ERRAC
The European Railway Research Advisory Council

# Railway Research and Innovation Agenda (RRIA)

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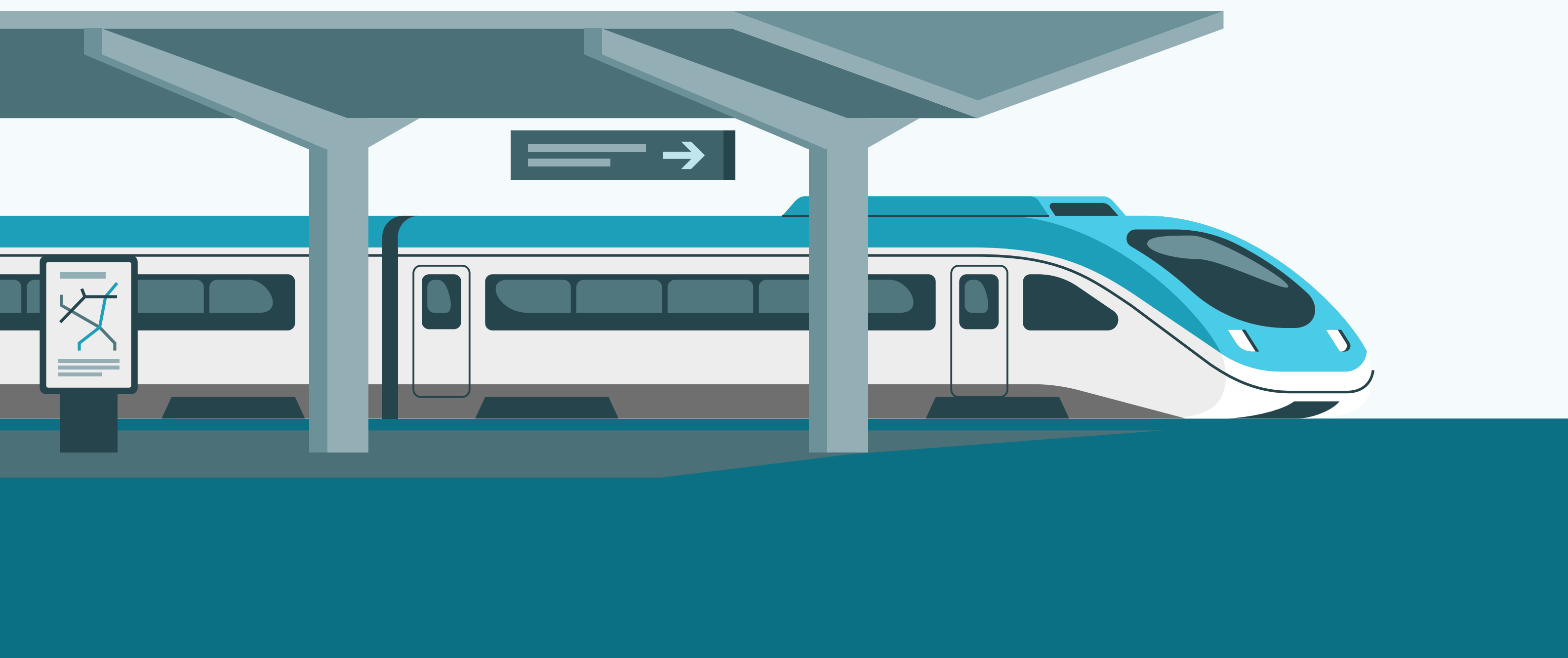
# Executive Summary



Supporting research and innovation to eliminate barriers to interoperability, enable full integration of rail systems-plus non-rail services, and accelerate digitalisation and automation, are essential components to deliver a high-capacity, sustainable and attractive multimodal European railway network that actively contributes to achieving ambitious goals for sustainability, decarbonisation and net zero. Railways are a ready-made agent facilitating a rapid transition to carbon neutrality.

The European Rail Research Advisory Council (ERRAC) in its 2020 Manifesto highlighted four key challenges around ***System technical performance, Sustainability, Multimodality and Personalised service and Inclusivity***. Following a consultation amongst its members providing a research outlook for each of these four challenges reinforced by the ongoing outcomes of Europe's Rail Joint Undertaking (EU-RAIL), three key strategic priorities to focus beyond the current Research Framework Programme have been defined. New knowledge, innovation and solutions identified include:

## Strategic Research Priority 01: *Resilience, net zero and competitiveness*

**01.1.** Fostering autonomy and sustainability e.g. methods to make design choices that diversify materials used, more effective manufacturing and construction methods, systems and operations automation, circular economy and parts and components that are traceable and have reduced carbon footprint whist minimising exposure to global supply chain issues.

**01.2.** Accelerated reduction of emissions both direct e.g. at the point of use, and indirect e.g. embedded in manufacturing, construction and end of life.

**01.3.** Adaptable, reliable and agile freight and passenger business models leading to increased market share.

**01.4.** Enhanced capacity of the rail system to accommodate increased assets utilisation.

**01.5.** Rapid implementation of reduced life cycle costs (CAPEX and OPEX) and life cycle externalities for best value to society.

## Strategic Research Priority 02: *Understanding systems interdependencies*

**02.1.** Develop common, proven and standardised methodologies, methods and tools allowing the use of systems thinking across all scales. These can include, for instance, digital shadows[1] and/or digital twins[2] as well as co-simulation approached. The implementation and expansion of the outcomes of the EU-RAIL programmes will be a critical platform to build upon for this area e.g. systems engineering principles, agility.

**02.2.** Understand the impact of deploying novel technologies and processes e.g. co-existence and legacy aspects.

**02.3.** Assess the role of people across scales e.g. rail subsystem & system plus system of systems.

## Strategic Research Priority 03: People-centric railways

**03.1.** Understanding and preparing for future user needs and behaviour in a multimodal context.

**03.2.** Human factors and experience implications resulting from the deployment of automation, increased volume of critical information flows and human-machine interface transformations with a particular focus on safe and efficient management of rail operations.

