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# **RESEARCH AND INNOVATION – ADVANCING THE EUROPEAN RAILWAY**

Future of Surface Transport Research Rail

TECHNOLOGY AND INNOVATION ROADMAPS

**ERRAC**  
The European Rail  
Research Advisory  
Council



# FOREWORD

**Rail has tremendous advantages compared to other transport modes:**

- CO<sub>2</sub> emissions are low: they represent 1,5% of EU transport emissions and have decreased by 43% from 1990 while transport ones have increased by 25% in the same period of time.
- Energy consumption is low: it represents 1,8% of EU transport energy consumption and has decreased by 20% from 1990 while transport one has increased by 29% in the same period of time.
- Use of land is light: rail can move 10 times more transport units per kilometer, while using 40 times less land than roads.
- In urban areas railway stations are easier to develop than airports.

**However, rail is not succeeding in raising its market share in Europe: freight is around 16%, and passenger traffic has been flat for years at about 6%.**

**What, then, should we do to boost rail's market share dramatically, leveraging its basic advantages?**

**As an answer, we need to address deeply the following five main challenges:**

- Increase rail attractiveness for passengers and goods (connectivity, fluidity, passenger experience, service extension ...)
- Increase rail competitiveness, reducing operational costs, as some non EU countries are managing to achieve good results in this respect
- Sustain and further develop the environmental friendliness of rail
- Decrease time to innovation through revisiting standardization and regulations, and moving to open technologies (communication, information systems, financial transactions/ticketing, localization, automatic driving)
- Sustain and further develop the railway sector robustness, through education, training, and improvement of processes and tools for design, manufacturing, and operation
- Effectively leveraging new technologies such as digitalization, new materials, big data, energy storage and efficiency, and many others.

**That is the very essence of the ten FOSTER-RAIL roadmaps**, aligned with the ERRAC Strategic Rail Research Innovation Agenda (SRRIA), paving an ambitious way forward to develop the railway sector in Europe for the decades to come, far beyond Shift2Rail, to make it sustainably competitive compared to Asia, and to improve overall transport efficiency in Europe.



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# INTRODUCTION

The EU funded FOSTER-RAIL project (1 May 2013 till 31 April 2016) was launched in order to support the work of the European Rail Research Advisory Council (ERRAC) to the European Commission. It addressed the challenge to strengthen and support research and innovation cooperation strategies in the European rail sector.

The project aimed at facilitating the dialogue among main stakeholders and actors in the European rail business at the European level and at the interface between the European and national level. FOSTER-RAIL continued the work already done by ERRAC and its working groups – principally the 2020 Vision document and the Strategic Rail Research and Innovation Agenda (SRRIA) as well as other reports such as the ERRAC ROADMAPS. Based on these roadmaps, the project partners continued to shape the research and innovation agenda and identified priorities for research focusing on improving railway business in the next decade.

This brochure summarises the outcomes of the FOSTER-RAIL project and in particular the 10 Technology Roadmaps showing the way ahead for a successful and sustainable railway market.

The output is intended for use by the sector itself on the one hand and for the European Commission on the other hand in developing its future Horizon 2020 work programmes and calls. FOSTER-RAIL serves as well as input to the Shift2Rail Joint Undertaking and its annual plans and calls.

The 10 separate FOSTER-RAIL Roadmaps on which this integrated report has been based can be downloaded from the ERRAC Website [www.ERRAC.org](http://www.ERRAC.org).





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1

# TECHNOLOGY AND INNOVATION

# TECHNOLOGY AND INNOVATION

## Making European Rail the safest, preferred and most attractive part of the whole journey

### SUSTAINED ENDURANCE: BUILDING IN THE FUTURE OF THE WHOLE JOURNEY

Railways in Europe are facing a number of key challenges including demand for increased capacity, improved reliability and reduced costs. Failure to meet these challenges will reduce the ability of the railways to meet the defined European objectives of modal shift from road to rail, improved mobility and transport efficiency and improvement in the environment.

To help meet these goals a large number of innovative measures are envisaged that today are almost ready to implement or that can be developed within quite a short time. This is the main focus of the Shift2Rail initiative which in turn is fully aligned with the roadmaps presented herein.

To substantially reduce costs of future rail transport and to make it even more environmentally friendly, a certain amount of long term research is required. These technologies are probably not ready to use in the immediate future but are necessary to ensure the initiation of a paradigm shift for rail as a preferred transport mode for passengers and freight in the next 30 years.

Some of the basic issues with rail transport that can be mentioned in this context and that railways suffer from are:

- Heavy vehicles that use more energy than necessary and cause excessive damage to the track ;
- High investment requirements and maintenance costs of the system ;
- The need for a new signalling system and the limited capacity of the system ;
- High noise emissions ;
- Adopting technological innovation driven by other sectors and not yet exploited by rail.

These issues are reflected in the Shift2Rail Master Plan and in the ERRAC SRRIA will be addressed in new projects to enhance the performance of the system.

ERRAC will maintain and promote the implementation of the roadmaps, evaluate new concepts and support those with potential to the point where industry is ready to implement them as part of its day-to-day business.



From a technological perspective, innovation is expected to produce more energy and resource efficient systems for rolling stock, infrastructure and operations. Integrated services for ticketing and traveller information and guidance, including for circumstances of service disruption, are expected to be of very high quality in Europe by 2050. Quality and safety and security management systems are foreseen to be harmonized across Europe to keep the promise of an interoperable European wide rail system by that time.

Major innovation trends in the rail sector are based on the integration of technologies, e.g. analog components converging with digital. Rail users expect fully-functional digital communication and information transmission during their journey.

Semi and fully autonomous and alternatively propelled car systems are expected to be a major competitor in 2050 to electrified rail mass transit. Sustainable mobility measures, based on local climate policy and planning which drives reductions in carbon emission in cities and city regions, promote modal shift towards rail transport.

Long distance rail services must adapt to climate change. More resilient infrastructure, with improved emergency maintenance services, is expected to be in place by 2050.

Rail research and innovation policies at the European level will be strongly driven by the need to strengthen European rail industries within competitive global rail markets, successfully delivering large rail project bids, including turn-key ones. On the other hand, rail research and innovation policies increasingly reflect a shift to rail strategy with more restrictions on road transport and the phasing out of conventionally fuelled vehicles in urban areas.







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# ATTRACTIVENESS OF RAIL AND PUBLIC TRANSPORT

# CUSTOMER EXPERIENCE

All European Railway Customers receive a timely efficient and safe service that demonstrates value for money

## IMPORTANCE

Customers, both passenger and freight, are central to everything the European railway does and are its primary focus. The challenges from other transport sectors will require the railway increasingly to focus on satisfying current customers and to attract new ones, including by expanding both passenger and freight services.

## CHALLENGES ADDRESSED

**Passenger Satisfaction:** Provide European rail customers (passenger and freight) with seamless, efficient and cost effective end-to-end journeys in a safe and secure environment.

**Passenger Experience:** Enhance the actual and perceived experience of every European railway passenger through smarter, cleaner and more engaging and appropriate facilities and services.

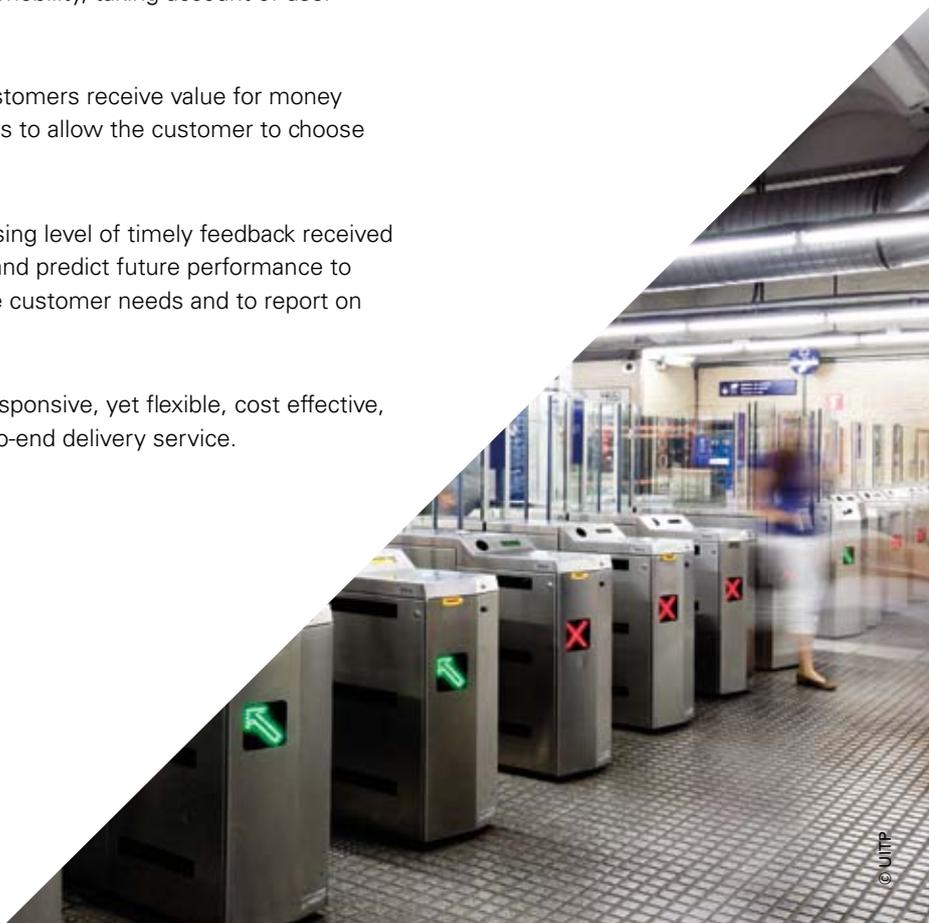
**Passenger Comfort:** Constantly improve the amount of passenger comfort for each type of journey; the short commute to the long leisure journey, both on and off the train.

**Passenger Access:** Introduce means of providing improved access for people of varying age, social category, life characteristics and level of mobility, taking account of user acceptance of innovative technical solutions.

**Passenger Value for Money:** Demonstrate that customers receive value for money along with an increasing amount of informed choices to allow the customer to choose the best value service that meets their needs.

**Passenger Priorities:** Sustain and exploit an increasing level of timely feedback received from European railway customers. Appraise actual and predict future performance to increase the ability to anticipate and quickly manage customer needs and to report on trends.

**Freight Priorities:** Deliver to freight customers a responsive, yet flexible, cost effective, monitored and where appropriate, integrated, end-to-end delivery service.



## TECHNOLOGY AND INNOVATION NEEDED

In order to continuously improve **Passenger Satisfaction** the industry will need technologies that:

- Improve the speed, efficiency of modal transfer to/from the rail segment of end-to-end journeys
- Provide personal and timely information, both active/direct to personal devices and passive via interactive and static signage
- Standardise the ways in which passengers interact with the railway across Europe in order to increase familiarity and reduce passenger stress

It is a priority to improve **Passenger Experience** innovative ways to:

- Increase accessibility of the railway to a wider demographic, including persons with reduced mobility (PRM)
- Expand the range of passenger facilities available; for example improve connectivity to communications systems, increase the range of personal services and travel options available
- Provide tools and services that undertake real-time analysis to enable service providers to address immediate and predict near-term passenger needs

There are two main areas where technology and innovation are needed to improve **Passenger Comfort**:

- On the train: providing adaptable and reconfigurable carriage interiors, along with decreasing the level of acoustic noise and vibration
- Off the train: increasing the comfort and attractiveness of stations and their surrounds, along with the ability to direct and move higher volumes of passengers through the station

In both cases, there is a need to make sure that future design and development is carried out with clear understanding of passenger needs.

Innovative ways to provide and present readily quantifiable and usable information that demonstrate **Passenger Value for Money** are required. Using this analysis, a subsequent requirement is to engage and inform passengers and to provide service operators with the ability to forecast future trends and customer needs. Further, there is an innovative requirement to exploit the value of this type of analysis to enable less risky capital investment programmes to be undertaken.

The main need associated with **Passenger Priorities** is to ensure passenger and other railway users' safety and security whilst they are in or near the railway system, with technology and innovation needed to:

- Monitor and manage safety and security threats in real time
- Federate and generally improve connectivity of sensors and associated safety and security systems, better to predict adverse incidents and to instigate mitigating actions before the incident occurs
- Be unobtrusive, interact with the passenger and general public only where and when necessary



**Freight Priorities** are led by operators needing flexible, rapid and cost effective freight services to

- Expand the railway capability to move freight at short notice ; potentially using the passenger network to move light and parcel freight
- Increase the real-time flow of freight related information, including tracking data, across the logistics chain

## VALUE

The growth in rail connectivity and improvement to end-to-end journey via efficient and simple modal exchange might be expected to realise a significant increment on current railway turnover by 2040. Each 10% increment would be worth an additional €4.4 billion a year (based on 2012 figures).

## Customer Experience Roadmap

AREA OF ACTION	Today	2020	2030	2040	2050	+2050
<b>Noise and vibration</b>	Decrease noise and vibration levels					
	Improvement of interior acoustic comfort for passenger					
<b>Logistics services</b>	Rapid reaction to queries - response time to enquiries in terms of service availability, routes, schedules, pre and end haulage satisfying customer demands					
	Integrated information systems handling the whole journey across modes and different mobility providers					
<b>Seamless passenger journey</b>	Adaptive interiors configuration for different types of users e.g. family activities, mobile office and group travel					
	Logical station layouts, good signage, location and maps and information on onward local ground transportation options					
	Comfortable waiting areas, research, understand and where feasible accommodate passengers' varying priorities at different hubs					
<b>PRM</b>	Mobility for all					
<b>Land use</b>	Improving the spatial appeal to passengers of the urban environments in which transport hubs are located					
	Customer needs and expectations including protection of privacy, and translation into functional service requirements					
<b>Customer needs and behaviour</b>	Mobility and location behaviour of individuals and firms					
	Social determinance of mobility behaviour					
	Measuring customer satisfaction and involving customers in service design and operation					
	Measuring customer satisfaction and involving customers in service design and operation					
	Accessibility as a tool and as an objective					
	New services which can be provided to customers in trains or stations, e.g. tablets, audio books, movies, night trains with single cells instead of compartments					
<b>Personal security</b>	Improve communications with customers : before, during and after service					
<b>Safety and homologation</b>	Design, technological and organisational measures to improve customer and staff security					
<b>Competitiveness and enabling technologies</b>	Management of degraded mode and minimising disruptions to passengers					
	Improved accessibility for specific categories					
<b>Security</b>	Key asset protection - Train security perception					
	Key asset protection - Station security perception					
	Human factors - Passengers and other users security perception					
	Detection Systems - No intrusive sensors					
	Detection Systems - No time spent in security check					
	Procedures, Regulations and standards - Privacy and personal freedom protection					

# STRATEGY AND ECONOMICS

Sustaining delivery of value  
for money for all stakeholders



## IMPORTANCE

This Strategy and Economics roadmap provides a high level approach to common factors affecting the European railway technology and innovation agenda that are not specifically covered in other roadmaps, as a guide for their development.

