road.

4. What will determine the nature of the future railway system?

Key drivers

- › Need for more capacity, primarily from existing transport infrastructure.
- › Integrated multimodal transport approach for:
 - long term investment planning;
 - transverse issues such as carbon emission pricing, passengers' rights, PRM, security.
- › Global shared system approach to regulation and standardisation to benefit from economy of scale.
- › Migration of functionality and value to on-board.
- › Necessity for green, energy efficient solutions.
- › Maintaining the current position of railways as the leader in safety for land transport.
- › Integrating AI developments (e.g. for ATO).
- › Resilience (adaptation to climate change, disruptions, reaction to pandemic).
- › Just Transition to be considered when moving towards more automation.
- › Train localisation as game changer, implementing new solutions such as Global Navigation Satellite Systems (GNSS).

Constraints

- › The need to preserve and enhance interoperability within and between modes.
- › The need to take account of the mismatch between the life cycle of digital and railway technology.

- › The changing role of Europe in the global ecosystem – dominance gradually being replaced by partnership.
- › Harmonised and synchronised transitions (e.g. efficient and effective deployment of ERTMS).
- › An effective implementation/deployment of the EU framework is necessary to realise an integrated Single European Railway Area as part of the Single European Transport Area.
- › The efforts made at European level cannot succeed as long as National Implementation Plans (NIPs) are maintained. Effectively, per essence, NIPs not only perpetuate the fragmentation of the European rail system but also prevent a synchronised harmonisation of development and innovation.
- › A Trans-European-Network without borders needs a strong EU framework that:
 - defines coherent EU targets for SERA as part of SETA that would include TSIs (future evolution, implementation, and transition);
 - agrees on an EU Implementation Plan, not NIPs;
 - simplifies the decision-making process for funding and monitoring considering the global positive impact at EU level and not at National/Sector/Company level;
 - allocates proportionate resources to EU initiatives to ensure proper integration, development, implementation and monitoring.
- › In comparison with Air and Maritime, seamless cross-border operations are possible when:
 - international rules apply, and
 - a common language is used.
- › Regarding the European railway system, the following hold.
 - A common language should be enforced for the EU harmonised technical/operational/safety requirements, i.e. to avoid translation of TSIs, CSMs, etc. in national languages with the associated problems of “errors” slipping into those versions. This is already the case for the ERTMS, TAP, TAF specifications, for example.
 - A common operational language for train drivers could be a political milestone.
- › The transition towards an integrated SERA within the SETA would be quicker and more efficient with an EU wide implementation plan.
- › This European Union Implementation Plan shall be based on concrete objectives (which can be derived from the Strategy for Sustainable and Smart Mobility).
- › The European plan needs to contain verifiable milestones – progress against which will need to be regularly assessed.

Constraints for future research and innovation needs

Research and Innovation must address the needs of the target railway and future integrated multimodal transport system(s).

To be more effective, research and innovation in the railway sector need to follow a set of principles derived from the characteristics of the shared railway system i.e. integrated, connected and shared network. Common issues (e.g. cybersecurity) must be addressed consistently across the shared system. Subject or nationally based approaches must not be allowed.

Research and innovation should follow a multi-party approach, based on openness, information sharing, but also risk sharing in order to exploit the synergy created.

All of the initiatives need also to be integrated and prioritised under a common framework for evaluation of economic and safety benefits.

Innovation in an ecosystem of many players (including private entities), which can be strongly influenced by policy and regulation, needs to ensure a proper balance between political, regulatory, and economic factors.

Innovation should be accompanied by a clear migration plan (that takes you from where you are now to where you want to be). This is because railways have a substantial installed infrastructure on which operates a very large fleet of vehicles that have long asset life. Migration planning has to include the concept of system version management. This is to ensure that the benefits of innovation are captured whilst at the same time optimising the benefits of forward and backward compatibility.

Because of the need to open up markets and long lifetime of the assets, innovation should use an open architecture for exchangeability and allow upgradeability.

All research and innovation typologies should be taken into consideration.

Prospects for feasible uptake (soft/hard innovation) should be taken into account, having the final customer at the centre of the attention.