**03.3.** Identifying assets, protocols and subsystems suitability for partial or total automation leading to the establishment of implementation plans that prioritise the wellbeing of people and organisations within a framework of competitiveness, resilience, and net zero.

**03.4.** Developing business models that incorporate user-centric design principles maximising the benefits that digitalisation and new technologies provide e.g. flexible rail services, integrated ticketing, multimodality and supply chain.

**03.5.** Developing spatial planning methods and tools that acknowledge the role of rail in structuring the built environment and creating move liveable communities.

[1] A digital shadow is a digital representation of an asset, sub-system or system that is constantly evolving through gathering of information from the field e.g. sensors.

[2] A digital twin is an evolution of a digital shadow where the model and the asset, sub-system or system co-exist in a real time loop.

However, to create the conditions for innovation it is also essential to identify and develop new knowledge for enablers to maximise the rapid adoption of the research outcomes. Specifically, the following enabling topics are deemed necessary:

### Digitalisation

Society is immersed in a digital environment and a paradigm shift is needed in the rail and transport sector to exploit and fully adapt to digital technologies. It is critical to develop common protocols and taxonomies as well as clearly defining governance structures and ownership of data to enable the research activities outlined in this document as well as maximise the chances of succeeding in achieving the overall goals for a railway that is at the heart of a future sustainable transport and mobility system.

### Governance and Policy

A successful transition to implementation of research outcomes requires clear governance structures to manage stakeholder interests as well as policies, standards and guidelines that facilitate rather than impede the rapid adoption of such outcomes.

### Co-creation

A critical aspect of research and innovation success is the incorporation at the very early stages of the different needs, capabilities and pooled resources in a structured and long-term framework from all the relevant stakeholders.

### Skills

The deployment of new technologies, interventions and processes requires the development of a matching skills agenda coordinated across Europe that caters for the recruitment of a diverse future workforce with the right set of skills as well as upskilling exiting employees whilst creating workplaces where all employees can be themselves and make their maximum contribution.

Ultimately, the combined benefits of a harmonised research agenda and matching enabling measures can have a profound effect in mobilising a critical mass of resource, expertise and action that activates a system change resulting in a high-capacity, sustainable and attractive European railway offer, boosting competitiveness and driving strategic investment in transformational technologies.

# Table of Contents

# 1. Introduction

## 1.1. Rail at the heart of a future sustainable transport and mobility system

Mobility lies at the heart of every European citizen's life. Yet the transport sector is accountable for nearly a quarter of Europe's greenhouse gas emissions and remains the primary cause of air pollution in urban areas. It is one of the few sectors in the EU economy where emissions still exceed 1990 levels.

The Commission's communication "Sustainable and Smart Mobility Strategy – putting European transport on track for the future" of December 2020[3] sets ambitious targets for the rail mode, i.e. traffic on high-speed rail to double by 2030 and triple by 2050, rail freight traffic to increase by 50% by 2030 and double by 2050, rail and waterborne-based intermodal transport to compete on an equal footing with road-only transport in the EU by 2030. Comparisons are based on the 2015 modal share figures: 7,6% for rail passenger transport (inland passenger-km), 18,9% for freight transport (inland freight tonnes-km). Nothing shows more clearly the challenges for the rail mode to deliver and quickly deploy solutions that will enable to reach the targets mentioned above!

The "Fit for 55" regulatory package, proposed by the Commission on 14.07.2021, aimed at aligning the EU energy and climate regulatory framework with the new greenhouse gas (GHG) emissions reduction objective of at least 55% by 2030 compared to 1990 levels. It strives to strengthen the internalization of external costs for air and road transport and therefore, ultimately, to allow fairer competition with rail.

Regarding scenarios for the future mobility, the 2023 Transport Outlook provided by the International Transport Forum (ITF) under the umbrella of the Organisation for Economic Co-operation and Development (OECD) considers as valuable the targets set by EC in a continuous increase of mobility, both for passengers (by 2050, increase demand by 65 to 79%) and freight (by 2050, increase of demand by 59 to 100%) depending on the scenarios even if others studies consider at the best a stabilization of the mobility demand. That means high requests for the rail mode, being able to increase the offer in order to meet the forecasted demand while at the same being more and more integrated with the other modes of transport.

Consequently, the railways and the wider transport sector face a number of key challenges:

- Maximise existing capacity.
- Infrastructure maintenance and upgrade including regeneration of the infrastructure associated to increased investments at the European level e.g. stations and multimodal hubs
- Climate change impact and adaptation.
- Decarbonisation agenda requiring associated alternatives to the use of fossil fuels.
- Inclusivity for a changing society e.g. ageing population.

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789

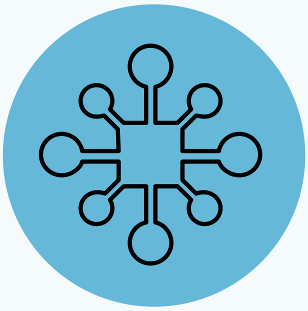
## 1.2. The role of rail as part of the overall solution.

Building upon the outcomes of the Shift2Rail partnership and the promising results of the Europe's Rail Joint Undertaking, this Strategic Rail Research and Innovation Agenda is ERRAC's updated roadmap for transforming rail into an even more sustainable, capable, flexible, efficient and cost-effective system as part of a fully integrated and multimodal transport service.

The 2020 ERRAC Manifesto for research and innovation highlighted a four key challenges:

**System technical performance**
Allowing a significant increase in capacity and flexibility, as well as a decrease in acquisition and operational cost of the overall European rail system enhancing the sub-systems' availability, reliability and operational efficiency.

**Sustainability**
Enhancing the green competitive edge of rail.



**Multimodality**
The ability to move people and freight by a combination of multimodal services, having rail as a green core.

**Personalised service and Inclusivity**
To provide a seamless and convenient travel service considering individual needs.