## CHALLENGES ADDRESSED

**Passenger Experience:** Increase the use of the European railway as the core element of multimodal, end-to-end journeys, by delivery of the best value for money and ease of use

**Customer Orientated Business:** Promote and sustain the interests of railway customers, who are at the centre of European railway business

**Customer Attraction:** Attract new and retain existing customers through provision of innovative and increasingly reliable, low cost, safe and secure travel services

**Customer Access:** Coordinate European expansion of railway service accessibility to a wider customer demographic

**Pan-European Value for Money:** Deliver cost effective, reliable and integrated pan-European rail services and associated efficient and timely modal interchangeability

**Faster Routes to Market:** Facilitate and enable increased and faster routes to market for novel technologies and innovation, removing barriers where appropriate

**Integrated Information:** Combine European railway information systems, to enable smarter, timely and high quality data and information to customers and operators alike

**Freight Competitiveness:** Develop and deliver technology and innovation that actively makes rail more attractive and usable to freight operators

**Affordable Travel:** Provide innovative ways to make rail more widely accessible; especially in improving the ability to tailoring services in order to meet short and mid-term user needs

**Environment and Safety:** Improve the European railway's 'green credentials' so that it continues to be the most energy efficient and safest mode of land travel

**Faster Time to Market:** Facilitate and actively encourage the rail industry supply chain in its ability to create and delivery new and novel technology and innovation in quick time

## TECHNOLOGY AND INNOVATION NEEDED

Technology and innovation is needed to improve and then sustain **Passenger Experience**, especially in areas such as:

- Urban mobility ; moving large numbers quickly and efficiently
- Modal integration ; ease and speed of changing between modes
- Delivering a 'single feel' to the Pan-European railway
- Improving robustness and resilience of the rail segment of end-to-end journeys

Provide means and support to cross-European initiatives that support **Customer Oriented Business**, especially through:

- Providing the means for service providers to bench mark performance, with examples of what 'good' looks like
- Expansion of cross-European customer focused training ; overcoming language and culture challenges associated with delivery of travel services to the travelling public
- Innovative delivery of co-operative business behaviours and associated incentives

With a special focus on **Customer Attraction** associated with urban services, there is a need to employ novel technology and innovation in order to:

- Make the European railway more attractive to a wider demographic
- Trial new methodologies that quickly match supply and demand, especially associated with adaptable pricing and variable service provision
- Encourage cross-Industry co-operative behaviour and associated management to maximises attractiveness of the rail segment of the end-to-end journey
- Improve and promote the robustness and resilience of the rail service

In concert with attracting new customers and maintaining current customers, there is a need to generically improve **Customer Access** to the railway, specifically for:

- Modal interchange for passengers with Reduced mobility (PRM)
- Improved access to rail services for a wider range of social groups
- Development and delivery of technology and innovation that enhances independence of and the ability for currently disadvantaged customers to use the railway

Develop and delivery common, co-operative and high quality tool sets that can be used to establish and support **Pan-European Value for Money** arguments by establishing a common means to:

- Measure the economic value of rail services
- Incentivise operators and infrastructure maintainers in providing value for money
- Measure whole life costs so comparisons can be made across Europe
- Encourage and promote invention and innovation as a 'business as usual' process

**Integrated Information** is essential to the improvement of cost and capacity ; technology and innovation needs to provide:

- High quality and timely integrated data and information available to passengers and operators
- Exploitation of data and information by 3rd parties for the benefit of passengers and operators
- Pan-European standardised methods and approved approaches when developing new / improved information services

- Pan-European governance for data and information
- Increased capability for knowledge management, storage and retention

Co-operation and co-ordination across Europe holds significant opportunity for **Freight Competitiveness**, with technology and innovation needed for :

- New and novel freight wagons and associated loading and unloading
- Cross-European means of coordinating, managing and exploiting freight operations
- Smart freight terminals able to move freight between modes in a timely and efficient manner
- Novel approaches to new freight services ; such as increased use of automation ; use of passenger services for light freight.
- Improved freight-related information services to track, manage and secure freight throughout the rail segment of its journey



**Affordable Travel** is associated with attracting new customers and with demonstrating value for money to existing customers, core needs include :

- Technology and innovation to reduce the overall cost of travel
- Improved capability for service providers and operators to dynamically tailor services to match need

The key elements of **Environment and Safety** associated with Strategy and Economics is the need to :

- Constantly improve the European railway's 'green credentials' through increased energy efficiency, reduction of waste, use of environmental friendly materials and so on.
- Ensure that the railway system is capable of managing weather extremes and climate change
- Increase the overall safety of the railway by removing or reducing safety risks
- Standardise, and where possible reduce procedures, regulations and standards associated with security and safety

In conjunction with route to market, **Faster Time to Market** sees the need for :

- Improved ability to quickly assess and realise the potential value of new technology and innovation
- A pan-European method to measure the (readiness) state of technology
- An improved means to promote and share novel technologies and innovations
- Improved ability to adapt or adopt technology and innovation from other business sectors

## VALUE

The incremental value of addressing the full range of structural factors outlined in this roadmap, in addition to the directly experiential matters in the Customer Experience roadmap, would also be seen through fare box revenue. Winning additional custom from a wider demographic basis could potentially double the increment.

# Strategy and Economics Roadmap

AREA OF ACTION	Today	2020	2030	2040	2050	+2050
<b>Optimise environmental and sustainable impacts of the life cycle of subcomponents</b>			Design procurement, installation, maintenance, operations and disposal			
			Political approach and economic assessment of feeding kinetic energy back to the public grid			
<b>General wagon issues</b>	New transshipment technologies and operational concepts for low cost terminals					
<b>Single wagons</b>	Integrated rail freight production concept (operational, commercial and technical) for increasing the utilisation of single wagon loads					
<b>Logistic services</b>					Dev. of transport services within single or multiple dry-ports in a TEN-T node concept	
	Horizontal collaboration between shippers of the same modality					
<b>TEN-T freight network</b>	Freight oriented and freight dedicated network					
	Development of TEN-T missing cross border links with efficient green co-modal nodes					
<b>Freight villages</b>	Merging TEN-T core and comprehensive network via green-type of primary, secondary and tertiary nodes					
	Spatial planning for mega hubs freight villages necessary for development of co-modality and long distance transportation, new designs and layout					
<b>Land use</b>	Urban green logistics associated to the mega hubs and freight villages					
	Land-use and spatial planning around sustainable efficiencies of public transport					
<b>Integration of urban traffic and travel information</b>	Development and implementation of appropriate performance regimes for mobility providers and infrastructure managers					
	Improving local integration of land-use, transport and environment					
	Integration of traffic and travel information					
	Definition of data quality					
	Integration of information on all types of externalities					
	Integration of information on electromobility					
	Governance models enabling the integration of traffic and travel information					
<b>Interchanges for passenger travel and transport</b>	Interoperability for customers through common multi-application processes on a single media: create a Pilot operation in a number of Member States in preparation for wider roll-out					
			Create a common EU-IFM application			
		Develop a commercial and technical framework for the sales and settlement of EU-IFM Products				
	Engage and merge with existing IFM Systems and other ITS services and transport modes (New) charging and pricing policies strategies					
<b>New city logistics concepts and interfaces for a more efficient freight delivery</b>	Design and operation of new generation resilient urban transport interchanges for greater integration of urban mobility networks					
	Financing and business models					
	Integrating interchanges with urban policies (Land use planning, economic development, smart cities, etc.)					
<b>Integrating urban mobility management</b>	Framework for stakeholders' involvement in greater exchange of information on urban freight delivery					
	New city logistics concepts, taking into account the impact of societal changes on commercial behaviour and goods delivery in urban areas					
	Network management strategies, integrated with sustainable urban mobility plans					
	Governance for the coordination of the network management tools					
	Short term forecasting models					
<b>Integrated urban mobility systems and governance</b>	Strategies and models to face serious network disruption, network management for climate resilience					
	Evaluation of models efficiency and network management tools and policies					
	Integration of an all modes and mobility options, and of a greater variety of network management tools, in network management systems					
					Actions influencing modal choice and travel behaviour: mobility demand management	
<b>Improving knowledge with data collection and analysis</b>	New mobility services (transport supply), including tailored services for different modes, social groups, territories and periods of time					
	More sustainable land development: new activities settlement and transport services					
	Mobility management and social networks					
	Consistent data collection and exchange on urban mobility and development and use of harmonised models supporting data analysis, land use and transport forecasts, cost-benefit and multi-criteria economic analysis and decision-making					
<b>Cooperation between stakeholders</b>	Analyse and understand user behaviour throughout the different stages of mobility in order to better reply to his needs while at the same time improving the business models. (date missing)					
	A study on each transport mode to understand where and which service have to be provided by each of them. The idea is to promote and finance each transport mode in its core business environmentally sustainable. (date missing)					
	Studies to promote the introduction and charging of the different transport modes according to the environmental impact costs (date missing)					
	Training needs and programmes					
<b>Energy and environment</b>	Promote cooperation for sustainable urban mobility (understanding, awareness, incentives, etc.)					
	Developing the robustness and resilience of transport systems (facing and recovering from incidents and disasters)					
	Interregional and/or European approach of urban mobility					
<b>Infrastructure</b>	Improving market up-take of EU research					
	Use of environmental friendly materials					
<b>Benchmarking</b>	Develop and use of energy efficient technologies					
	Adaptation of the existing railway system to the new climate conditions					
<b>Safety</b>	Tools and measures for better economic management of railways					
	Capacity improvements for lines and nodes to allow shorter train intervals, less crowded trains and increased punctuality					
<b>Security</b>	Technological and operational methods for decreasing the cost of infrastructure development while at the same time improving the infrastructure quality					
	Benchmarking inside Rail sector and between transport sectors International cooperation for more efficient transport systems and technical harmonization					
<b>Economics</b>	Extreme Climate events and resilience					
	European level crossings risks ranking					
<b>Regulatory framework</b>	Procedures, Regulations and standards - PPP					
	Procedures, Regulations and standards - International Security Organisations					
	Delivering whole life asset performance					
	Research into the organisational and regulatory environment necessary to encourage the adoption of innovations and the step change in cost and quality of service necessary to achieve the sector' and the Commission's ambitions:					
	- How to incentivise infrastructure managers to innovate to simultaneously improve services and reduce costs?					
	- What are the roles of train operators, regulators and governments in achieving this?					
	- How can passenger franchising be designed to encourage innovation? Who should procure assets, how to specify requirements and how to overcome the inevitable short time horizons and risk aversion of franchisees?					
	- How to ensure that the different players in the rail system work together to ensure system optimisation rather than the pursuit of sub-optimisation of their own particular part of the system, but without leading to discrimination against new entrants					



3

# A WHOLE SYSTEM APPROACH

# CAPACITY, PERFORMANCE AND COMPETITIVENESS

Double the operational carrying capacity of the European Railway, improve performance and competitiveness

## IMPORTANCE

To meet the ambition that the railway in Europe should make a bigger contribution to the economy and society, there has to be much better utilisation of the current network, the performance quality of the services provided, and the overall competitiveness vis-a-vis other forms of transport, such as the private car. Fundamental to this improvement is a radical improvement in capacity management, reducing the need to plan, invest in and deliver major new infrastructure schemes, which are expensive and often opposed.

## CHALLENGES ADDRESSED

**Infrastructure Availability:** Remove the risk of unplanned unavailability and minimise the time needed for planned unavailability (i.e. possessions) of the European railway infrastructure.

**Infrastructure Capacity and Capability:** Develop the capability of the railway infrastructure to meet increased customer and operator demand so that associated business benefits may be realised and new ones established. Present infrastructure bottlenecks and capacity deficits are defined by today's technology and modus operandi. Future, more advanced, operation models are needed to diminish capacity shortages.

**Infrastructure Exploitation:** Improve the availability and expand the capability to exploit railway infrastructure in a timely, cost effective and customer focused manner. Exploit the improved infrastructure to make effective and extended use of train paths. The infrastructure will need new signalling systems, with computerized optimization of the traffic and the traffic flow, a system linked with the ATO, and to include Traffic Management, AI prediction of time and distance, i.e. providing optimal solutions in real time for immediate whole system benefits. This will drastically improve system flow and throughput and facilitating the blending of different types of trains, giving a much higher capacity of the present network.

**Passenger trains and Freight Wagons:** Increase the efficiency of future vehicles in terms of productivity and capacity. The vehicles need to communicate with each other and use ATO (Automated Train Operation) to optimize the operation and take a full advantage of novel signalling systems. There is also a need for improved braking performance, longer trains hauling much more cargo and trains using advanced technology; all to allow a higher utilization and lower cost per produced unit. Improve the overall capability and especially the carrying capacity of freight wagons.

**Freight Terminals:** Increase the capability, including capacity, handling and throughput, of freight terminals in time to take advantage of the enhanced infrastructure.