Conclusions

- ▶ Make rail investment attractive with revenue opportunities by providing visibility of the net benefits for the whole origin to destination.
- ▶ Invest in the most feasible and reliable target system where political risks are mitigated.
- ▶ Put modal shift as priority and identify the most effective actions to make it happen in time.
- ▶ Focus on what will help the railways in their new role. Avoid wasting time and money provoking a modal shift in areas where railways are inherently weak.
- ▶ Evolve from technology driven to demand driven.
- ▶ Minimise the railway specific solutions, minimise the subject specific solutions.
- ▶ Move towards less infrastructure (e.g. No need for catenary where hydrogen cells are sufficient to fuel the trains) and more mobile intelligence (e.g. Transfer of functionalities to on-board).
- ▶ Develop the multimodal approach for the benefit of end-users and citizens.
- ▶ All measures that can directly or indirectly improve market efficiency are to be welcomed:
 - market evolution,
 - political evolution, and
 - anything non-railway specific that helps in this direction.

5. The elements of the problem that can be realistically addressed

As a first step, it is necessary to develop a methodology for the analysis and prioritisation of the relative cost/contributions of proposed initiatives at European level. Europe's Rail Joint Undertaking with the System Pillar where the main EU rail actors are involved offers the opportunity to undertake such analysis and prioritisation.

Elements of the target system will also provide guidance for the development of the European Specifications for Interoperability.

For instance, suppressing diesel propulsion will require the development of alternatives, among which fuel cells will represent a significant part. It is essential to ensure from the beginning the availability of European wide solutions for the transfer of hydrogen from the infrastructure to the rolling stock to avoid that each Member State develops specific non-interoperable solutions.

Another example is the intelligent wagon: when provided with a (digital) automatic coupler, freight wagons will still need to be operable with different types of locomotives and wagons. European Specifications for Interoperability will have to specify the necessary mechanical and data interfaces to ensure that the transition from the manual coupler to the automatic coupler(s) does not jeopardise interoperability.

From a passenger perspective, the future modular trains will have to ensure to all European passengers an equivalent level of safety and accessibility. European Specifications for Interoperability will play an essential role in this harmonisation so that passengers, in particular those with reduced mobility, may travel by train where information on accessibility is available.

This will enable a structured targeting of efforts between the following subject areas:

- › technical,
- › regulatory, and
- › market/political.

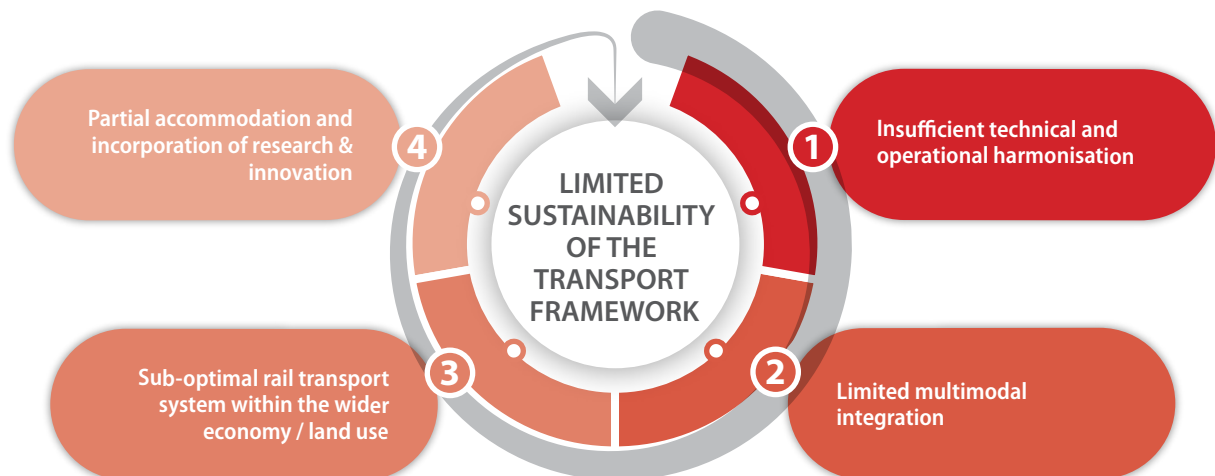
ANNEX 4.