This document provides a strategic overview of the key thematic research priorities beyond the current Research Framework Programme (section 2) built upon a consultation on the four challenges indicated above (section 3) leading to a summary of the main conclusions (section 4) including a proposed set of key enablers to unlock the innovation potential for the rail sector.

# 2. Strategic Research Priorities

Building upon the challenges described in section 1 and in the context of urgent societal needs to boost productivity, rapidly accelerate decarbonisation processes in the face of climate change and provide inclusivity and fairness for European citizens, targeted and actionable research is required.

The consultation carried out around the four 2020 ERRAC Manifesto Challenges has focused on the following aspects i.e. system optimisation, multimodality, sustainability, and inclusive & personalised service (see section 3 for details). Based on the outcomes across all four challenges, the following areas have been identified as key strategic priorities to unlock a more sustainable and competitive railway sector.

## 2.1. Strategic Research Priority 01: Resilience, net zero and competitiveness

Climate change and its effects pose an undeniable threat to society and by extension, transport systems. This is manifesting itself in the form of risks to cyber and physical infrastructure, rolling stock, supply chains, and the health and livelihoods of communities. Whilst it is imperative to mitigate and decarbonise transport and railway systems, adaptation to manage these risks is also essential to achieve reliability and competitiveness.

Research is needed to identify and address the intertwined challenges of resilience and net zero, for both existing and new infrastructures, and to identify and provide viable solutions for new vulnerabilities that may occur resulting from the net zero transition, including critical interdependencies with digital and power systems. This provides an opportunity to demonstrate the benefits and opportunities that come from reimagining and rethinking how the railway system can play a pivotal role in delivering mobility to both people and the goods and services the European economy relies on.

Resilience goes beyond assets. The multifaceted aspects affecting competitiveness need to be considered in the context of a resilient and adaptable railway system. New insights and solutions are required to boost adaptive capability leading to:

- Fostering autonomy and sustainability e.g. methods to make design choices that diversify materials used, more effective manufacturing and construction methods, systems and operations automation, circular economy and parts and components that are traceable and have reduced carbon footprint whist minimising exposure to global supply chain issues.
- Accelerated reduction of emissions both direct e.g. at the point of use, and indirect e.g. embedded in manufacturing, construction and end of life.
- Adaptable, reliable and agile freight and passenger business models leading to increased market share.
- Enhanced capacity of the rail system to accommodate increased assets utilisation.
- Rapid implementation of reduced life cycle costs (CAPEX and OPEX) and life cycle externalities for best value to society.

## 2.2. Strategic Research Priority 02: Understanding systems interdependencies

Railways are an integrated set of people and assets organised to move passengers and goods in a safe, timely, reliable and energy efficient manner. Efficiently controlling the multiple interfaces between subsystems is an essential requisite to successfully manage complex systems. Socio-technical systems, such as the railway, also require guaranteeing the needs of people and the environment are considered appropriately and respected at all times.

Systems thinking provides a suitable framework to approach how railways are designed, operated, maintained and governed. This framework requires an awareness and consideration across multiple scales that is complex by nature. However, restricting this approach solely to the rail system and its sub-systems is not sufficient. The successful integration of rail in a resilient and future-ready European multimodal transport system also requires a systems-of-systems approach whereby interactions between the railway and other modes are considered as well as interdependencies between energy systems, telecoms & Information Technology (IT) systems and transport. These interdependencies are particularly relevant when considering the challenges associated with Research Strategic Priority 01.

Research is needed to:

- Develop common, proven and standardised methodologies, methods and tools allowing the use of systems thinking across all scales. These can include, for instance, digital shadows[4] and/or digital twins[5] as well as co-simulation approached. The implementation and expansion of the outcomes of the EU-RAIL programme will be a critical platform to build upon for this area e.g. systems engineering principles, agility.
- Understand the impact of deploying novel technologies and processes e.g. co-existence and legacy aspects.
- Assess the role of people across scales e.g. rail subsystem & system plus system of systems.

## 2.3. Strategic Research Priority 03: People-centric railways

None of the above can be realised without understanding the behavioural dimension of the system. This encompasses not just the end-users e.g. passengers and freight customers, but also the human capital running the railway. Adding a human lens to the way the railway is run and designed plays an essential role in achieving the sector's goals.

Behavioural aspects are particularly relevant when considering the deployment of automation across the rail system, especially during the co-existence phase with legacy and not fully automated assets and protocols. Similarly, the digitalisation of society needs to be reflected in the way users interact with the system. Failing to do so poses a significant risk of decline in patronage and market share.

Acquiring new knowledge on these issues is fundamental. Priorities include:

- Understanding and preparing for future user needs and behaviour in a multimodal context.
- Human factors and experience implications for safe and efficient management of rail operations resulting from the deployment of automation, increased volume of critical information flows and human-machine interface transformations with a particular focus on safe and efficient management of rail operations.
- Identifying assets, protocols and subsystems suitability for partial of total automation leading to the establishment of implementation plans that prioritise the wellbeing of people and organisations within a framework of competitiveness, resilience, and net zero.
- Developing business models that incorporate user-centric design principles maximising the benefits that digitalisation and new technologies provide e.g. flexible rail services, integrated ticketing, multimodality and supply chain.
- Developing spatial planning methods and tools that acknowledge the role of rail in structuring the built environment and creating move liveable communities.

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# 3. Four key challenges & opportunities

Following and extensive consultation work coordinated by various ERRAC working groups associated with the manifesto challenges, research needs and opportunities have been identified paving the way to cross-cutting research priorities as described in previous sections. These outcomes are outlined in this section.

## 3.1. System optimisation

Optimising the rail system as a whole requires considering the network and its surrounding environment as an interconnected whole, rather than focusing on individual parts of the system in isolation. The rail system includes physical infrastructure, rolling stock and equipment used for operation and maintenance as well as interactions between subsystems. It also extends to the economic, ecological and social context, including passenger demand, economic viability, and environmental impact.