## TECHNOLOGY AND INNOVATION NEEDED

Reliable **Infrastructure Availability** is essential to railway operators and customers. The roadmap identifies specific technology and innovation needed to improve reliability:

- Intelligent infrastructure, equipped with a range of static and mobile, automated and autonomous sensors that are able to communicate with each other to provide a 'running commentary' on the infrastructure's current and predicted status
- Established and revised (as appropriate) 'degradation laws' that provide increasingly accurate actual and predicted states for railway assets
- Data and information protocols that enable users to design systems that are able to communicate with each other, exchanging and exploiting high quality data and information
- Intelligent and interactive planning support systems that are able to establish priorities and interface with operators and maintainers alike (and that provide Customer Information as appropriate)
- Expanded and capable 'off live system' test and commissioning facilities and 'dry run' installation rehearsal to minimise live system down-time during renewal / upgraded

The key technology and innovation need recognized to improve **Infrastructure Capability** is the requirement to remove / reduce the impact of level crossings on railway operations:

- Use of advanced train positioning technologies, coupled with intelligent and remote level crossing control systems, to guarantee safe passage of trains at permitted line speed
- Development and installation of intelligent 'fail-safe' systems that significantly reduce the risk to the general public, railway employees, local pedestrian and vehicular traffic
- Innovative ways to undertake behavioural analysis associated with level crossing duty cycles in order to maximise both rail and local (foot & vehicle) flow rates that optimise safety

Ahead of integrated and advanced traffic management systems and associated capabilities (e.g. closer running, dynamic block control, etc.) there is a need to model and predict train operations. A homogenous speed simulator (HSS) is required to ensure **Infrastructure Exploitation** associated with optimising operational capacity in a dynamic and repeatable manner.

Dynamic, real-time time-tabling to optimise **Train Paths** is seen as key to effective operations; where rolling stock duty cycles are maximised for service and revenue generation. An identified technological prerequisite is for train to train and train to 'ground' communications with innovative requirements for:

- Train to train communications in (near) real time and capable of exchanging appropriately secured train status information, especially in support of real-time timetable optimisation
- Train to track communication technology is (initially) equally important and needs to offer the opportunity for the train to report infrastructure status



Future technology and innovation, partly enabled through enhanced and guaranteed train to train communications, is needed to deliver:

- Real time traffic management and associated high resilience operations
- Smooth driving systems
- Convoying and dynamic coupling
- Fully autonomous operation

Increasing the amount of freight carried on the European Rail network is a key requirement with technology and innovation needed for both **Freight Wagons and Freight Terminals**:

- Implement, or associate with a globally integrated, freight booking service and associated freight management systems that is able to maximise duty cycles and minimise the running of empty freight wagons
- Develop IT and IS (and associated legal instruments) that are capable of authorising the international movement of freight with minimal certification within Europe
- Technology to improve the operational capability of freight wagons
- Innovation to expand the throughput of freight terminals, especially exploiting autonomous and intelligent freight handling systems

## VALUE

The value derived from improved capacity, performance and competitiveness comes through reduced (or avoided) costs, increased customer receipts and wider economic benefits. Recent examples include Eurostar, Thalys and TGV which have largely replaced air travel on key routes.

# ENERGY AND ENVIRONMENT

Every kWh generated or used earns real value with no detrimental impact on the environment



## IMPORTANCE

The European Railway has an important role to play in minimising its impact on the environment through managing its energy related emissions and securing continuity of supply in order to provide a reliable service, and in using available resources in a highly effective and efficient manner. A whole system approach is needed to energy management, including traction energy, which predominates, but also energy used for all the other railway functions. A whole-life view of assets, including the management of parts, materials recycling/disposal. must be considered

## CHALLENGES ADDRESSED

**Rolling Stock:** Increase the use of hybrid propulsion solutions incorporating energy storage systems to give aided operational range and flexibility and reduced dependence on diesel fuel along with increasing energy efficient, lighter trains with low-loss traction systems, plus increasing focus on 'emission hot spots' (e.g. idling diesels, unplanned stop / start).

**Infrastructure:** Introduce and then maximise benefit from managed electricity supply using SMART Grid technologies coupled with increasing the residence and variety of supply resources (e.g. main grid, local renewable, recovered, etc.) , with reduction of associated environmental impacts.

**Operations and Management:** Deliver advanced driving capability coupled to intelligent and adaptive traffic management systems to reduce energy consumption and increase energy efficiency, and that realise associated environmental benefits related with noise, vibrations and emissions.

**Support and Communication:** Implement of pan-European systems to report on energy and environmental metrics and co-operative approaches to tackling the issues of extreme weather and climate change.

## TECHNOLOGY AND INNOVATION NEEDED

**Rolling Stock** consumes a significant proportion of the energy used by the railway and needs to continuously improve its efficiency and effectiveness in converting effectively energy resources into traction and on-board services. The associated three key areas for technology and innovation identified are :

- Lighter Trains : the use of **mechatronic** systems, lighter materials and innovative approaches to weight reduction are envisaged

- Hybrid Traction: innovative technology applied to improving **diesel fuel** engines is required, along with the development and incorporation of hybrid energy solutions that maximise operational effectiveness. **Energy resources**, especially their resilience and availability for traction drive are a focus for innovation and in reducing the rolling stock contribution to environmental impact
- EE Auxiliaries: Technology and innovation to reduce energy consumption of on-board systems (heating, lighting, etc.) are needed.

**Infrastructure** covers energy distribution, energy generation and energy usage, especially at stations. Technology and innovation is required for:

- SMART Grid: Delivery of managed energy distribution systems that maximise efficiency and report, in a qualitative manner, are required in order to demonstrate effective energy usage thus a Pan-European approach to **SMART Grid** technology and innovation is envisaged.
- Advanced Traction Energy Supply: Sustained and efficient **Energy Supply** for rolling stock traction is critical for railway operations and innovative and technological advances in electrical energy distributions, development of higher voltage systems is anticipated, plus an increasing ability for regenerated energy to be returned to the grid.
- Non-Traction Energy: Innovative ways are required to support the belief that there is considerable potential for locally generated and renewable energy resources to be used to power local **non-traction** systems, especially at stations and terminals; further, excess energy could be used/sold for local consumption.

The key requirement for **Operations and Management** is to increase and steadily improve management of rolling stock, enabling it to be driven more efficiently and in an eco-friendly manner, specifically:

- Traffic Flow Management: Innovative ways for **energy reduction** and environmental impact through integrated traffic management
- Communications between TMS & DAS: Develop systems that increase the **energy efficiency** of driving through DAS supported driving and real time links with TMS

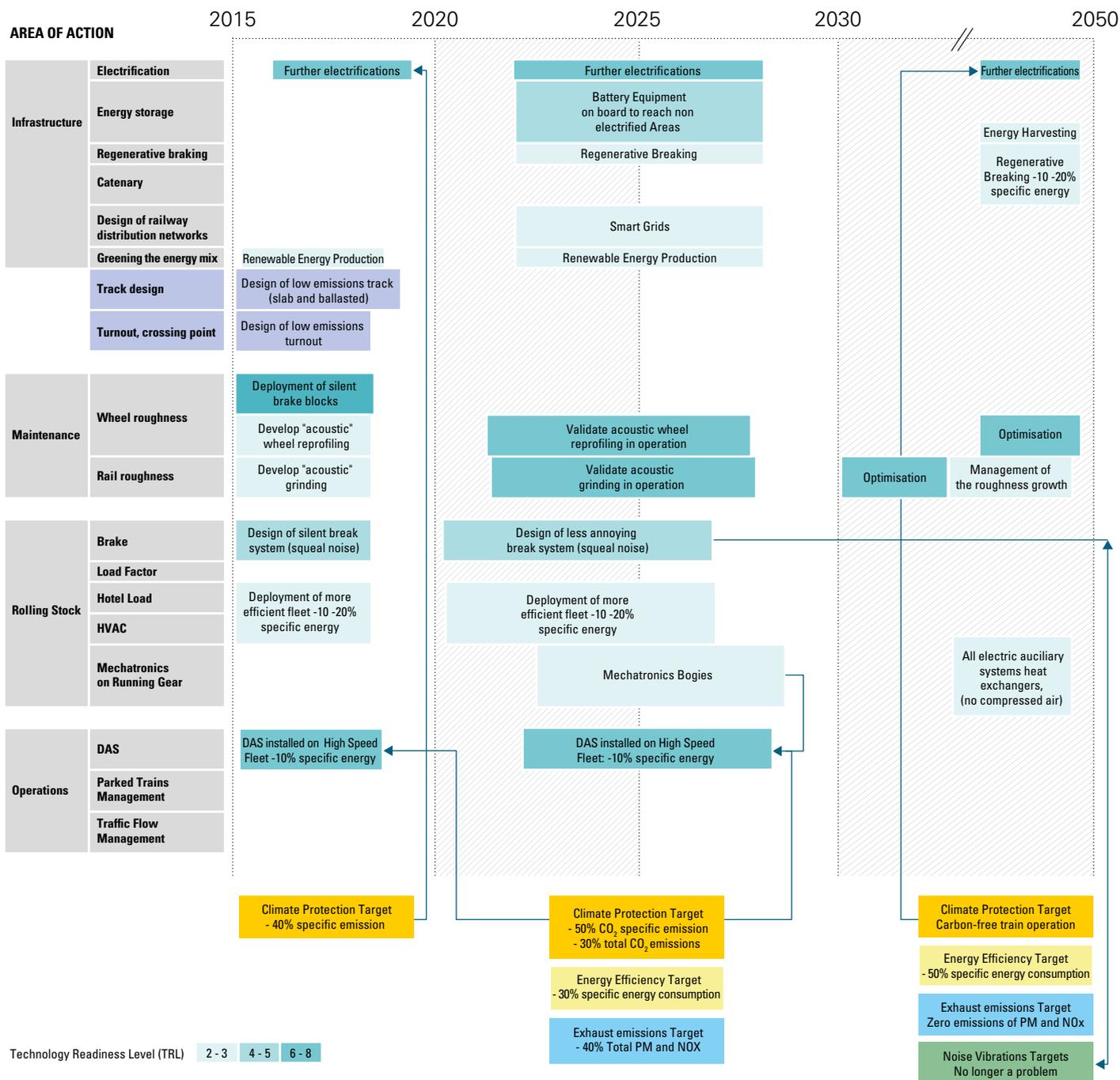
Three areas for technology and innovation have been identified to Energy and Efficiency **Support and Communication**:

- Noise and Vibration: There is a need to reduce **noise and vibration** levels across the railway and reduce associated impact on the environment. This is a pre-requisite for 24 hour operation
- Energy & Carbon reporting: The European railway needs to measure its energy efficiency and effectiveness in coherent and uniform ways to enable it to consider areas for action, as well as understanding its contribution to environmental issues
- Climate Change: Increased incident of weather extremes and climate change will impact the railway; technology and innovation is necessary to provide **climate resilience** and the ability to operate and recover from extreme weather related events. Technologies that protect infrastructure and trains from heat, water (rain, snow, ice, flood, etc.), and allowing a degree of end-to-end journey provision are sought

## VALUE

Traction energy for European railways costs EUR 5-19 billion so further improvements - beyond the halving already delivered between 1985 and 2011- would be very financially valuable. Enhancing rail's already sector leading environmental performance can help contribute to meeting global greenhouse gas emission reduction strategies – the target is 40% reduction from the 1990 level by 2050 – primarily via modal shift.

# Energy and Environment Roadmap



# SAFETY AND SECURITY

Keeping everyone safe and secure while they use, work for, or connect to the European Railway

## IMPORTANCE

Safety and Security are essential to the well-being of the European railway, its customers, employers and employees. Maintaining at least the current high level of safety and looking to make further improvements, is of European and national importance. Similarly, and as the railway carries increasing volumes of passenger and goods and uses IT based technologies, the railway must be capable of managing new and emerging security threats, especially related to cyber based threats and terrorism. This needs to be done for urban and mainline rail systems in a way that does not compromise the integrity of the end to end journey, which should be seamless, or impose undue barriers for users of the network.