Justification of the target railway system

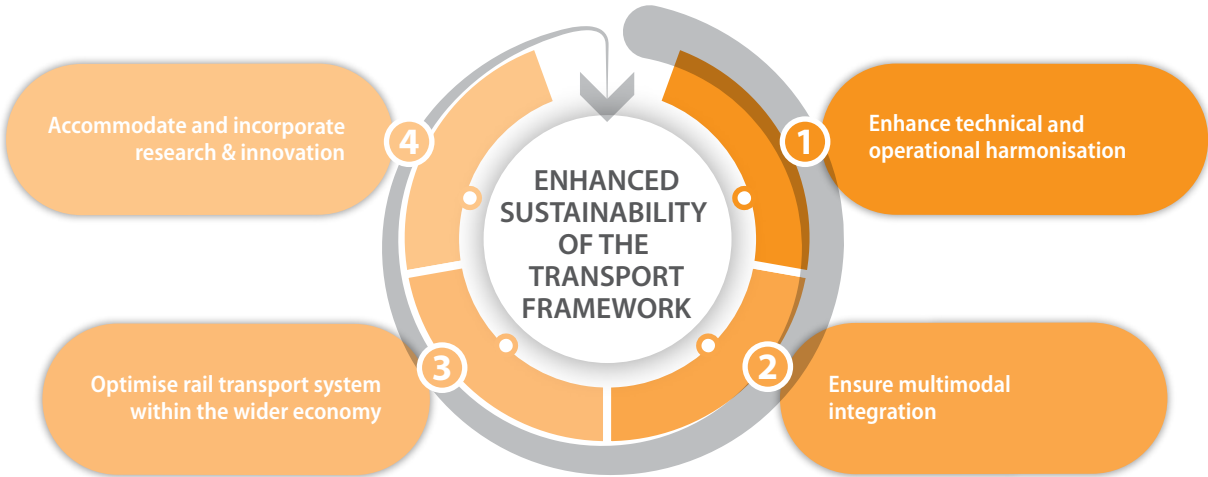
The justification of developing a compelling vision setting out a dynamic framework for the target railway system developed below is based on the following elements (in line with the Agency's approach to impact assessments in accordance with the Commission's Better Regulation Guidelines).

- › Identification of **problems** and **problem drivers**.
- › Specification of **objectives**.
- › Definition of **options**.
- › Assessment of **impacts**.

The overarching problem and the associated problem drivers are highlighted in the following chart. These problem drivers were already detailed out in Section 2 of this document where the rationale for defining the railway target system was put forward.