If rail is to become the backbone of a sustainable European mobility system, it must significantly reduce internal and external costs, such as harmful emissions and noise, enhance quality of service by improving reliability e.g. service punctuality and address resilience, increasing also its capacity to support a growth in market share.

This section considers opportunities for improvement within each rail subsystem as well as across these. Subsystems are governed by the Technical Standards for Interoperability (TSIs), namely: infrastructure, energy, control command and signalling, telematic applications, rolling stock, maintenance, and operation and traffic management. Research needs focus on improving the system performance by maximising a combined capacity, reliability, durability and safety of the whole system whilst minimising internal and external costs. The system optimisation will be built on the further development of the System Pillar as part of Europe's Rail Joint Undertaking (EU-RAIL).

This optimisation process is also impacted by the following:

- Harmonisation and standardisation of subsystems, operational rules and product architectures.
- Migration and deployment of new technologies and legacy issues considerations.

The approach presented above must tackle the inherent conflict between the investment needed to improve the system performance with the goal of cost reduction. Beyond its technical function as key enabler of prosperity, the well-known socioeconomic and environmental benefits of rail transport as well as its positive impact on the European sector competitiveness must be weighted on cost-performance trade-off decisions.

The principle of system thinking must be embedded into the overall research and innovation agenda. To ensure successful rail collaborative interventions, it is crucial to look at a holistic rail system optimisation including strengthen collaboration between subsystems e.g. infrastructure and rolling stock, and key stakeholders e.g. suppliers and operators/infrastructure managers. These initiatives should prioritise systems thinking, which involves identifying underlying causes, anticipating consequences, and optimising the rail system accordingly. Additionally, it is essential to understand how various components of the rail system interact with each other whilst ensuring overall stable operational conditions.

The concept of Industry 5.0 "as transition to a sustainable, people-centric and resilient European industry"[6] can serve as inspiration to the European rail system and a guiding set of principles for the identification of key innovations for system optimisation. For instance, an inclusive and sustainable rail system with a high level of service personalisation within a multimodal framework can only be achieved if the rail system adopts a people-centric approach.

To adopt such approach, rail must contribute to make the system more attractive for passengers, freight customers and workforce. A reliable and safe railway is essential to position the system as the backbone of European mobility. In addition, innovations must contribute to the system capacity increase to meet the growing demand for a sustainable transport system.

[6] https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en

A people-centric system also means that the workforce must be placed on the centre of the system. This opens up a unique opportunity to create a framework to attract the required talent for the further development of the rail system by introducing a learning organisation model and thus contributing to increasing productivity.

As an illustration, the following selection of technology clusters supporting the concept of Industry 5.0[7] could be considered for adoption by the railway system:

- People-centric solutions and people-centric technologies that interconnect and combine the strengths of humans and machines.
- Real-time based digital twins and simulation to model entire systems.
- Cyber safe data transmission, storage, and analysis technologies that are able to handle interoperability.
- Artificial Intelligence e.g. to detect causalities in complex, dynamic systems, leading to actionable intelligence.
- Technologies for energy efficiency and trustworthy autonomy as the above-named technologies will require large amounts of energy.

An additional consideration is that subsystems interact with each other through different interfaces as well as with elements outside of the system. Transversal elements impact all subsystems and support the coordination of the efforts towards the harmonisation of the future rail system and innovation deployment. Relevant transversal elements include standardisation, externalities and regulation.

### 3.1.1. Research outlook

The needs defined by the EU-RAIL System Pillar on harmonising and coordinating the integration of the rail system as well as the categories defined in the Standardisation and TSI Input Plan (STIP) serve as a potential guide for the identification of specific research topics. As an illustration, these include among others:

- Operational harmonisation
- Traffic CS and interface to TMS/CMS
- ATO GoA2/3/4
- ASTP (Absolute Safe Train Positioning)
- FDFTO (Full Digital Freight Train Operations)
- FRMCS (Future Railway Mobile Communication System)
- Onboard Enhancement
- Cybersecurity
- Safety management
- Trackside assets
- Digital Twin
- Digital asset management, data spaces and models
- Driving control, Adhesion management
- Energy management and supply
- Alternative propulsion, traction energy

[7] https://op.europa.eu/en/publication-detail/-/publication/8e5de100-2a1c-11eb-9d7e-01aa75ed71a1/language-en

In addition to this, the identification of future specific research topics should consider recent documents such as the description of research needs described in the EURNEX Rail system Optimisation[8]:

Future research should also be organised around the identification and further development of enablers needed for the progress of each research topic.

The enablers should be selected according to their capacity to contribute to the overall objectives of maximising capacity, reliability, and safety of the rail system whilst minimising internal and external costs. Their impact on the technical functions of the rail system and the sociotechnical interfaces must also be considered as well as different temporal scenarios:

- Short-term vision (scenario 2030): Based on harmonisation and deployment of technologies being currently developed and close to market with high TRL.
- Long-term vision (scenario 2050): based on cutting-edge innovations with focus on experimental research with low TRL. Fundamental research must be the driver of this vision.

The definition of both scenarios must include and assessment of the expected readiness of the technologies being currently developed. In addition, the new research priorities must be aligned with the previous work carried out.

The research outlook with regards of systems optimisation should consider the following common aspects:

- Promoting systems thinking which identifies root causes, anticipates consequences and optimises the overall rail system. Subsystem interfaces and system functions should be placed at the forefront of this approach to explore the interaction with each other as well as with external factors e.g. socio-economic, energy, climate, biodiversity, other modes.
- Developing a people-centric rail system that engages its workforce in the development and deployment of innovation and evaluating their impact on rail passengers and freight customers
- Delivering railway optimisation involves extensive research, collaboration, integrated systems thinking, evaluation, implementation of best practices, continuous improvement, and training. It enhances performance, efficiency, and sustainability through innovative technologies, comprehensive assessment, and partnerships. The industry achieves extensive improvements and benefits stakeholders by considering interdependencies, identifying root causes, and implementing best practices.
- Boosting digitalisation of railways.
- Continuous monitoring to ensure ongoing optimisation and adaptation to evolving needs, supported by a skilled workforce through training and knowledge transfer.