## CHALLENGES ADDRESSED

**Safety:** Safety comes with an associated cost burden and maximising human and asset safety to appropriate 'cost sensible' degrees is a continuing theme, as is the development of innovative ways to mitigate safety risk and increase safety awareness. Eleven challenge areas have been identified where safety will benefit from the application of technology and innovation:

- **Replace personal judgment by clear pass-fail-criteria:** Provide a stricter more quantitative assessment of safety risk and associated decision making processes across Europe
- **Recognise assessment bodies instead of certification by accreditation scheme:** Enhance the process and not the procedure for safety accreditation and deliver appropriate levels of informed certification
- **Reduce time to market for Innovation:** Develop innovative approaches to understanding the safety impact and associated mitigation earlier in the modelling and product design phase
- **Replace cost and time-consuming field tests by simulation:** Increase the use of technology enabled simulation to assess safety of new products and services
- **Benefit safety procedures and methods by innovation:** Exploit information and intelligence obtainable from new and upgraded technologies to complement safety awareness
- **Re-Balance active versus passive safety:** Prepare and educate as opposed to prevent and respond; increase awareness of safety risks (active) to reduce the need for intervention and restriction (passive)
- **Adapt safety demonstrations accepted in other industries:** Engage with adjacent and other industries to share best practice, and deliver commensurate abilities to adopt / adapt such novel (to the railway) safety approaches (i.e. benchmarking)
- **Improve Reliability, Availability and Maintainability (RAM) aspects in the context of safety:** Look to technology and innovation to address and improve safety challenges, along with increasing the awareness of the safety benefit possible with improving RAM

- **Safeguard digitalised and automated operations:** Reduce safety risks associated with increased digitalisation and automatic operation of systems
- **Increase cross modal safety:** Increase safety of the end-to-end journey, especially at modal interchange, by working with other operators and service providers
- **Reduce personal accidents:** Address the continuing sources of highest safety risk to rail staff and other users – slips, trips and falls: Look for new materials and other solutions to reduce further this persistent risk area



**Security:** The European railway faces a range of security threats; from simple passenger misbehaviour to serious international incidents. These threats are constantly changing and evolving, with new threats emerging without warning. The use of technology and innovative approaches is needed to assist in keeping the railway secure against current and future security threats. Two key challenge themes have been identified:

- **Increase Protection:** Increase the use of new and novel technology to improve physical security of passengers and assets; improve procedural security to plan and manage security threats; improve security to prevent of the need for intrusion; and coherent and constantly improving cyber security commensurate with the threat and in-line with the deployment of digital technologies
- **Increase Resilience:** Increase the use of new and novel technologies to limit the amount of damage and impact of a security incident; increase the speed and ability to deploy fall-back levels; improve cooperation, communication and emergency management processes and procedures along with rapid recovery management which is able to return the railway to normal operation in quick time

## TECHNOLOGY AND INNOVATION NEEDED

In terms of **Safety** the key technology and innovation needs identified are aligned to ten themes:

- **Replacement of personal judgment by clear pass-fail-criteria:** Develop objective criteria for pass-fail - technical issues and associated processes and transparency needed
- **Recognition of assessment bodies instead of certification by accreditation scheme:** Establish and promote recognition criteria
- **Time to market for Innovation:** Develop novel technological and innovative ways to reduce unjustified barriers to innovation; especially with respect of innovative tools for big data and data analytics
- **Replacement of cost and time consuming field tests by simulation:** Provide standards for cross-industry acceptance of simulation tools and generally improve the applicability of risk-based safety approaches
- **Safety procedures and methods should benefit from innovation:** Innovative ways of technology screening in order to discover potential novel safety related opportunities and delivery of associated and supporting transparency and regulation, with particular attention to human factors (HF)
- **Re-Balancing active versus passive safety:** Technology is needed to reduce passive safety provisions and compensate by innovative active safety contributions (e.g. improved educational approaches)
- **Adaptation of safety demonstrations accepted in other industries:** Innovative ways to Initially benchmark and then look to reduce railway unique / specific safety standards by adapting common industry standards for safety

- **Improving Reliability, Availability and Maintainability (RAM) aspects in the context of safety:** Research is needed on safety contributions from RAM in a wider scope than technical safety, and especially research in to human machine (HMI) and organizational interface under the RAM framework
- **Digitalisation, automation and autonomous operation:** Technology and innovation to assess safety relevant impacts of automation and autonomous operation and then to determine if/how the legal framework has to be improved in order to support the new challenges
- **Cross modal safety:** Innovative ways to develop a safety approach along the entire end-to-end journey and freight logistic chain with associated development of legal frameworks and standardisation

The European Railway faces an increasing variety and intensity of Security threats and looks to technology and innovation to deliver new and improved ways to protect passengers, staff and railway assets:

- **Physical Security:** Innovation in identification of change of state or location of components and/or assets, technology to support biometric identification and verification without violation of personal rights for the purpose of improving customer, staff and freight, freight security
- **Procedural Security:** Innovation to maximize staff capability in managing and improving security by using novel technologies; innovation to reduce the impact of security related activities (e.g. search) especially relating to use of automation and novel ways to identify security critical situations offered by new and upgraded operational IT systems
- **Perceived Security:** Innovative ways to deliver the perception of security to the railway user that are not especially obtrusive or covert and to improve technical approaches to security, especially the role the media industry is able to play in security awareness throughout the end-to-end journeys
- **Cyber Security:** Technology and innovation are needed to analyse the potential of risk based security versus rule based security with the aim to improve railway network architectures in terms of security. Similarly there is a need to understand the security requirements for hybrid IT networks (shared versus self-sustaining networks), especially encryption methods and associated management (securing data in open networks). There is an implicit need to understand the risks of using open source software and to search for novel and emerging technologies to improve data interfaces in terms of security, ability to detect anomalies and the ability to manage threats to security (big data and data analytics). The architecture of embedded networks should be a particular focus. Increasingly intelligent and novel processes and applications to predict of security threats, especially regarding future communication platform 5G, are needed.



To support the improvements in Security there will be a need to **Increase Resilience** as well:

- **Limitation of damage and impact:** There is a need for innovative self-sustaining railway cyber networks (possibly using parallel network approaches) in addition to relying on the public internet for secured systems for safety, control, M2M, maintenance. Also included is the need for business continuity management (BCM) methods, procedures and algorithms to safe-guard vital functions by intentionally dropping non-vital functions and associated hardware.
- **Fall-back level:** Innovative ways to deliver economic and security improvements associated with fall-back systems
- **Emergency Management:** Technology is needed to improve response time and associated capability to limit the consequences of a physical or virtual attack on railway or adjoining systems
- **Recovery Management:** Innovative approaches and associated novel technologies are needed speed up the time taken to recover railway operation and restart crucial business processes after a major incident

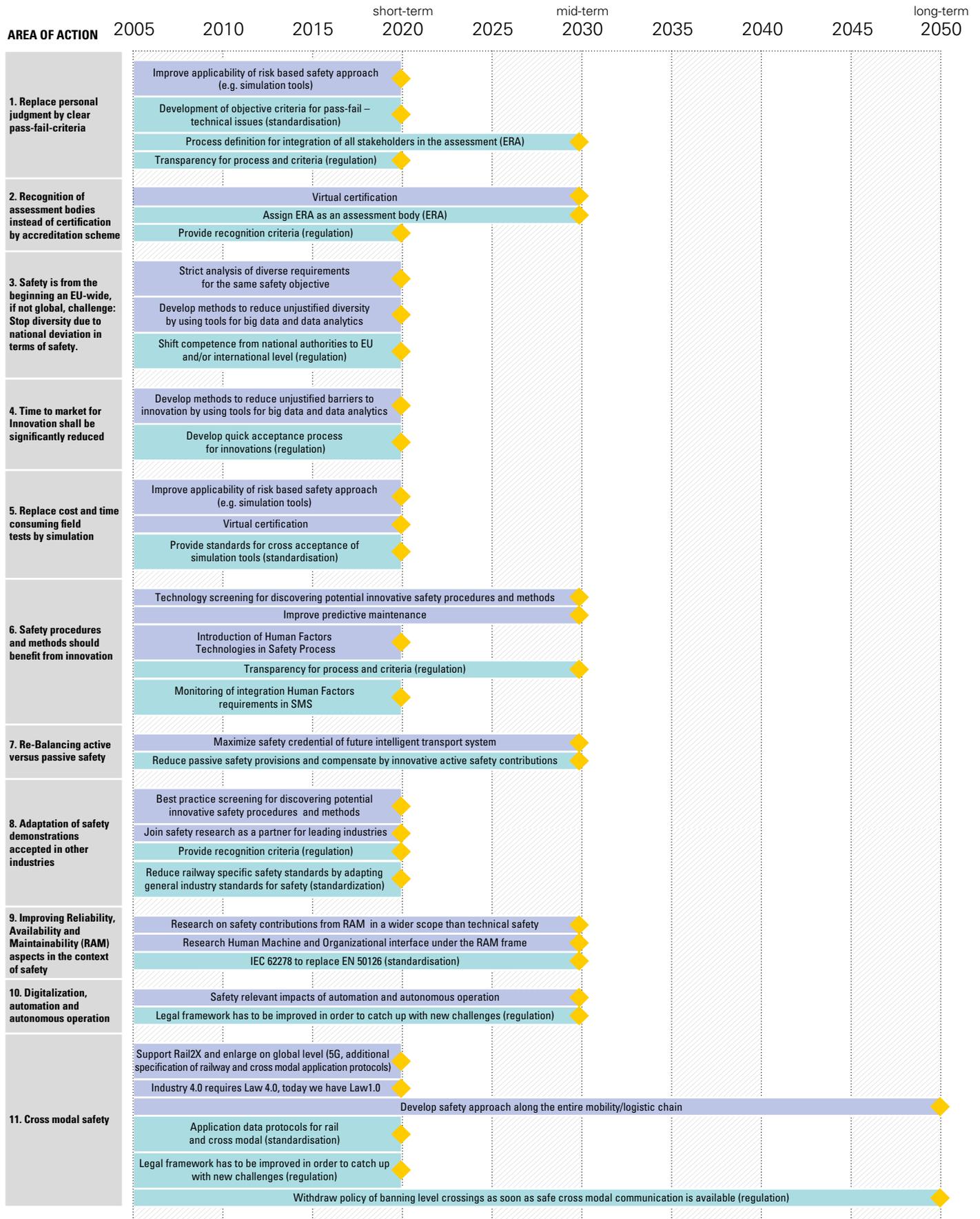


## VALUE

Innovation to improve safety, coupled with current strategies, has the potential to make significant reductions in the average (over recent years) of 40-45 passenger fatalities and the far larger number of serious and minor injuries occurring on Europe's railways each year, and to improve the protection of railway staff.

Security risk reduction, and increased protection and resilience, by preventing even a single major incident and perhaps many smaller scale security events, would have immense value to railway customers and staff and to wider society.

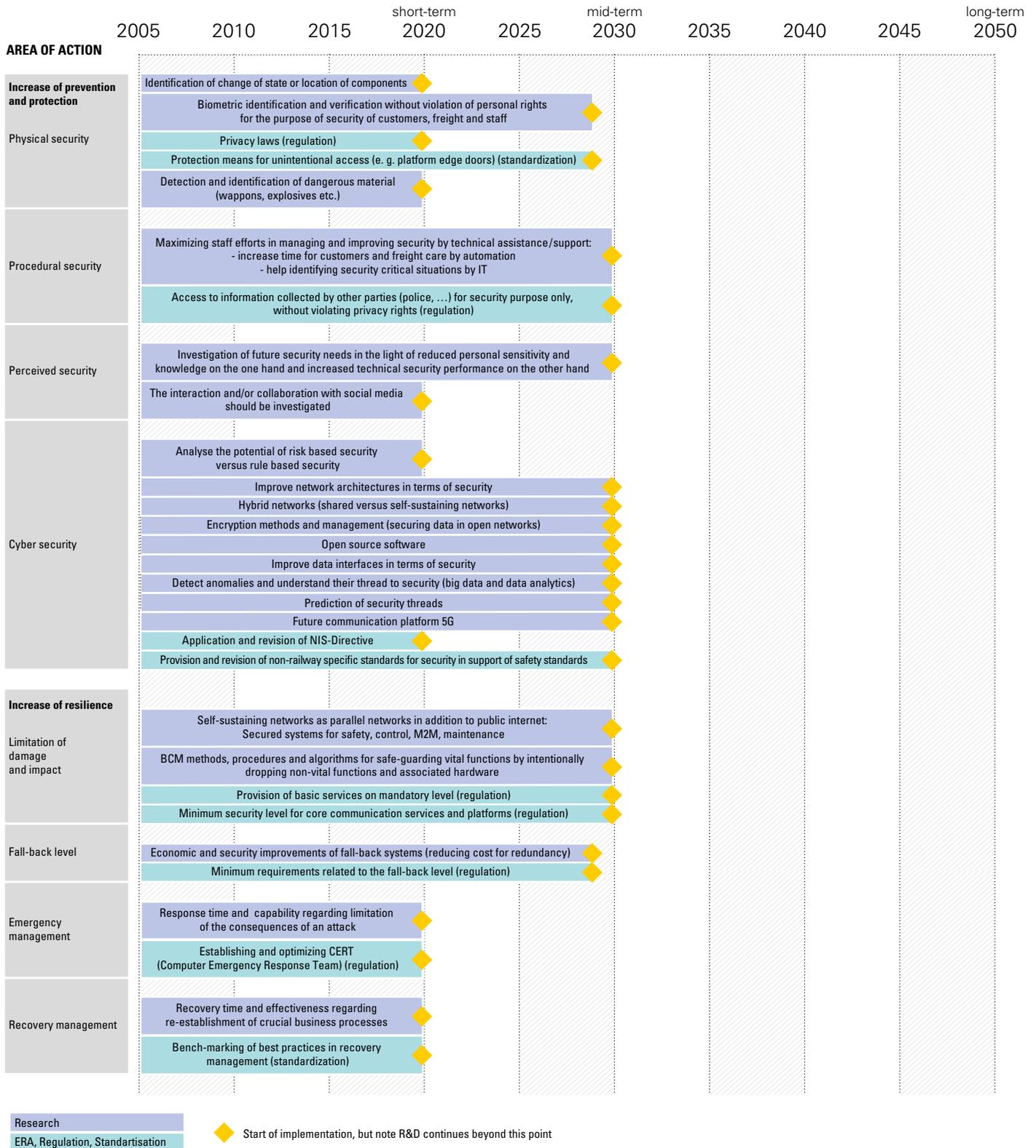
# Safety Roadmap



Research  
ERA, Regulation, Standardisation

◆ Start of implementation, but note R&D continues beyond this point

# Security Roadmap







4

# ASSETS

# CONTROL, COMMAND AND COMMUNICATION

## Precise control, flexible command and connected communications across the whole European Rail Network

### IMPORTANCE

Control, command and communication (CCC) systems are pivotal to increasing efficiency and safety of transport networks and associated operations; flexible CCC delivers the capability for the train operators to deliver excellent customer service with variable demand in a cost effective manner. New digital technology (including as developed for 5G) is anticipated to enable the safe introduction of a new concept of operation, based on trains running much closer together, and more automation of train operation. This could form the basis of a fundamental shift in the economics of railway businesses.

### CHALLENGES ADDRESSED

**Real Time Traffic Management:** Modernise traffic management systems to take advantage of new and emerging technologies: moving from fixed block to electronic block to no-block control; enable very close running (convoying) by 'virtual coupling' of trains; exploit the increase to operational capacity and associated flexibility in service provision to make the most of the existing infrastructure. Move beyond the current ERTMS capabilities towards fully automatic train operation.