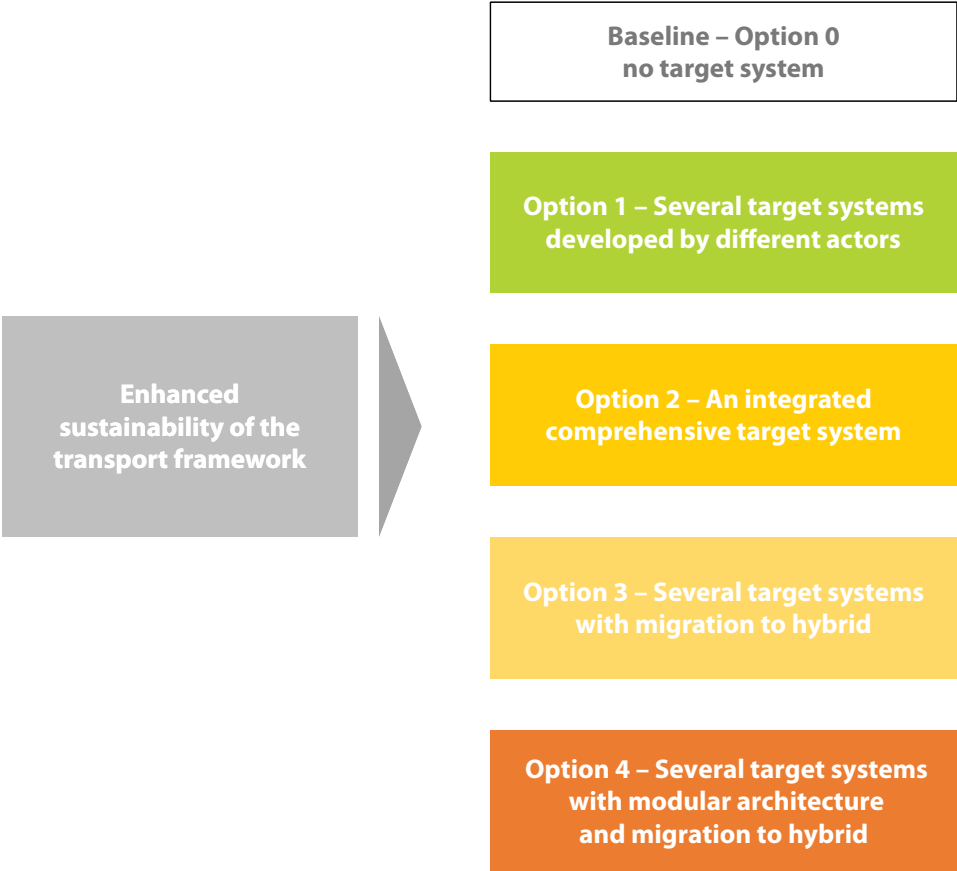


Objectives are then specified as the positive mirror of the problem and problem drivers.



Five options are defined (including the baseline) considering whether:

- › no, one or several target systems are involved;
- › modular architecture is implemented and applied.



Each of the four options are then assessed qualitatively. The qualitative assessment concerns the extent to which each of the four options can be expected to achieve the four objectives.

| Criterion/objective | Baseline | Option 1 | Option 2 | Option 3 | Option 4 |
|---|-----------------|-----------------|-----------------|-----------------|-----------------|
| Enhance technical and operational harmonisation | 2 | 3 | 5 | 4 | 4.5 |
| Ensure multimodal integration | 1 | 2 | 4 | 5 | 5 |
| Optimise rail transport system within the wider economy | 1 | 2 | 3 | 5 | 5 |
| Accommodate and incorporate research and innovation | 2 | 3 | 4 | 5 | 5 |
| AVERAGE | 1.5 | 2.5 | 4.5 | 4.8 | 4.9 |

Baseline scoring. Limited or no progress on any of the four objectives is expected without the definition of a target system. However, in the case of objectives 1 and 4 a score of 2 is foreseen because even under the baseline option there could be some technical and operational harmonisation and research and innovation could still be incorporated within the railway system.

Option 1 scoring. Multiple (and incompatible) target systems could facilitate some progress on all objectives. However, this would only be to a limited extent in the case of objectives 2 and 3. Multimodal integration and optimisation of railways in the wider economy does require a coherent railway system view.

Option 2 scoring. Substantial progress on most of the four objectives is expected. In particular, this is the case for objective 1. For objective 1 an integrated and comprehensive target system would facilitate harmonisation at all levels of the railway system. However, this option may hinder an optimum to be reached from an economic perspective (see objective 3).

Option 3 scoring. This option builds on Options 1 and 2 but recognizes the importance of facilitating the transition towards a railway system enhancing the elements already in existence today. As such the Option concerns the outlook with several target systems migrating to an economically viable hybrid target system. In this Option, there is not a truly single EU target railway system but a set of several target systems.

Option 4 scoring. This Option is closely linked to Option 3. The only difference is that specific attention is given to the consistent application of modularity for the different parts of the railway system. It means:

- ▶ a steady/stable skeleton of the railway system, as part of the transport system, with the interfaces and the common basis/transport policy,
- ▶ with modular elements: communication, data exchanges, signalling, automation, other.

Overall, the application of modularity should increase technical and operational harmonisation, thereby leading to a higher score for Option 4 compared to Option 3.

This Option is closer to achieving an EU target railway system within the Single European Railway Area.

On this basis, Option 4 has the highest score and is therefore the preferred option. Careful consideration should be undertaken with regards to the extent to which the System Pillar developments/Europe’s Rail is consistently aligned with this Option in order to ensure an optimal outcome.

ANNEX 5.

Abbreviations and terminology

1. Abbreviations

| | |
|----------------------|---|
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| ATO | Automated Train Operation |
| CAPEX | Capital Expenditure |
| CCS | Control Command and Signalling |
| CEF | Connecting Europe Facility |
| CNC | Core Network Corridors |
| CR | Conventional Rail |
| CSM | Common Safety Method |
| CT | Combined Transport |
| DAC | Digital Automatic Coupler |
| DatEX | CEN Standard for the exchange of traffic related data |
| DMI | Driver Machine Interface |
| EC | European Commission |
| EN | European Standard |
| ENE | Energy |
| EP | European Parliament |
| ERA | European Railway Agency (now EUAR – European Union Agency for Railways) |
| ERTMS | European Rail Traffic Management System |
| ESG | Environmental, Social and Governance |
| ETA | Estimated Time of Arrival |
| ETCS | European Train Control System |
| EU | European Union |
| Europe's Rail | Europe's Rail Joint Undertaking |
| eVTOL | electric Vertical Take-off and Landing |
| FAIR | Findable, Accessible, Interoperable and Reusable |
| FRMCS | Future Radio Mobile Communication System |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GNSS | Global Navigation Satellite Systems |
| GoA | Grade of Automation |
| HS | High Speed |
| ICT | Information and Communications Technologies |