## System Optimisation

**Holistic approach:**

- Railway System operation
- Control & Command
- Energy management
- Communications & Physical infrastructure management

**Humancentric Design and Inclusivity (Industry 5.0 -> Rail System 5.0):**

- Emphasis on a human-centered approach in system development
- Creating jobs and promoting education in the rail transport sector

[8] https://www.eurnex.org/wp-content/uploads/2023/12/Railway-System-Optimization_ERRAC_EURNEX_2023.pdf

## 3.2. Multimodality

Multimodality is a key catalyst addressing progress on societal challenges and propelling the European Union to reach its ambitious environmental goals by improving the pivotal role of railways in the transport and the wider mobility and logistics system. Railways should serve as the heart of a comprehensive multi-modal transport system, being complemented and augmented by combined mobility solutions to provide door-to-door services that improve flexibility and reach. Solving the railway's relative lack of flexibility promoting modal shift and greener alternatives would unlock a better, more attractive and effective multimodality.

Multimodality is also applicable to freight and logistics. Boosting the market share of rail freight is pivotal to achieve the goals set by the European Union with particular emphasis to environmental performance and safety aspects.

Paramount importance needs to be placed to bolster international rail freight corridors offering the possibility to move a substantial volume of goods along transport axes. This can be achieved by addressing the challenges imposed by fragmentation, across transport modes and Member States, that is driven by. lack of standards and technical interoperability, divergent legislation, border checks as well as internal organisational and verification procedures.

In practice however, using more than one transport mode can be cumbersome and discouraging for users. Interventions are needed focusing on the development of multimodal hubs and the virtual aspects of the journey. From an operational perspective, a primary challenge remains in delivering an optimised combination of transport services and paths as well as effective real-time adaptive capacity and operations meeting evolving demand.

Efficient multimodality has the potential to improve the quality of life of a vast amount of European population and to support the European Union's ambitious climate goals, including a substantial reduction in carbon footprint and emissions. Additionally, it supports specific objectives such as the development of circular and carbon-neutral cities and the improvement of cross-border intermodal freight transport.

### 3.2.1. Research outlook

A significant acceleration of research and innovation underpinned by the development of enabling technologies and unwavering policy commitment is needed to achieve growth and encourage a modal shift towards eco-friendlier transport. In addition, a set of societal, geopolitical, economic and technological changes are taking place, significantly impacting multimodality.

Multimodal hubs are drivers for urban regeneration. These spaces need to evolve incorporating the benefits of augmented services underpinned by new technology and digitalisation, without any physical barriers and able to optimise crowd flows prioritising system performance whilst providing a safe, reliable and enjoyable experience. Integration with active travel is essential. Radically novel methods are required to deliver these large infrastructure transformations with minimal impact.

The virtual dimension of a journey is becoming progressively more immersive and has increasing importance in how users enjoy and engage with their experience in the context of multimodal trips. Digital and physical environments are increasingly blurred from a user-centric standpoint. This is influenced by a challenge of changing user expectations seeking orchestrated and seamlessly interconnected multimodal travel. The vision aims to facilities a system where users are expertly guided through their multimodal journeys, as the digital environment tools are capable to seamlessly aggregate the fragmented information captured from the external environment, aiming to offer the best personalised guidance to end-users.

Innovative solutions contributing to the reinforcing the network of smart multimodal terminals and ports, their access points and scope is vital. This requires exploring alternative business models to include first and last mile e.g. by using urban rail.

The streamline of logistics and freight transport for agility and ease of use need to be accelerated. In this sense and to the benefit of multimodality, the adaptation of relevant tools and methods derived from passenger mobility applications can accelerate the transition. Efficient and seamless logistics need to be supported by solutions that ease predictability and planning and operational arrangements that are essential to make businesses use rail as a mode of transport.

Addressing the mobility challenge in urban environments implies the establishment of the rail system as the heart of a multimodal transport system that is naturally fit for mass transit, along with an advanced integrated and multi-layered urban planning capable to support the transition to a smart city, where notably the needs of key mobility generators e.g. businesses, educational establishments, health provision and actors converge and negotiate to smooth traffic peaks, while making possible on-demand supply. Urban rail systems play a key role in close coordination with other public transport modes and active travel to provide all users with a full efficient multimodal urban mobility service.

Population distribution along sub-urban, peri-urban and rural areas represent a major challenge for delivering a good quality, efficient, sustainable service, that should also be convenient, accessible, frequent and inclusive. Rural and sub-urban areas are expected to provide growth potential and multimodality is crucial to enhance flexibility to rail services, together with effective land planning and a systematic approach and on-demand transport. Complementing on-demand mobility services is essential to ensure the connection of all rural locations.

## Multimodality

**Challenges …**

- Physical and virtual dimensions
- Urban and suburban, periurban and rural areas
- Mobility and logistics

**… to be reflected by key aspects of multimodality:**

- Multimodal Transit physical hubs
- Digital environment
- Freight and logistics multimodality
- Passengers' multimodality

## Sustainability

**GREEN – Keeping Rail's competitive edge**

- Frugal Trains & Tracks
- Accelerating Phase out Fossil Fuels
- Integrating Renewable Energy

**CLEAN – Healthier users and ecosystems**

- Air quality, reduction of noise, vibration and pollution to land and water
- Biodiversity

**FUTURE READY – a resilient, digital and adapted railway**

- Stations and liveable cities
- Climate change adaption

## 3.3. Sustainability

The world and Europe are facing the threat of exceeding several key planetary boundaries including loss of biodiversity, clean air, climatic stability and scarcity of natural resources. The railways, in collaboration with other sectors and systems, can lead the way in creating a sustainable future which can be clustered around three streams, 'Green', 'Clean' and 'Future ready'.