**Integration:** Support a modular approach to develop, build and integrate CCC capability under an overarching systems perspective. Base this on open functional based architecture to avoid being bound to proprietary systems and obsolescence resulting from technology developments

**Security:** Provide dynamic security systems that continuously provide appropriate levels of physical and cyber security for the operator and customer alike and responsive to new, emerging and hypothetical threats

**Resilience:** Increase the resilience of the primary CCC systems to all forms of unplanned incident and fast reacting secondary systems able to seamlessly take over and maintain service levels while the primary system is restored

### TECHNOLOGY AND INNOVATION NEEDED

Technology and innovation is needed to deliver systematic improvements to allow **Real Time Traffic Management Systems** to fulfil their potential. Priority areas include:

- Autonomous train control
- Train location and integrity
- Smart driving (e.g. environmentally aware; ECO driving)
- Reducing operational costs

A significant focus for Real Time Traffic Management is its contribution to increasing the operational capacity of the European Railway and technologies are required to provide :

- Capability to manage traffic flow in real time
- Driver Awareness Systems (DAS), especially with regard to 'future signal' information
- Increase the ability of train operation to be independent of track-based systems

Rapid and cost effective, effortless, **Integration** of CCC systems is a key requirement and affordability of technology and innovation is a significant driver. Identified needs include :

- Modular CCC systems, with attention to off-train qualification and testing that enables speedy and simple system upgrade
- Robust and cost effective standard design, test, installation and maintenance of signalling infrastructures (Development Priority)

Another key area associated with Integration is interoperability;

- CCC systems need to have pan-European interoperability, guaranteed through specification, test and acceptance practices.
- Key on-board systems (e.g. on-board IT) will need to balance autonomy with interoperability of associated track-side systems.
- Rolling stock braking systems (especially freight) are to be designed to allow new train consists to operate safely, whatever their composition.

It is important that CCC systems continue to meet the required levels of **Security** and maintain trouble free operations in the face of changing and evolving threats. The key technology and innovation requirements identified are in :

- Communications security: especially increased GSM-R security without compromising safety or operations
- Cyber security; commensurate with cross-European and common signalling languages as well as securing increased networked connectivity of disparate systems

The European railway will need to become increasingly resilient against existing and new operational risks and threats. Innovative approaches to improve **Resilience** and speed up incident recovery time are anticipated and may be addressed through :

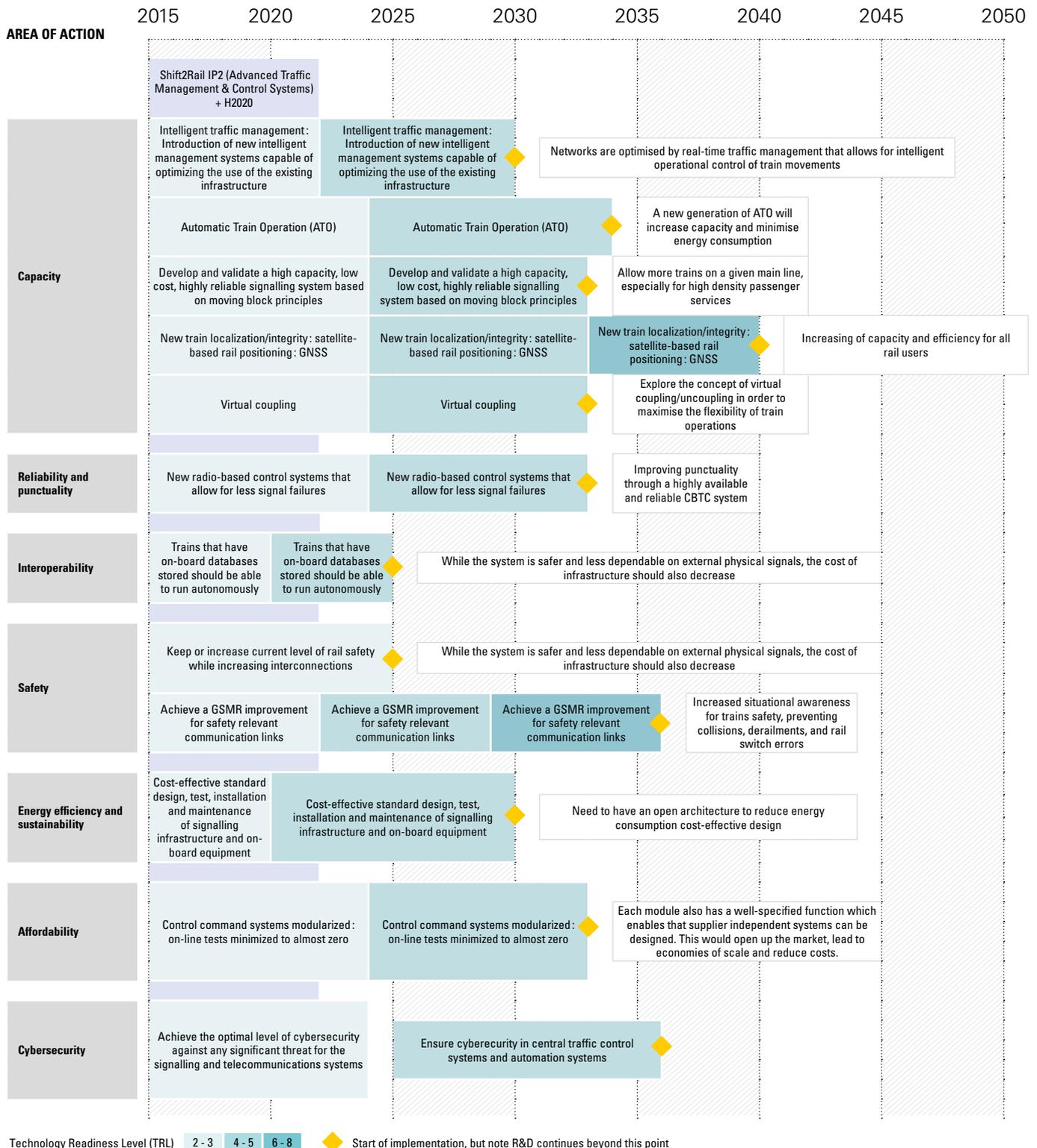
- Enhanced whole life asset cost and associated availability and maintainability using innovative and modular approach to system design
- Driver Advisory (Assist) Systems (DAS) used to reduce the risk of control induced failures
- Increased integration of CCC systems to deliver graceful degradation & operational redundancy to allow operators to deliver acceptable services in spite of unplanned incidents

## VALUE

The primary value derives from creating and using additional operational capacity within the existing railway network. The value of doubling operational capacity across Europe, assuming 50% take up of that additional capacity, is estimated at EUR 22 billion in revenue (based on 2012). Also the high cost of providing additional infrastructure will have been avoided.



# Control, Command and Communication Roadmap



Technology Readiness Level (TRL) 2-3 4-5 6-8 ◆ Start of implementation, but note R&D continues beyond this point

# INFRASTRUCTURE

Intelligent infrastructure that predicts and reports its status, along with automatic or autonomous maintenance that does not impact Customer Services



## IMPORTANCE

The railway cannot deliver cost sensible services without a reliable, resilient and cost effective infrastructure. Creating new and maintaining existing infrastructure is the largest investment - and cost - for the European railway. It is important that technology and innovation deliver opportunities to reduce the cost associated with infrastructure while at the same time increasing its availability and the ability to meet service demand.

## CHALLENGES ADDRESSED

**Construction and Maintenance of Infrastructure:** Technological and innovative approaches to building and maintaining the railway infrastructure will become increasingly important in order to make the railway resilient to changing requirements, enabling affordable construction and maintenance along with ease of update and introduction on new ways of working and flexibility to meet emerging and growing markets. In the near term innovation is needed to meet challenges associated with track forms, switches and crossings and novel low-carbon footprint long life materials. Existing rail infrastructure needs to have intelligent monitoring to prevent costly failure and to support predictive maintenance.

**Infrastructure based supporting systems and service:** There are three key areas to be addressed to deliver continuous improvement to the reliability, availability and maintainability of the European railway:

- **Reliable and Resilient Infrastructure:** A novel and pan-European approach to improve reliability of assets and service, with the persistent aim to improve maintenance planning and reduce the number of unplanned events/incidents along with improved recovery of the system after planned and unplanned activities.
- **Intelligent Infrastructure:** Deploy assets and sensors with increasing amounts of intelligence, able to self-learn as well as provide concise and considered intelligence on current and predicted future state. The challenge is to allow incidents to be managed before they happen.
- **Situational Awareness:** In order to prevent costly failure and to support predictive maintenance it is important to analyse in real and near real time the data, information and intelligence being provided to support operational and maintenance decision making, especially with regards to incident information, security, safety and planned interventions.

**Governance, management and finance of the infrastructure:** Railway infrastructure is a cooperative and complex suite of interacting systems within an even larger and inherently more complex transport domain. Being able to manage it effectively and in a cost efficient manner is essential:

- **Optimise Performance:** Increase infrastructure systems ability to work together and with adjacent systems (e.g. modal exchange systems) in a seamless and intelligent manner, especially with regard to supply of high quality and timely data for operational decision making. This raises the challenge for innovative modelling tools, whole-system approaches to life cycle and modularisation, and increased ability to manage weather extremes and climate change.
- **Whole Journey Connectivity:** The railway is a key part of international end-to-end journeys for passengers and freight; and it needs to provide a high quality and desirable alternative to short and medium distance air travel as well as seamless modal interchangeability, without unnecessary delay and minimum regulation.
- **Freight Access:** The key challenge for freight is to make it increasingly easy for freight operators to access increasingly capacious freight (and passenger) terminals and then see their freight loaded, moved and unloaded swiftly using automated processes, along with an increase in the ability to move freight across international borders on environmentally friendly and fast freight trains that deliver into multi-modal logistic chains.

## TECHNOLOGY AND INNOVATION NEEDED

Financial and social drivers require the rail industry to look to new and novel ways to **construct and maintain infrastructure**. This requires the industry to seek new and emerging technologies and innovation associated with:

- Novel materials, exploiting the potential of, for example, low carbon footprint materials, emerging materials (e.g. graphene, foam metal) and the increased use of recycled materials
- Adoption of new processes and technologies such as nanotechnology, biotechnology
- Modularisation of infrastructure assets and components
- Increased use of Building Information Management (BIM)
- Effective monitoring, and automation of rapid maintenance processes
- Improved understanding of infrastructure failures, leading to reduction in asset whole life cost
- New knowledge in Rolling Contact fatigue and other defects in the rail head such as rail corrugations
- New switch and crossings principles, more reliable, quiet and that allow higher speeds

There needs to be an increasing focus on ensuring the railway infrastructure is able to meet emerging and future challenges, such as climate change, extreme weather events, new freight gauges, new control and command traffic management systems and especially is able to take advantage of new communication technologies.

As demand for railway services increases ahead of the ability to build new track, so the railway will look to technology and innovation to provide the ability to maximise operational capacity (i.e. all-day operation) and will need increasingly sophisticated, intelligent and connected **Infrastructure based supporting systems and services** aimed at:

- Providing a **Reliable and Resilient** infrastructure where remote condition monitoring, condition and risk based maintenance are the norm and supported by coherent and cooperative maintenance planning. Infrastructure systems need to be highly and predictably reliable and resilient, able to offer graceful degradation and rapid recovery to normal service if impacted by an unplanned incident.

- Developing sensor technology and associated semantic algorithms to exploit an increasing amount of usable intelligence ‘moving’ around infrastructure systems in real time. This, coupled with a robust system framework, will lead to an increasingly **Intelligent Infrastructure** able to monitor, manage and in some cases self-repair itself.
- Increasingly sophisticated and connected sensors and integration with on-board train systems are likely to facilitate a quantum leap in **Situational Awareness** to be exploited by automated and operational decision processes. Technology is needed to assess emerging situations and novel and innovative interventions applied before criticality is reached, furthermore, elements of the information can be passed to customer systems and used to inform and guide passengers (and freight).
- Instrumentation for new inspection technologies, remote monitoring and health assessment of tunnels, embankments and bridges. Portable on-board monitoring systems connecting infrastructure data and vehicle performance.



A feature of future support systems will be their ability to dynamically optimise the railway and provide operator flexibility as well as increasing levels of satisfaction for railway operating companies and other customers.

Improved and enhanced **Governance, management and finance of the infrastructure**, commensurate with the implementation of new technologies and innovation in building, maintaining and operating the railway is needed. Further, in the European context these will need to be coherent across national boundaries so as to maximise the opportunity for seamless end-to-end journeys. Although cost driven, there will be a persistent need to deliver high quality, flexible and improving range of railway services. Technology and innovation both have a key role to play in being able to balance cost and service expectations:

Specific technical innovations for infrastructure will include:

Materials:

- Resilient materials for use in track forms
- Self-healing nanotechnology based materials for use in structures
- Life-extending waterproofing materials for masonry

Inspection methodologies:

- Trackside systems for remote condition monitoring
- The application of SONAR, LIDAR, hyperspectral and ultrasonic techniques
- Inspection by robots, UAVs, hybrid air vehicles and satellites
- Use of service trains for regular inspection
- Improved algorithms for predictive analysis and timely intervention

New infrastructure design:

- New user-centric crossing designs
- Novel simplified switch and crossing designs to capitalise on the development of mechatronic bogies