| | |
|----------------|---|
| IEC | International Electrotechnical Commission |
| IL | InterLocking |
| IM | Infrastructure Manager |
| IMF | International Monetary Fund |
| INF | Infrastructure |
| IoT | Internet of Things |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Standard Organisation |
| IT | Information Technology |
| ITF | International Transport Forum |
| ITS | Intelligent Transport Systems |
| JRC | Joint Research Centre |
| KPI | Key Performance Indicator |
| LX | Level crossing |
| MaaS | Mobility as a Service |
| MMTIS | Multimodal travel information systems |
| MS | Member State |
| NAP | National Access Point |
| NetEX | CEN Technical Standard for exchanging Public Transport schedules and related data |
| NIP | National Implementation Plan |
| NSA | National Safety Authority |
| NTR | National technical rule |
| NTS | Non-technical skills |
| NTV | Nuovo Trasporto Viaggiatori |
| OCL | Overhead contact line |
| OECD | Organisation for Economic Co-operation and Development |
| OPE | Operation |
| OPEX | Operating Expenditure |
| OSJD | Organisation for Cooperation between Railways |
| OTIF | Intergovernmental Organisation for International Carriage by Rail |
| PESTEL | Political, Economic, Social, Technological, Environmental, and Legal |
| PSI | Public Sector Information |
| R&I | Research and Innovation |
| RBC | Radio Block Centre |
| RINF | Register of Infrastructure |
| RNE | Rail Net Europe |
| RU | Railway Undertaking |
| SaaS | Software as a Service |
| SERA | Single European Railway Area |
| SETA | Single European Transport Area |
| SIL | Safety Integrity Level |
| SMART | Specific, Measurable, Assignable, Realistic, Time-related |
| SMS | Safety Management System |
| SNCF | Société Nationale des Chemins de Fer |
| SP | System Pillar |

| | |
|---------------|--|
| STRIA | Strategic Transport Research and Innovation Agenda |
| SWOT | Strengths Weaknesses Opportunities Threats |
| TAF | Telematics applications for freight services |
| TAP | Telematics applications for passenger services |
| TCMS | Train Control Monitoring System |
| TDS | Train Display System |
| TEN-T | Trans-European Networks for Transport |
| TIS | Train Information System |
| TMS | Traffic Management System |
| TSI | Technical Specifications for Interoperability |
| UIRR | Union Internationale pour le transport combiné Rail-Route |
| UK | United Kingdom |
| UN | United Nations |
| UNECE | United Nations Economic Commission for Europe |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| US | United States |
| VR | Virtual reality |

2. Terminology

- › **Canonical data model.** A type of data model that aims to present data entities and relationships in the simplest possible form in order to integrate processes across various systems and databases.
- › **EU-13.** Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.
- › **GoA3.** Automatic driving without driver, but other staff present in the train, to take back control of the train when needed
- › **GoA4⁽⁸⁸⁾.** automatic driving without any staff in the train
- › **Micromobility⁽⁸⁹⁾.** Definitions, classifications, and regulatory frameworks for micromobility vary across the world. Bicycles are the smallest micromobility vehicle in most countries' classifications. The term micromobility emerged around 2016 with connected bicycle, scooter, and moped sharing services. The term "micro" can refer to the vehicles used, which are typically less than 500 kg, but also to the short-distance trips that can be fun, cheap, and convenient.
- › **Semantics interoperability.** Reaching consensus on the meaning of data elements and the relationship between them (common vocabularies to describe data entities).
- › **Through-ticketing.** A system whereby a traveller passing through a number of different transport networks can purchase one ticket for the complete journey.

⁽⁸⁸⁾ <https://ertms.be/activities/automatic-train-operation>.

⁽⁸⁹⁾ https://www.itf-oecd.org/sites/default/files/docs/safe-micromobility_1.pdf.

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