### 3.3.1. Research outlook

### 3.3.2. GREEN: Keeping Rail's competitive edge

Rail must lead the greening of transport. Whilst Europe's rail has been able to improve its energy efficiency consistently, seeking solutions to make further efficiencies will reduce the cost and emissions of rail. Rail assets, including infrastructure and rolling stock, can be the first to be net zero embodied construction carbon and with zero waste.

Research into accelerated integration of innovative resource, energy efficiency technologies and practices is needed, including lessons learnt and partnerships across sectors and modes of transport. Integration and adaption of best practices in energy management for heating, cooling, and lighting from other sectors can further contribute to these efforts. Advancing low-carbon manufacturing, supply chain management and construction solutions to reduce emissions effectively can also contribute to these goals.

The green credentials of rail can be enhanced by investigating and adopting alternatives for new manufacturing and construction practices that embrace concepts of zero embodied carbon and circularity. Quantification of potential savings from solutions is important as it is addressing operational risks to support roll out acceleration. Research into how to best design, procure and construct trains and infrastructure underpinned fully by circular economy principles can lead support rails leading competitive edge.

Accelerating the phasing out of fossil fuels. Whilst electrification is the primary approach to decarbonise railways in Europe, due to technical or economic reasons, some 'hard to electrify' stretches of the infrastructure and rolling stock remain.

There are current power and operational constraints e.g. safety, range, and supply to solutions such as hydrogen and battery as well as sustainability concerns for biofuels, which reduces its application potential. Alternatives need improvement so that take up can be accelerated and become common place.

The non-electrified services will be the hardest to phase out due to costs, supply, and technology limitations. Environmental impact assessments for new types of systems are required to ensure a comprehensive and sustainable approach to rail expansion.

A potential approach to tackle this involves developing a clear road map to achieve complete decarbonisation establishing rail as the first mode to become net zero carbon. Working in collaboration with the energy sector and other transport modes, it would require accelerated action and implementation in the 'hard to electrify' areas such as low traffic routes, maintenance and construction equipment and heavy haul freight. It will also require to take a whole-lifecycle impact approach to the green traction solutions considering a holistic view of sustainability, supply chain constraints and operational impacts.

Integrating Renewable Energy. There is a need to strategically plan in a holistic way the expansion on both rail and renewable energy supply in Europe. Railways footprint includes ownership of large areas of land, which can act as an open smart grid, connecting to other electrified units such as adjacent land, buildings, businesses, electric shared vehicles, buses or micro mobility solutions. Some of Europe's rail undertakings have set targets and begun to integrate additional and dedicated renewable energy production into the railways for manufacturing, buildings, traction energy use and infrastructure.

Investigating the optimal Integration and adaptation of renewable energy generation technologies in the rail environment can yield significant benefits. This research should lead to identifying the role of rail in electricity distribution, energy harvesting and security, grid stability, peak demand regulation and energy storage potential and connect through partnerships and collaboration with the energy sector and other transport infrastructures and electric road vehicles - e.g. complementarity in partnership on battery and charging technology with car and bus. By using superconducting materials integrated to the renewable solution, efficient transmission might be achieved, and power losses can be reduced.

### 3.3.3. CLEAN: Rail for healthier people and ecosystems

Rail must continue reducing negative externalities to protect health and wellbeing.

Air quality, noise, vibration and pollution to land and water. Air pollution is growing in public, political and scientific consciousness. Although railways contribute a relatively small share of transport emissions, and the phase out of diesel-powered rolling stock will make a significant impact on air pollutants, a deeper understanding of other pollutants such as particulate matter and wear emissions is essential to mitigate risks to human health and habitats. Pollutants to soil and water are also a risk due to use of toxic chemicals in asset management, accidental spills or the application of heavy metals on the railway land. Public pressure and legal constraints on these substances are increasing. Noise and vibration emissions are considered major externalities, adversely affecting health and quality of life for both wildlife and humans living near or working on the railways. Potential implications for physical and mental health and well-being are not yet fully explored.

The above poses the challenge to minimise the harmful emissions to be as low as practicable possible minimising their impact on health and well-being. Whole life cycle measuring, monitoring, and reporting the footprint for externalities should be conducted collaboratively. It can support the adoption of long-term monitoring practices, incorporating quantifiable metrics, implementing open-source databases, and covering digitalisation. It also needs to consider every part of the system and life cycle including retrofitting and renewals. Optimisation of auxiliary equipment, along with the integration of remote demand-based control using software, to efficiently address both air quality, noise, and vibration issues. An industry-wide " no harm approach" needs to be developed along with whole system optimisation to manage the adverse impacts of railways on soil and water. The focus should be on eliminating toxic and hazardous chemicals, integrating new methods into asset management through rigorous cost-benefit analysis.

Coupled with the Climate crisis, the world is on the brink of a biodiversity loss crisis. Across European key species and overall diversity of animals and plants are increasing at risk with the erosion of habitat size, connectivity, and quality. Railways can be both a hazard to wildlife as well as a haven. There are serious risks of severance of animal habitats and collisions with railway equipment but also, as a relatively untouched linear green corridor, railways can support a rich mosaic of ecosystems. Healthy, appropriate, and diverse ecosystems alongside the railway deliver important services to society and the railways as carbon sinks, for visual and landscape benefits, for water storage and management, for embankment stabilisation and protection from the extremes of climate change. There are many great potential benefits from managing lineside biodiversity as an asset.

To address the biodiversity challenge, there is a need to test and demonstrate the effectiveness and the integration of monitoring, prevention, and nature conservation solutions to help railways to be more proactive in this area of growing knowledge and action. Blue and green infrastructure is to be considered along grey infrastructure as a railway asset.