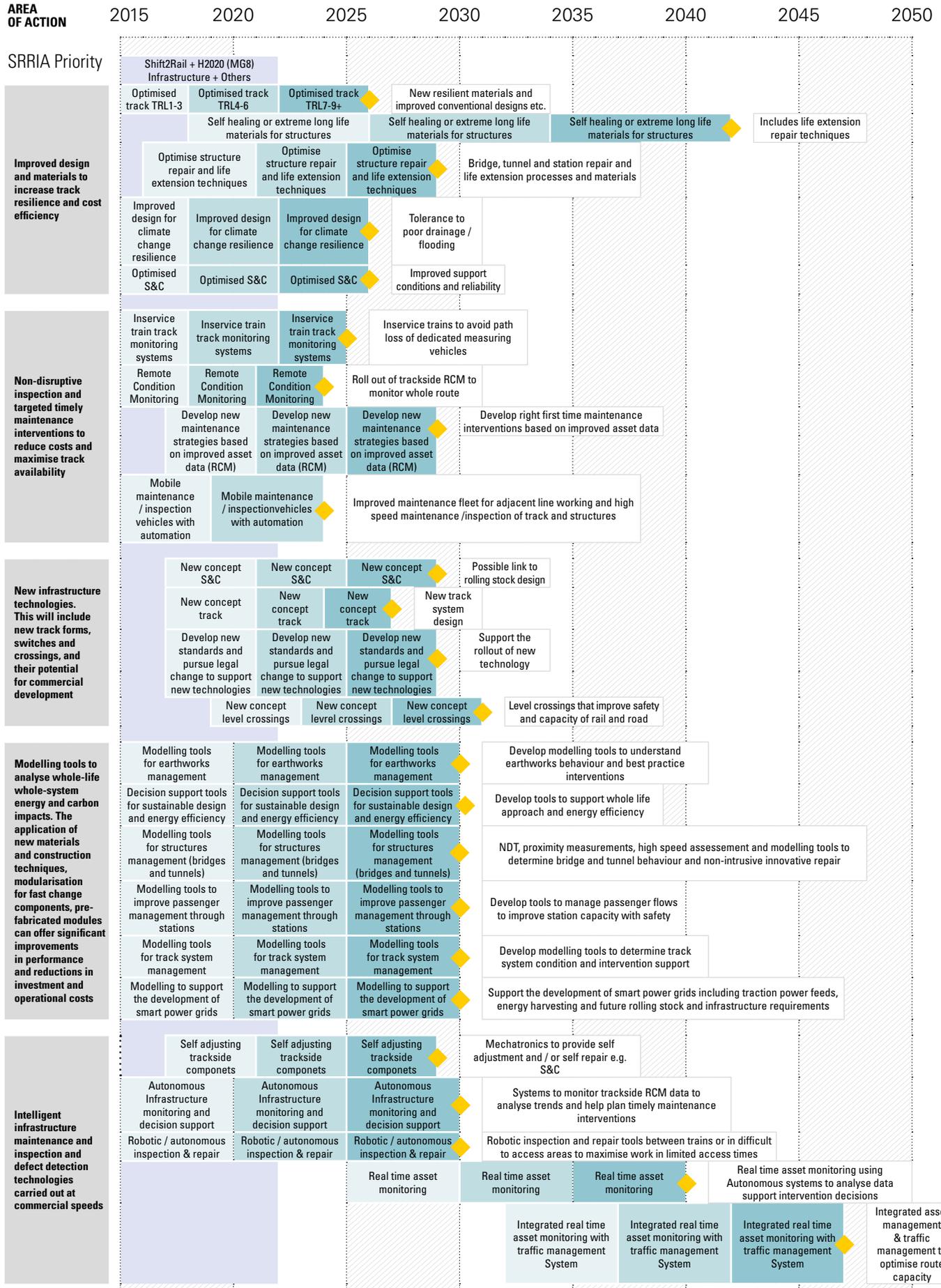
- Modelling tools to support the understanding of a range of physical processes and the potential outcomes and business impacts of interventions – earthworks behaviour, bridge and tunnel behaviour, track system response to loadings, S&C response to weather, energy systems, power grids and energy harvesting, passenger flow at stations, whole system effects.
- Novel track maintenance methodologies including mechatronics.

## VALUE

Reduction in lineside equipment based on more in-cab signalling, coupled with benefits from deploying and exploiting 'intelligent infrastructure' are likely to result in significant operational and capital cost savings. For instance, halving of infrastructure maintenance costs (operational) by 2040 would save EUR 12 billion per year and renewals / replacement costs by 75% (EUR 9 billion per year).



# Infrastructure Roadmap



Technology Readiness Level (TRL) 1 - 3 4 - 6 7 - 9+ Start of implementation, but note R&D continues beyond this point

# ROLLING STOCK

## Intelligent rolling stock actively manages itself to deliver efficient and cost effective performance

### IMPORTANCE

The capability and comfort of rolling stock is probably the largest factor associated with the customer's experience; passengers look for ease of access, comfortable and plentiful seating in a pleasant service driven environment. Freight operators require cost effective capacity, easy handling of freight on and off trains, plus fast transit between terminals.

### CHALLENGES ADDRESSED

**Comfort and Connectivity:** A key challenge is to offer and deliver more capacious and comfortable passenger rolling stock and maintain its attractiveness through its whole life, with associated performance enhancements such as braking, coupling and passenger access.

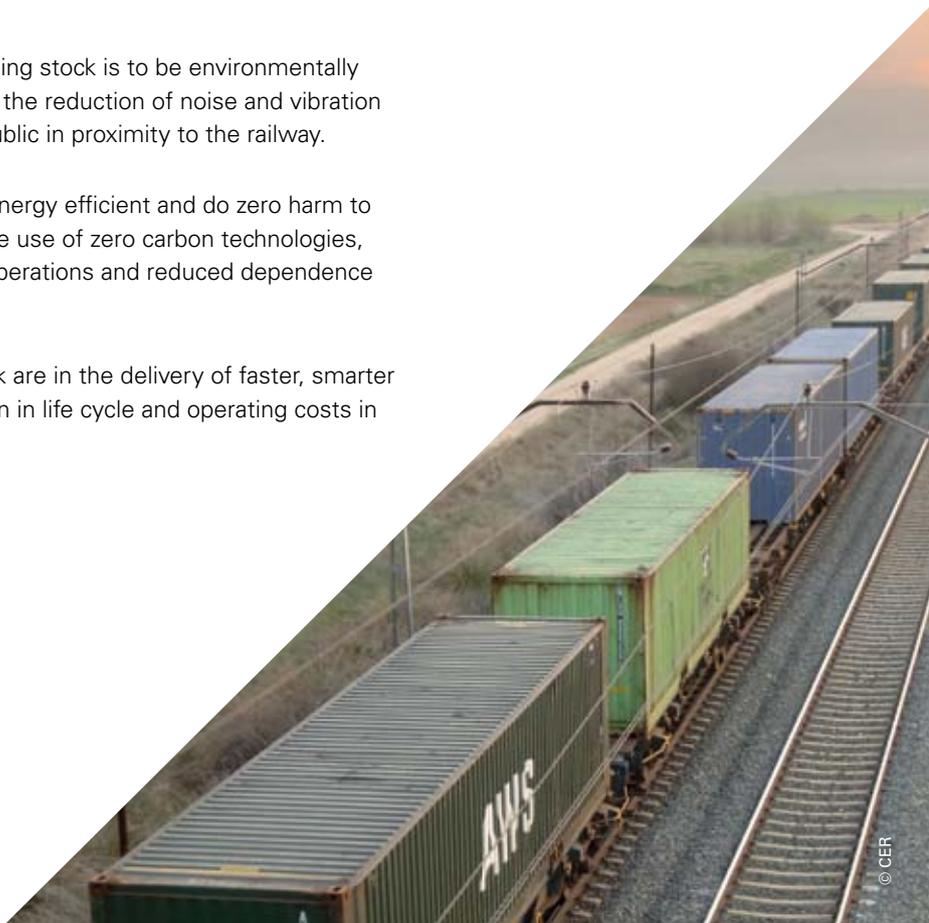
**Value for Money:** Promote common rolling stock standards and design elements to encourage a greater and more competitive supply chain, in order to speed up and generally enable the implementation of new passenger and freight rolling stock solutions. The drivers are mass reduction, capacity enhancement and track friendliness, and overall reduction in the whole life cost of acquisitions, operations and maintenance.

**Reliable Service:** Increase the availability and reliability of rolling stock, utilising new and emerging technologies that have minimal need for maintenance and the potential for rapid upgrade through increased use of common and interchangeable sub-systems and modules.

**Travelling Environment:** The new and modified rolling stock is to be environmentally friendly, with associated challenges to contribute to the reduction of noise and vibration for both passengers (and freight) and the general public in proximity to the railway.

**Eco-Friendly:** Rolling stock has to be increasingly energy efficient and do zero harm to the environment which may be achieved through the use of zero carbon technologies, recyclable materials, optimised & energy efficient operations and reduced dependence on high particulate fuels.

**Freight:** The key challenges for Freight Rolling Stock are in the delivery of faster, smarter wagons and more capacity with significant reduction in life cycle and operating costs in order to make rail freight competitive and attractive.



## TECHNOLOGY AND INNOVATION NEEDED

- For passenger transport, technology and innovation are needed to address Comfort and Connectivity of rolling stock with particular attention to : modern design tools, new materials and lighter structures for comfortable, spacious and configurable interiors that enable trains to service a range of passenger and journey types, new innovative subsystems for better acoustic performance and comfort aiming at improving the attractiveness of the interiors, improved connectivity enabled by improved operational performance (e.g. smooth acceleration and braking), the ability to load and offload passengers at transit stations and to prepare the train for another journey at terminal stations (i.e. dwell time management).
- All rolling stock will need to be increasingly cost effective to acquire, operate and maintain in order to deliver continuing improvements in **Value for Money**. Important targets for technological and innovative approaches are to:
  - Increase the competitiveness of the European rolling stock supply chain through the implementation of innovative “zero maintenance” products and solutions
  - Increase the range of common and modular sub-systems and equipment through standard system architectures
  - Introduce innovative track friendly rolling stock that is able to reduce the impact of the track-train interface and thus reduce operational and maintenance costs for both rolling stock and infrastructure

Particular attention will be given to reducing the whole life cycle cost of rolling stock and associated assets through :

- Hybrid Traction : multiple power sources (e.g. battery, on-board electrical generation)
- Intelligent management of EE auxiliaries
- Integration of future power semi-conductors
- Innovative power generation and drive systems (e.g. hydrogen powered)
- Increasing energy efficient and loss-less systems, especially associated with HVAC
- Simpler and more agile qualification and certification processes to support rapid design, prototyping and testing facilities
- Mass optimisation, balancing the need for vehicle strength and robustness in mass efficient manners

Providing an increasingly **Reliable Service** requires continuous improvements to efficiency, maintainability and availability, all delivered with appropriate levels of safety and security :

- Exceptional reliability is deliverable through a combination of technological factors : highly reliable components in a well-structured ‘low stressed’ system (i.e. one that operates well within design parameters), plus the ability to easily upgrade as new and better components become available.
- Low cost maintainability can be achieved by removing the need for maintenance ; reducing unplanned failures and fault conditions through use of intelligent sensing and increasingly accurate current and predicted future asset state conditions allowing ‘repair by replacement ahead of failure’. (e.g. remote condition monitoring (RCM), risk based maintenance, on-condition maintenance).



- Technology and innovation is needed to increase availability, without the need for increased assets and spares tying up valuable capital; better planning of asset cycles, in part enabled by RCM and on-board health and usage monitoring systems (HUMS) is seen as a key driver.
- The main area for technology and innovation identified for rolling stock safety and security is the continued need to prevent train derailment, collisions and to mitigate associated effects, especially noting the potential advances in traffic management (i.e. closer running), increased density of trains on some routes and the current challenges associated with level crossings.

The main need associated with the **Travelling Environment** is to reduce noise and vibration, both acoustic noise inside passenger compartments and aerodynamic noise, especially trains transiting stations at high speed. Reduction of on-board vibration levels and the associated impact of vibration on people and equipment is also a key technology and innovation need.

There is an ongoing requirement for rolling stock to be **Eco-Friendly**, in design, build and operation. This can be achieved by:

- Increased use and development of eco-friendly specifications and improved performance
- Harmonisation of standards and associated eco-driven policies
- Common and quantifiable 'Eco-Design' certification

Technology and associated innovation is needed to deliver new solutions for cost efficient freight rolling stock designs with improved capacity and optimised weight and suitable functionalities for different types of freight. Specific attention is required in:

- Cost effective methods for assembling and managing longer trains
- New transshipment technologies and operational concepts for low cost terminals
- Faster flexible freight trains performing like passenger trains (especially operation and speed)
- Automatic coupling and decoupling
- New traction and braking management for improved performance
- Urban light freight services; carriage and delivery
- Automatic identification, location and cargo monitoring

## VALUE

Rolling stock typically represents about 15% of the cost base of rail operations, so about EUR 16 billion per year across Europe. A 15-30% saving in whole life cost, based on technical innovation and new operational patterns, could be worth up to EUR 100 billion. More efficient and attractive rolling stock would also increase the competitive position of the European rolling stock manufacturing industry.

# Rolling Stock Roadmap

AREA OF ACTION	2015	2020	2025	2030	2035	2040	2045	2050
<b>Offering more spacious travelling environment for passengers</b>	Adaptive interiors configuration for different types of passengers (family activities, mobile office and group travel) and constant evolution (time scale of week, season and society) of the demand							
	Improvement of interior acoustic comfort for passengers							
<b>Increasing vehicle operational reliability</b>	New more reliable components and technologies							
	More reliable architectures for key sub-systems							
	PHM (prognostic and health management) system Research in condition-based maintenance regimes							
<b>Improving vehicle performance</b>	Advanced braking							
	Flexible coupling between consists							
	Better accessibility to reduce dwell times							
<b>Reducing vehicle life cycle costs</b>	Hybrid Traction: Multiple power sources including energy storage on-board							
	EE Auxiliaries - Optimisation and development of intelligent management auxiliaries							
	Future generation of power semi-conductors beyond SiC (Silicon carbide) e.g. diamond							
	Innovative Propulsion - Implementation of hydrogen fuel cell of RAMS/LCC incl. the aspect of hydrogen production & storage							
<b>Environmentally friendly rolling stock with special emphasis in the reduction of the emission of noise and vibrations and mitigation of their impact</b>	Energy and Environment - environmental friendly and energy efficient HVAC							
	Improved prediction methods and design solutions to reduce aero acoustics noise of high speed trains Reduction of N&V annoyance towards exterior							
<b>New paradigms for cost efficient freight rolling stock designs with improved capacity and optimised weight and suitable functionalities for different types of freight.</b>	General wagon issues - Modern wagon concepts with low noise, track friendly and more reliable bogies. Increased speed capability with no increased track attrition. Incentivisation of track friendly equipment							
	Freight and Urban Mobility: Interfaces and complementarities: New techniques and vehicles for urban freight delivery							
<b>Urban, suburban and regional</b>	Competitiveness and enabling technologies - innovative constituents increasing RAMS whilst decreasing LCC							
	Competitiveness and enabling technologies - Tram-train							
	Competitiveness and enabling technologies - Innovative design, devices and constituents Research in condition-based maintenance regimes							
<b>Adapting/revisiting RS standards and norms to increase the competitiveness of the railway transport system</b>	Energy and Environment - Eco-procurement specifications and harmonisation							
	Eco-design label for rolling stock - Based on key criteria covering significant environmental aspects: Energy-CO <sub>2</sub> , Materials, Noise							
	Pursuing virtualization of certification/homologation							
<b>Improving safety and security</b>	Safety - Train collisions preventions and effects mitigation (active and passive safety)							
	Safety - Enhanced vehicle preventive maintenance							

# IT AND OTHER ENABLING TECHNOLOGIES

Federated IT across the European Union delivers timely data and information enabling a quantum change in overall operational efficiency and service delivery

## IMPORTANCE

Improving the passenger and freight end-to-end journey experience requires a step change in the speed, efficiency, quality and exploitation of data and information by European railways. IT and other enabling technologies provide a huge opportunity to raise service quality but will also be used by the railway's competitors, so are critical to its future attractiveness and success.