Integration of the mitigation hierarchy in rail maintenance, upgrades, and reconstruction/retrofitting of rolling stocks processes can ensure safe and reliable network operation, while actively promoting biodiversity conservation. Use of smart, remote monitoring systems where applicable, and encourage open information sharing to enhance and refine future approaches and practices. Biodiversity recording and reporting practices should be enhanced by using integrated BIM and GIS solutions. Other approaches include efforts to minimise environmental impact of new construction projects by avoiding excessive aggregate extraction and consider indirect biodiversity effects in broader sustainability strategies and planning, favouring sustainable "no harm" materials and design. Explore the latest knowledge in ecosystem services and management, learning from experts on how to design and foster an optimal green corridor for the benefit for a safer and more reliable railway that also benefits our customers and neighbours. A deeper understanding on animal collision, forestry, vegetation, and soil management (including land stabilisation) and sustainable drainage and water management should be explored. Introduce nature-based solutions and ecosystem services thinking to broaden the opportunities of lineside asset management to benefit wildlife and habitats.

### 3.3.4. FUTURE READY: a resilient and adapted railway

Stations and liveable cities are core to a vision for new sustainable cities using public transport as an enabler for sustainable and healthy living. Depot and station design and operations can benefit from integration with strategic spatial planning and working with city planners. Through principles of Transit Orientated Design (TOD), the feeling of safety for passengers can be boosted, active and healthy mobility encouraged, passenger traffic increased and tenant businesses benefit. Rail expansion and improvement can be designed in a way to prevent urban sprawl, congestion, and nuisances.

Rail can and must support cities and communities to be a well-functioning compact urban form. Solutions should explore strengthening the connection between rail actors, urban and spatial planning experts. Research should also consider how railways can adapt and design their stations or depots with strategic planning. It will provide a deeper understanding of the urban form and the impact railways can have in shaping future cities of Europe to be healthier and more liveable places. Construction and operational techniques would need to be explored to reduce disturbance to people and business.

Climate change adaptation is an essential component of future ready railways. Due to a rapidly changing climate, extreme weather hazards are becoming more frequent including extreme precipitation, extreme temperatures, electric storms, and high winds. Some of the expected problems are critical and compromise safety e.g. track buckling, broken rails.

The challenge includes understanding the levels of vulnerability and most effective solutions across rail and as an interdependent service to other modes and the energy sector. The absence of resilience indicators makes demonstrating the need of allocating funds to increase preparedness against climate change difficult.

The research agenda will deepen understanding on the vulnerability of the infrastructure and operations using advanced digital tools, considering opportunities for integrating nature-based solutions and innovative asset management and emergency procedures. Structural and engineering solutions for climate adaptation should be advanced using communication technologies and the decision-making process. The process of translating weather forecasts into mitigation and impact avoidance work needs investigating and upgrading. Drainage condition monitoring and remote-monitoring process on slopes is required and geotechnical subsurface investigations in hotspots need to be conducted. Clear vulnerability measurement techniques and fully holistic impact assessment methodologies should be advanced and shared based on harmonised views on future scenarios and modelling.

## 3.4. Inclusive and personalised service

For rail to be competitive and attractive, it must be affordable for all potential users. Inclusiveness also means affordable, still innovative, rail transport for both goods and passengers, including urban, medium & long-distance and high-speed services.

The railway system must provide affordable services even when investing in innovation and assets, and thus must drastically reduce its capital and operating costs. The introduction of advantageous new technologies needs to take place at reduced life-cycle cost (CAPEX & OPEX). Implementation and deployment must be rapid and effective. Future solutions should look at new types of vehicle and infrastructure solutions that are simpler, cheaper and faster to manufacture, deploy and operate, based on new architectures and designs that should explore shorter lifespans, still increasing their standardisation, flexibility and modularity, whilst always maintaining the established safety levels. The application of AI and other innovative digital technologies to all processes from the design to the certification of the railway assets should also strongly contribute to the reduction of the CAPEX.

Innovation and affordability must go hand in hand with achieving an effective reduction of CAPEX and OPEX, making the rail system more economically sustainable.

The right of using railways should remain as universal as possible. European citizens living in rural areas could also benefit from railways if such lines are affordable and profitable. Because of the relatively high costs for keeping rural lines operative, most of them are disappearing, leaving road transport as the sole means to get to the main hubs or even the final destination. Revamping such rural lines and creating new ones is a cornerstone to bring the required capillarity to the railway system. This will be only possible if new innovative concepts are put in place to make these lines affordable and attractive.

### 3.4.1. Research Outlook

Contributions to the above could include investigating holistic innovations such as the development of quickly deployable infrastructure made of standardised premanufactured building blocks where small battery-based rail vehicles controlled by swarm intelligence could automatically operate. Such operations should follow service-on-demand principles, also ensuring personalised services.

Standards and regulations should be adapted to new rural lines concepts by lowering their requirements where possible to the actual needs of the concept benefitted by the new technologies. This is a major enabler to achieve the goal of reducing costs and making rural lines affordable and hence attractive for investment and operation. The latter is obviously linked with economical inclusiveness as well.

In the context of public transport, the railway sector faces a combination of challenges such as changing travel patterns and fundamental conflicts of objectives e.g. ageing assets versus raising passenger expectations. Today, passengers have more options than ever and railway operators can no longer rely on ever-rising passengers' numbers. When choosing the best option, a positive passenger experience is vital in convincing people to opt for public transport over the abundance of other choices available.

An inclusive design approach aims to remove any barrier that might prevent users from getting the most benefit possible so that everyone can participate equally and confidently, including the ageing, disabled and those on remote locations. It's a recognition that passenger satisfaction hinges not on aspects such as speed, efficiency, and reliability alone but on various other cognitive, sensory, and emotional factors. These factors, as well as humans in all their complexity, must be considered for future concepts.

From a cognitive point of view, the journey perception takes place in the brain, not necessarily through the senses. This is the main reason to consider adaptive functions, that is, cognitive expectations. Research should explore approaches that add a human lens to existing practice e.g. development of a passengers' experience framework.

Consequently, public transport services must be adapted to facilitate a new business model. Instead of only maximising total capacity for rush hour, the new paradigm should focus on a better utilisation of all assets by further encouraging a targeted modal shift towards now less used public transport options e.g. sleeper trains. Putting the passengers first will be an essential part of this paradigm shift that should start with relevant improvements in inclusivity, which will significantly increase the sector's sustainability.

Identifying approaches leading to a successful management of the necessary technological transformation also applies to freight, for instance through:

- Personalised Service for freight customers.
- Realtime Monitoring
- Integrated services with all stakeholders
- Communication and good user experience (UX)

Despite its energy and environmental advantage, rail freight is not competitive in areas such as speed of delivery, costs, and logistics. Some of the reasons for this are connected to last mile delivery and mobility, but others are to speed e.g. cargo is usually treated as a secondary user on the network and priority is given to passenger transport. Research areas that could contribute to reverse this trend to achieve integration with last mile delivery include:

- use of data for logistics and trip planning,
- integration of systems and data flow between stakeholders across EU,
- increase of speed and traffic flow along optimisation of energy consumption and lower costs.

Combining software-related innovation and research e.g. apps, with relevant hardware environments can enhance their impact. An illustration of this are flexible vehicle interiors that can be adapted between peak and off-peak times and to various functionalities and use cases e.g. business or leisure travel plus other considerations such as seasonal aspects. Additional benefits of such interventions include sustainability given the capacity of such adaptable environment to remain relevant as user needs evolve over the time span of the rolling stock. This category includes exploring solutions such as smart digital interiors that can adapt according to time, location, destination or train configuration, dynamic zoning concepts instead of first and economy class to match requirements/needs.

To implement these types of concepts and to create a levelled playing field for the sector, research is needed covering a wide range of needs, impairment or limitation any group of passengers may possibly have. Consequently, a Customer Centric Design (CCD) process should be implemented when developing railway innovations.

A constant gathering of data using existing transport infrastructure to understand usage patterns over extended periods of time is an essential precondition to gain the necessary understanding of possible future operational adaptations e.g. load balancing. These data could feed large-scale digital twin applications. Based on real-time simulations and pattern recognition e.g. machine learning considering extensive databases, these highly complex digital twins will be able to provide a reliable decision-making basis to adapt operations including maintenance. To enable the use of these applications, initiatives around open IT and data standards need to be further expanded.

For rail freight, the creation of reliable digital customer platforms that offer new services to customers are needed. Such platforms should be designed as an open ecosystem to attract third parties e.g. start-ups to drive innovation by utilising these data. This approach would also support the development of new business models and to rethink the current ones to include on-demand services and to enable more freight volume to be shifted to rail.

## Inclusive and Personalised Service

- Economical inclusiveness
- Geographical inclusiveness
- Personalised Passenger Services
- Personalised Freight services
- Change of Mindset from Design for Trains towards design for users

# 4. Conclusions

## This document has detailed the outcomes of an extensive consultation amongst ERRAC members articulating a research outlook for four core challenges, namely:

- System optimisation
- Multimodality
- Sustainability
- Inclusive and personalised service

Some of the highlights included in this outlook include the need to apply systems thinking to build upon the outcomes of existing research e.g. EU-RAIL, explore mechanisms to enhance the benefits of multimodality for both passengers and freight, the need to maximise the inherent sustainability benefits of railways contributing to the net zero agenda, identify approaches to create a future-ready railway that is resilient and adaptable to the challenges posed by climate change e.g. extreme weather events and embracing digitalisation to develop competitive railway services that are also user-friendly and inclusive.

Particularly relevant is the idea of seeking inspiration from the principles behind the concepts of Industry 5.0 "as transition to a sustainable, human-centric and resilient European industry" and Society 5.0 where "advanced IT technologies, Internet of Things, robots, artificial intelligence and augmented reality are actively used in everyday life, industry, healthcare and other spheres of activity, not primarily for economic advantage but for the benefit and convenience of each citizen" [9]

In the context of the European Commission policy direction, this document has set up the agenda for the next Research Framework Programme around three strategic research priorities capturing the recommend topics identified by the ERRAC membership, namely:

1. Resilience, sustainability and competitiveness
2. Understanding systems interdependencies
3. People-centric railways

However, to create the conditions for innovation it is also essential to identify and develop new knowledge for enablers to maximise the rapid adoption of the research outcomes. Specifically, the following topics are deemed necessary:

- **Digitalisation**. Society is immersed in a digital environment and a paradigm shift is needed in the rail and transport sector to exploit and fully adapt to digital technologies. It is critical to develop common protocols and taxonomies as well as clearly defining governance structures and ownership of data to enable the research activities outlined in this document as well as maximise the chances of succeeding in achieving the overall goals for a railway that is at the heart of a future sustainable transport and mobility system.
- **Governance and Policy**. A successful transition to implementation of research outcomes requires clear governance structures to manage stakeholder interests as well as policies, standards and guidelines that facilitate rather than impede the rapid adoption of such outcomes.
- **Co-creation**. A critical aspect of research and innovation success is the incorporation at the very early stages of the different needs, capabilities and pooled resources in a structured and long-term framework from all the relevant stakeholders.
- **Skills.** The deployment of new technologies, interventions and processes requires the development of a matching skills agenda coordinated across Europe that caters for the recruitment of a diverse future workforce with the right set of skills as well as upskilling exiting employees whilst creating workplaces where all employees can be themselves and make their maximum contribution.

Ultimately, the combined benefits of a harmonised research agenda and matching enabling measures can have a profound effect in mobilising a critical mass that activates a system change resulting in a high-capacity, sustainable and attractive European railway offer, boosting competitiveness and driving strategic investment in transformational technologies.

[9] European Commission, Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A., ***Industry 5.0 – Towards a sustainable, human-centric and resilient European industry***, Publications Office of the European Union, 2021,

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