## CHALLENGES ADDRESSED

**Freight:** Integrate freight IT systems to provide live tracking and monitoring of freight status and position, supplying the information and intelligence to the supply chain

**Passenger:** Provide real time access, through push and pull technologies, to an increasing range of general, bespoke and personal services aimed at informing and entertaining the passenger before, during and after their end-to-end journey

**Mainline:** Exploit 'big data' and associated data and information flows, especially relating to asset and service status

**Urban Mobility:** Use IT and other technologies to reduce the stress of urban journeys

**Urban, Suburban and Regional Rail:** Optimise and homogenise (big) data flows between types of rail sector services to improve interoperability and modal interconnectivity with adjacent transport providers

**Safety and Security:** Ensure that IT systems are designed to meet safety needs and able to stay ahead of security risks, especially cyber threats

**Strengthening Competitiveness:** Exploit real and near real time customer data and intelligence to improve and increase services offered



## TECHNOLOGY AND INNOVATION NEEDED

Central to the IT enhancement of the railway is the Connected Train – featuring data exchange for operational, engineering and customer service purposes - train to trackside data connectivity. This will be based on ubiquitous wi-fi and mobile coverage.

Key IT technology and innovation needed for **Freight** is associated with providing increased and automated generation of operator and customer management services :

- Increasingly intelligent freight management systems
- Faster implementation of low-cost freight solutions
- Increased automation of freight handling enabled through accurate situational awareness of where freight is and where it needs to go
- Improved logistic services, exploiting automated data and information capture to provide real time tracking (for example)
- Intelligent freight systems to support elimination of 'empty running'

Use of IT to enhance and deliver increasing **Passenger** satisfaction before, during and after their end-to-end journey, with attention to :

- Use of semantic web approaches to engage with passengers during their end-to-end journey and especially enhance modal exchanges
- Cooperation with other modes to seamlessly and automatically exchange real time and analysed Passenger data in order to predict and prepare passenger service needs
- Implementation of novel and multi-modal simplified passenger travel permissions (ticketing) reducing the stress in planning and purchasing travel services
- Integration with other Operational systems in order to deliver real time travel information, especially that associated with planned or unplanned incidents.
- Use of satellite positioning systems and own traffic monitoring systems for the detailed real time information including possible disruptions and accurate forecasting of the arrival time.
- Proper algorithm design and distributed/parallel computation to handle such large and complex datasets

IT Technologies to support **Mainline Rail**, especially relating to the introduction of ERTMS, dynamic timetabling and increasingly accurate and precise train position information through integration of position data from several technologies (GNSS, Optical, Tracking, etc.)

Improving **Urban Mobility** for passengers and freight, especially novel approaches to :

- New city logistic concept
- Improved integration of urban mobility systems
- Seamless end-to-end urban journeys, aided by interoperable ticketing and integrated travel and transport information

The two key themes for **Urban, Suburban and Regional Rail** IT and enabling technologies to address are :

- Exploit and develop IT systems that enhance competitiveness and attractiveness of rail-based transport solutions, especially relating to operation and information flow
- Deliver increased personal safety and security throughout the end-to-end journey, and especially across international boundaries



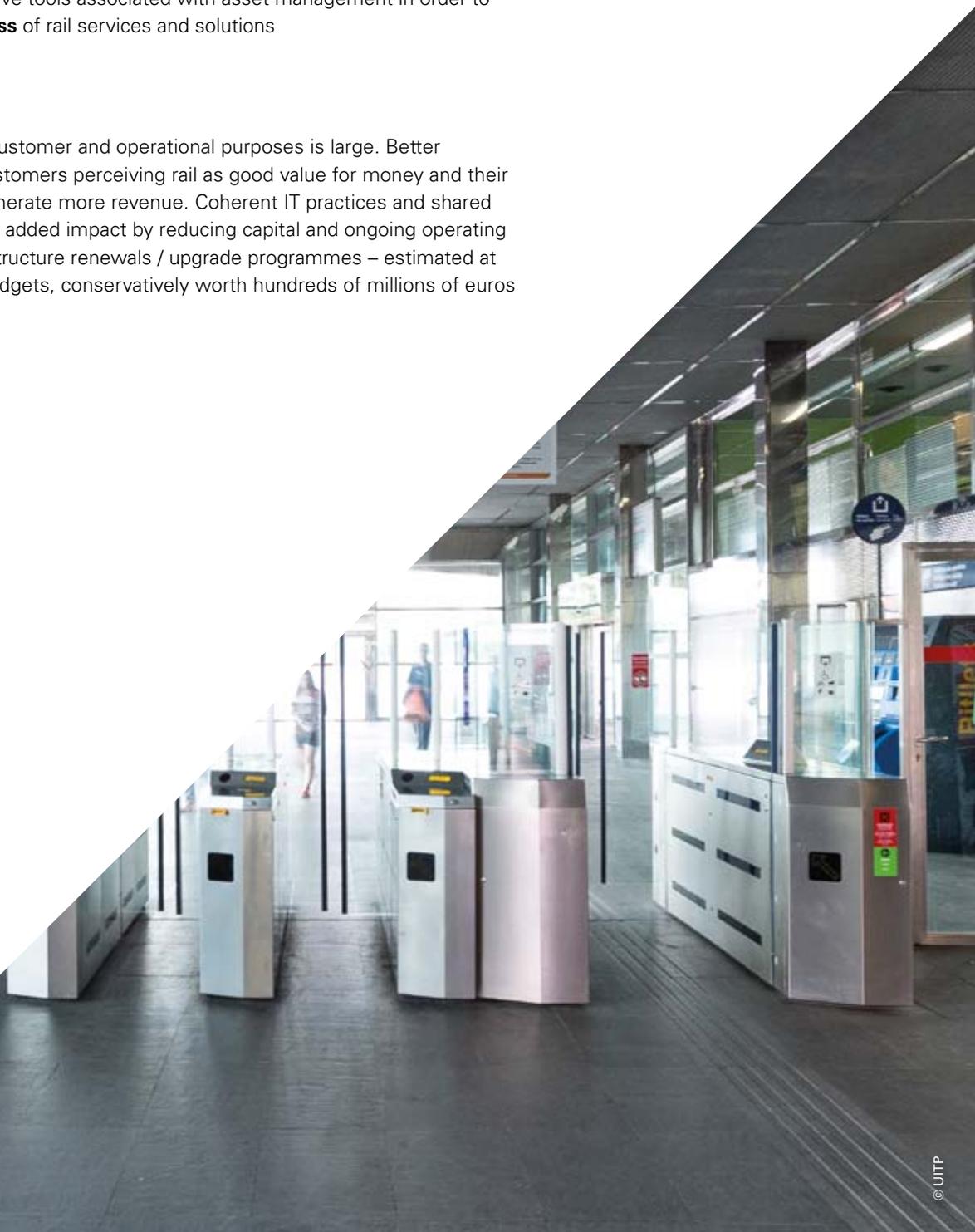
IT and IS systems are critical to improving European Railway **Safety and Security** and significant technology and innovation will be needed for:

- Ensuring a balance between personal privacy freedoms and information needed for security and safety management
- Using increasingly intelligent sensors able to determine and manage threats to safety and security
- Real time threat analysis derived through integration of data from several source and types (optical, video, chemical, behavioural, etc.)
- Increased cooperation and implementation of cyber security to European Railway systems
- Providing situational awareness for rail staff - personal / train warning system that allows people to work when trains are not close and warns them when they are

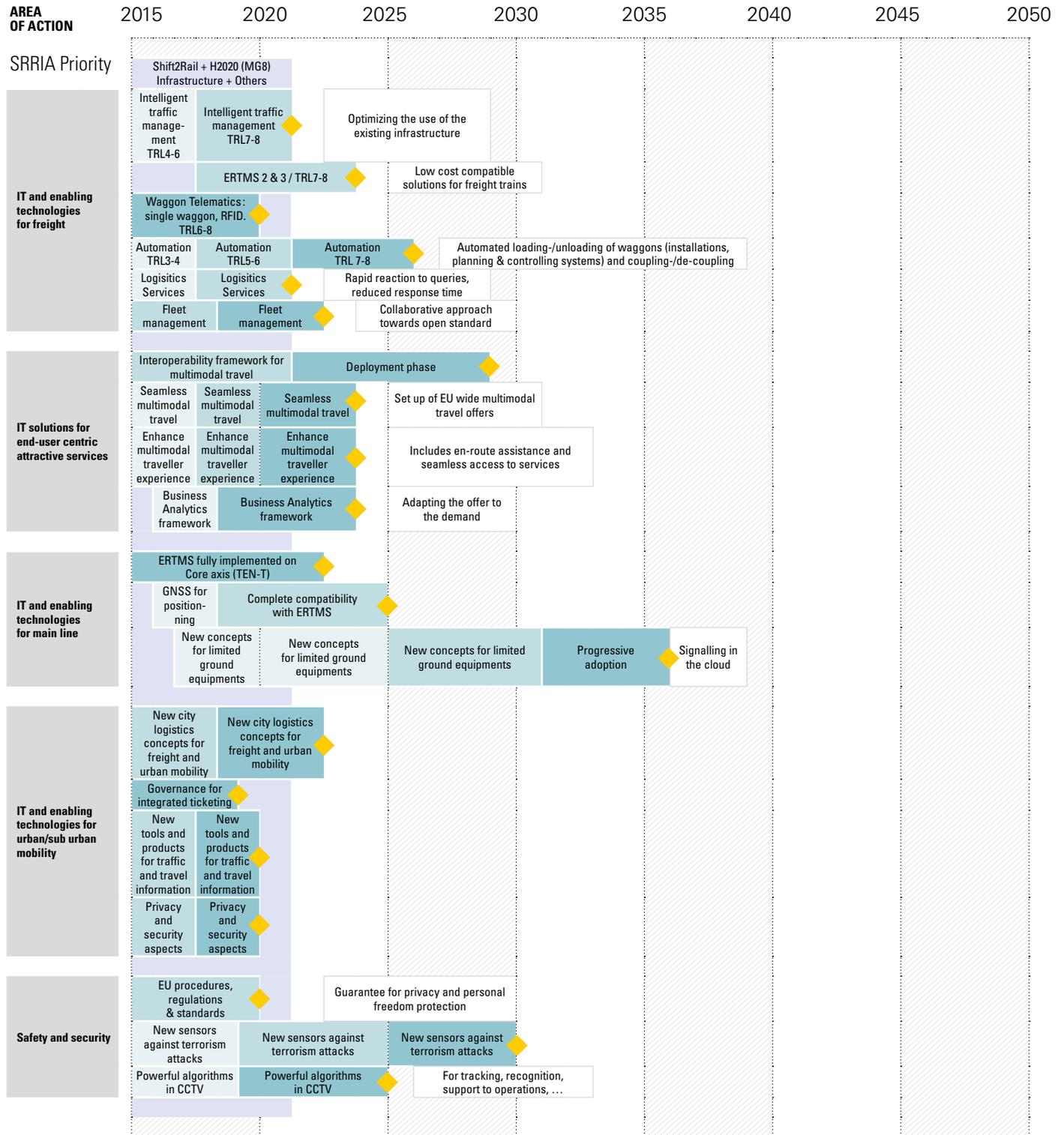
Improvements to whole life asset management and especially development of increasingly accurate predictive tools associated with asset management in order to **Strengthen Competitiveness** of rail services and solutions

## VALUE

The value of modern IT for customer and operational purposes is large. Better connectivity will result in customers perceiving rail as good value for money and their increasing patronage will generate more revenue. Coherent IT practices and shared approaches can have a value added impact by reducing capital and ongoing operating costs, for instance for infrastructure renewals / upgrade programmes – estimated at 5-10% of the programme budgets, conservatively worth hundreds of millions of euros in future investments.



# IT and other enabling technologies Roadmap



Technology Readiness Level (TRL) 1 - 3 4 - 6 7 - 9+ ◆ Start of implementation, but note R&D continues beyond this point

# TRAINING AND EDUCATION

## Sustainable pan-European flow of motivated, educated and skilled human resources

### IMPORTANCE

It is essential that the European railway, in all its forms (heavy rail, metro, light rail, tram, etc.) has a sustained and sustainable supply of high quality, trained and skilled human resources across a range of disciplines. Advantage will be drawn from the mobility and exchange of these resources, to pass on best practice and lessons learned

### CHALLENGES ADDRESSED

**Characterisation of skills and competence needs:** Achieve a thorough understanding of the range of skills and competence needed by the European railway along with current populations and predicted demand provide an essential foundation to resource planning, both in the resources to deliver the training and skills and a reservoir of talent able to undertake the same

**Higher education offer:** In line with quantifying the human resource needs, it is important to understand the range of training and skills development courses on offer across Europe; and to look for current best practice in course delivery

**Advanced Training courses:** A challenge to be addressed is the delivery of flexible forms of advanced training, to enable managerial, professional and non-professional staff to deliver the doctrine of continual business improvement

**EURAIL - The European Railway University:** Instigation and delivery of a high quality and sustainable 'virtual university' for railway personnel

**Meeting expectations of end users:** Expand and implement ways for employers to ascertain proficiency of railway personnel, employees to promote their skills and training; and to create confidence between the industry and educational suppliers

**Harmonized European Transport/Rail PhD:** A relevant major recommendation of the project DETRA ([detra.fehrl.org](http://detra.fehrl.org)) is the need for a commonly defined "European Doctorate (PhD) in Transport" and the need to define specific guidelines for such a PhD format

### TECHNOLOGY AND INNOVATION NEEDED

Innovative approaches to **Characterisation of skills and competence needs** will be required to support and improve on existing activities especially with regards to:

- Quantitative assessment of emerging and proposed railway systems to ascertain future human resource skills and levels and how these may be met
- Increased ability to move human resources within and between the rail and adjacent sectors which, in turn, influences demand and quickly highlights specialism shortages
- Improved awareness of career professional development and associated development pathways with regards to employment of new and novel technologies on the railway

- Generic approach to improving the overall competence of human resources in a railway context associated with (for example) :
  - Emerging technologies, products and services such as light weighting, crashworthiness, joining railway dynamics, fire resistance, advanced materials, monitoring sensors, information technologies, big data, rail infrastructure etc.
  - Human-Machine Interfaces & Human factors engineering
  - Asset management
  - International and cross border cooperation, collaboration and globalisation
  - Customer needs awareness and customer interactions



Based on the results of the SKILLRAIL, RIFLE, TUNRAIL and NEAR2 projects, there is still a need to improve the **Higher Education offer** :

- Quantify and generally assess world-wide availability of higher education in a rail industry context
- Work with industry to assess human resource demand and associated skill levels
- Match higher education levels (BSc & MSc) with industry demand and expectation
- Establish higher education skills and training courses aimed at senior and executive levels in the rail industry

There is a perceived demand for **Advanced Training Courses** for professionals and middle to upper management levels in the rail industry. Working with appropriate educational providers the need is to :

- Create professional profiles for people operating in the technical, legal, international, IT, systems and communications domains (for example)
- Continue the introduction and development of high quality and intuitive knowledge management systems for railway competencies
- Tailor the delivery of advanced courses to employer need and employee engagement
- Promote and support life-long learning
- Exploit new and emerging delivery mechanisms : virtual learning environment, e-learning

The SKILLRAIL project has launched the **EURAIL “European University of Railway”**. As a corporate service of EURNEX, its main mission is associated with the creation, dissemination and transfer of knowledge within the railway sector. The first objective is to unite the efforts of the different railway stakeholders seeking to share information and training.

Use of technology and innovation to better understand and meet the **expectation of end users** ; service providers, the wider rail industry and the associated supply chain need to develop :

- Co-operation and collaboration between rail and non-rail organisations to improve overall industry proficiency
- The co-ordination between industry need and education supplier in terms of the educational content of training and skills development ; suggested approaches include strategic alliances between industry and academia, regular workshops, improved mobility of academic staff and railway training professionals around Europe

To ensure the required mobility of labour a European recognition of skills and a corresponding adaptation of national initial vocational training is recommended for train drivers and stewards of the sector. The European Qualification Framework can provide a common basis for the European transport sector to pursue this aim.

A **harmonised European Transport /Rail PhD defined** “European Doctorate (PhD) in Transport” would provide acquisition of:

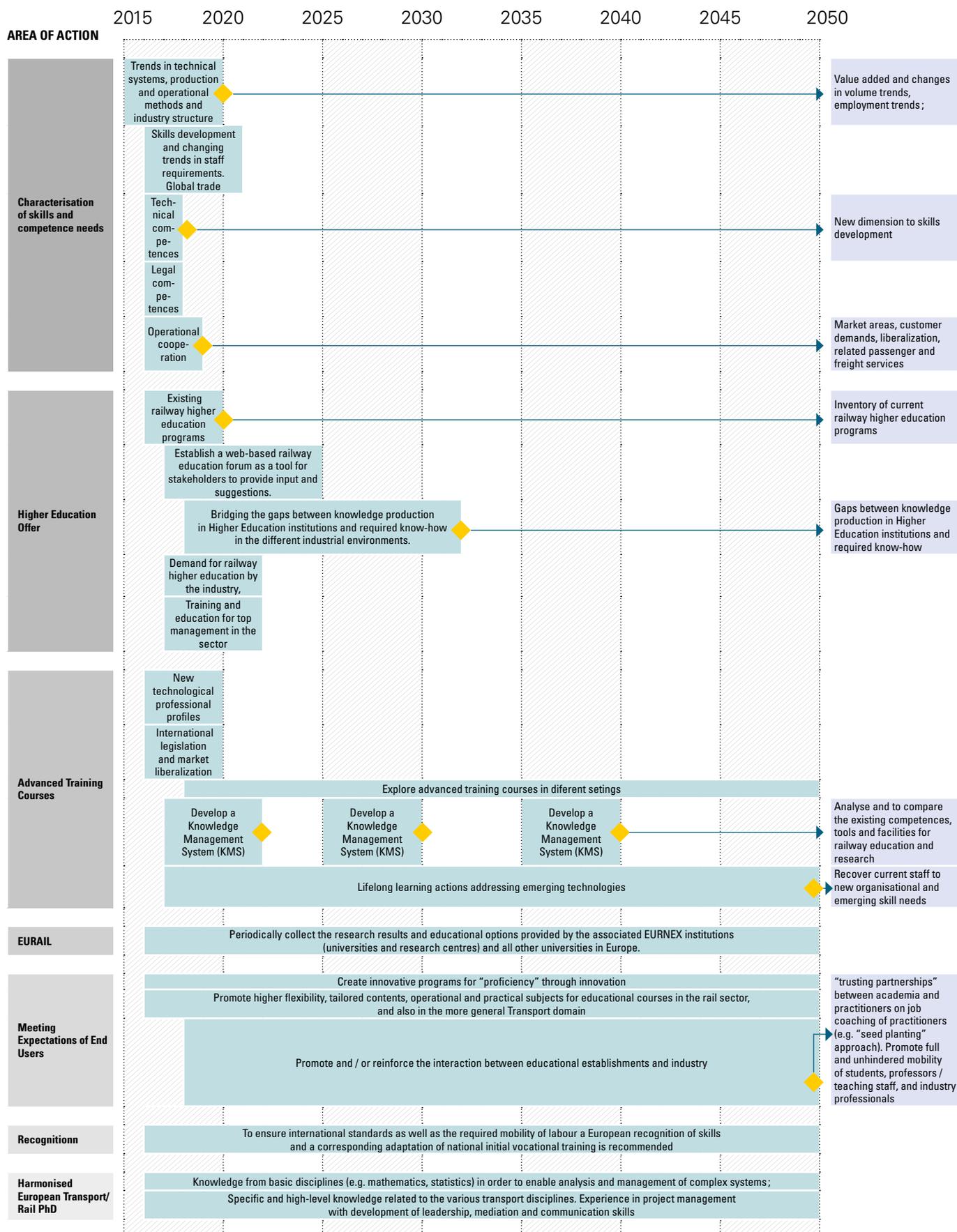
- Knowledge from basic disciplines (e.g. mathematics, statistics) in order to enable analysis and management of complex systems
- Specific and high-level knowledge related to the various transport disciplines
- Experience in project management with development of leadership, mediation and communication skills

## VALUE

Having sufficient and capable human resources is essential to deliver the opportunities noted elsewhere in this paper. In itself, the risk and associated cost of labour shortages (e.g. premium rates for rare skill sets) will be reduced, and though the total number of people working on the railway may reduce, average wages of the remaining, more skilled employees, will be higher. The savings in reducing labour associated with improved whole life costs is implicit in the values described elsewhere in this document.



# Training and Education Roadmap



◆ Start of implementation, but note R&D continues beyond this point





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# CONCLUDING REMARKS

# DELIVERING INNOVATION, PROGRESS AND IMPACT

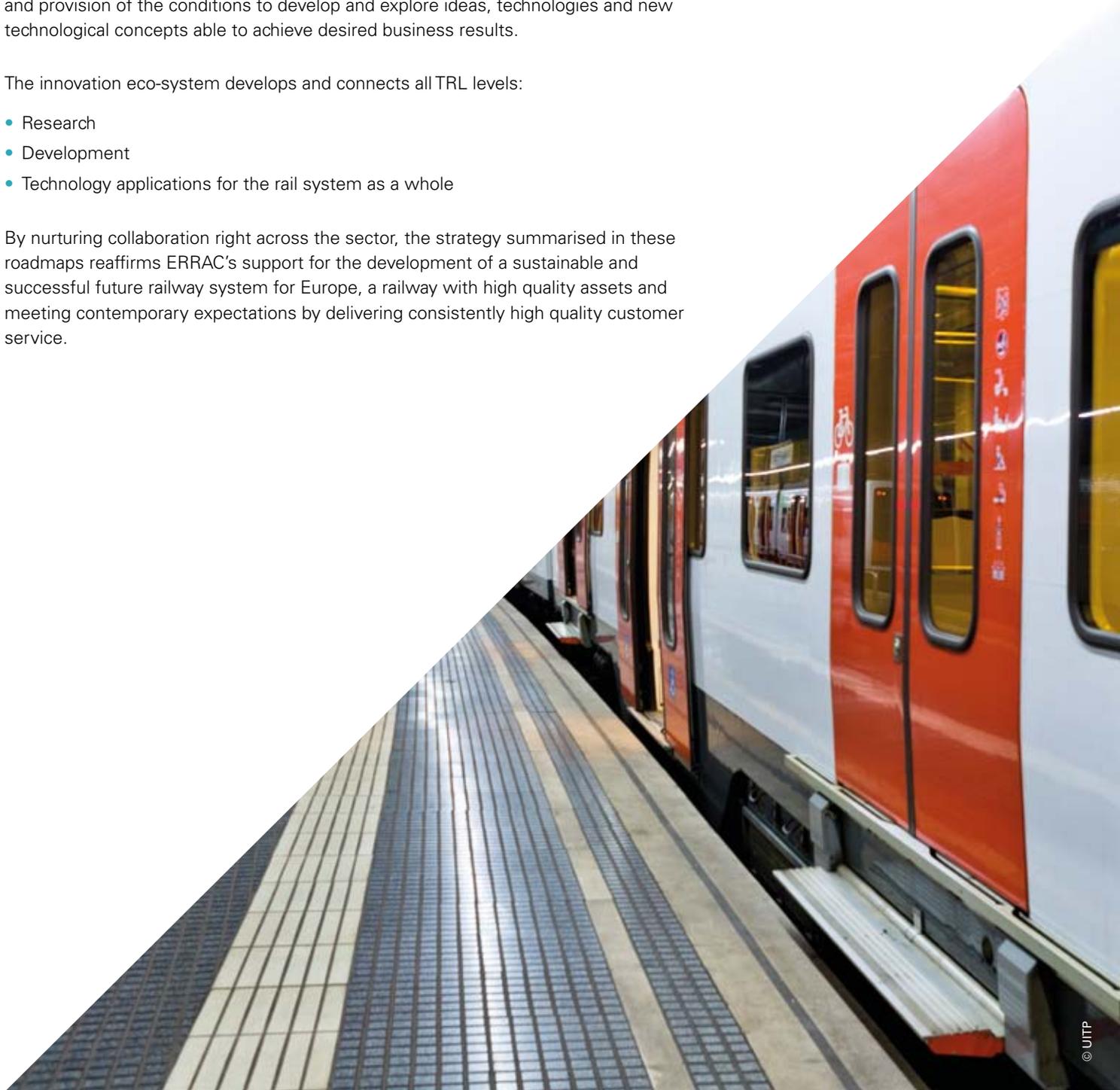
These roadmaps describe a challenging agenda for research and innovation in the rail sector in the coming years and decades. Some of it is already in hand or started by Shift2Rail and other initiatives. Other parts are aspirational, yet realistic. A range of low technology readiness level (TRL), basic research topics for longer-term development will support breakthrough technologies that should be addressed with special support from Shift2Rail. If the railways of Europe and their partners in industry and academia can deliver on these challenges, the future of the sector is very bright, with great benefit to all who use and work in the railway.

The effective development of the innovation processes is in itself a major challenge, requiring the establishment of a strategy focused on the identification of opportunities and provision of the conditions to develop and explore ideas, technologies and new technological concepts able to achieve desired business results.

The innovation eco-system develops and connects all TRL levels:

- Research
- Development
- Technology applications for the rail system as a whole

By nurturing collaboration right across the sector, the strategy summarised in these roadmaps reaffirms ERRAC's support for the development of a sustainable and successful future railway system for Europe, a railway with high quality assets and meeting contemporary expectations by delivering consistently high quality customer service.





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# ACRONYMS

<b>AI</b>	Artificial Intelligence
<b>ATO</b>	Automatic Train Operation
<b>BIM</b>	Building Information Management
<b>BCM</b>	Business Continuity Management
<b>CCC</b>	Control Command and Communication
<b>DAS</b>	Driver Advisory System
<b>EE</b>	Energy Efficient
<b>ERRAC</b>	European Rail Research Advisory Council
<b>ERTMS</b>	European Rail Traffic Management System
<b>EURNEX</b>	European Rail Research Network of Excellence
<b>HUMS</b>	Health and Usage Monitoring Systems
<b>IT</b>	Information Technology
<b>LIDAR</b>	Light Detection and Ranging
<b>M2M</b>	Machine to Machine
<b>PRM</b>	Persons with Reduced Mobility
<b>RAM</b>	Reliability, Availability and Maintainability
<b>SONAR</b>	Sound Navigation and Ranging
<b>SRRIA</b>	Strategic Rail Research and Innovation Agenda
<b>TRL</b>	Technology Readiness Levels
<b>UAV</b>	Unmanned Aerial Vehicle





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