Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Guidelines for further research and development activities

Submission date: 29/11/2017

Deliverable 56.2

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605650

Collaborative project SCP3-GA-2013-60560
Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations
FP7-SST-2013-RTD-1

Lead contractor for this deliverable:

- UIC

Project coordinator

- Union Internationale des Chemins de fer, UIC

Executive Summary

This report is a deliverable for Work Package 5.6 under Sub-Project 5 (SP5) of the Capacity4Rail (C4R) project. C4R, a 4-year H2020 project was set up in 2013 to deliver innovative research to lay the foundation to support and enable the transformational change needed to achieve the 2050 vision. The key milestones that encapsulate current thinking within the EU Railway sector to achieve the EU's vision of 2050 Railway are:

- By 2020:
  - Framework for multi-modal transport, Information Management and Payment system
- By 2030:
  - Modal transfer from road to rail – 30% of freight on >300km journeys
  - EU wide multi-modal TEN-T core network
- By 2050
  - Modal transfer from road to rail – 50-% of freight on >300km journeys
  - Rail share- 50% of medium distance passenger traffic
  - All core networks connected to major airports
  - High quality/high Capacity rail network

Specifically, the aim of the C4R project was to answer the research question, "How to obtain an affordable, adaptable, resilient and automated high capacity railway, for 2020, 2030 and 2050?" The project has addressed a broad swathe of the challenges through Research, Development and Innovation (R,D & I) work carried out in four Sub-Projects (SPs), with each of the four SPs addressing different aspects of the railway system. A fifth Sub-Project, SP5, had the role of driving the overall approach and ensuring that the project adopted a whole systems approach.

The 2030/2050 targets have been collated and set against the five C4R aspects of Affordability, Adaptability, Resilience, automation and High-Capacity. The definitions for these five aspects developed specifically from the C4R perspective, in conjunction with the trends and influencing factors that are expected to influence the rail and the transport sector in general, that have driven the specific research activities in the project are provided in the report. The early review of the transport sector has shown that, in general, progress is being made but it is too early, since the publication of the 2011 EU White Paper, to measure the collective impacts of the investments to date.

The work carried out in C4R represents initial steps, in some selected areas, in the move towards the 2030/2050 vision for Rail. Research, innovations and outputs from the C4R project comfortably fall into four main categories:

I. Infrastructure: covering selected topics in Track, Bridges, Switches & Crossings and Advanced monitoring techniques

II. Rolling stock: covering selected topics related to innovative freight wagon designs, automatic couplers and improved designs for interchanges in terminals;
III. Operations: covering selected topics related to enabling faster recovery from extreme weather events, faster and responsive timetabling, common data architectures to enable integrated and effective use of data sets
IV. Railway system: covering selected topics related to the use of a whole system approach.

C4R research has made some important contributions towards meeting some of the challenges facing the railway industry in meeting the 2030/2050 targets. A detailed breakdown of the innovations and outputs (totalling 26) from C4R and brief descriptions are provided in the report. Detailed descriptions of each of the outputs are provided in the specific Task reports. The research from C4R has resulted in the development of some ‘products’ and ‘tools’ that are potentially at low Technology Readiness levels, (potentially around 4). These include, for example:

- Innovative modular slab-track designs, Switches & Crossing concepts, low-cost sensors for supporting continuous remote condition monitoring. The products have reached demonstrator stages and early validation studies have been carried out;
- Decision support tools & models (e.g. track design optimisation, Operations planning and ad-hoc incorporation of additional train paths, management of Network Disruption, Rail Capability Trade-offs tool) to help improve efficiency and performance of railways. The tools have used case study data to show their applications and how they can be used to improve aspects of the railway system.

A significant proportion of the remainder of the work in C4R has focused on early stage research and development, supported by some analyses (e.g. LCC, multi-criteria, scenario) to show the validity of the research and its potential (with further development) to contribute toward the progress to 2050 Rail.

The roadmaps presented in the earlier report, SP5, D5.1.1 have been revised to show the areas where C4R has contributed to the five aspects, Affordability, Adaptability, Resilience, Automation and High Capacity. The major challenges facing transport continue to be lack of capacity, increasing congestion, need to reduce environmental impact and address the mobility needs in a period of changing demographics and exponential growth in the introduction of new technologies. C4R has laid a very valuable foundation on which success can be built and a key element of the success of the C4R project will therefore lie in the handling of the outcomes and ensuring that the benefits of the research are realised. A brief description of the potential next steps needed to facilitate the realisation of benefits from the investment into the C4R project is provided. Some progress has been made in taking forward some of the results from C4R (e.g. SP2 work on freight) but more needs to be done. A main aspect of ‘next steps’ has been identified as the development of a proactive engagement strategy with internal and external stakeholders and ensuring that the momentum of progress is maintained.

Table of contents

Abbreviations, Acronyms and Glossary

Abbreviation / Acronym	Description
C4R	Capacity4Rail
ERTMS	European Rail Traffic Management System
LCC	Life Cycle Cost
MCA	Multi-Criteria Analysis
R,D&I	Research, Development and Innovation
SP	Sub-Project in C4R; C4R has 4 technical sub-projects (SP1 to SP4); one over-view sub-project (SP5) and the dissemination sub-project (SP6)
TEN-T	Trans European Network - Transport

1. Background

The 2011 White Paper on European Transport[1] defined the long-term transport and mobility needs of European countries. The targets that were set out to achieve these needs included (inter alia): (a) a reduction in transport-related greenhouse gas emissions, (b) a modal shift of freight from road to rail and/or waterways, (c) a modal shift of medium-distance passenger travel from road to rail, (d) expansion of the European high-speed rail network, (e) the completion of the TEN-T core network - including rail links to core airports and core seaports, and (f) implementation of ERTMS.

Following on from the White Paper, the European railway community published Challenge 2050[2] which set out the shared perception of the sector's 2050 vision of the European Railway System. This reiterated the goals identified in the White Paper and described its purpose as "to orient and guide the railway sector, as well as policy makers and stakeholders, to enable the innovation and investment on which sustainable mobility in Europe depends".

Capacity for Rail (C4R), a 4-year H2020 project was set up in 2013 to deliver innovative research to lay the foundation to support and enable the transformational change needed to achieve the 2050 vision. Specifically, the project aim was to answer the research question, "How to obtain an affordable, adaptable, resilient and automated high capacity railway, for 2020, 2030 and 2050?" The C4R project has addressed a broad swathe of the challenges through the Research and Development (R&D) work carried out in four Sub-Projects (SPs), with each of the four SPs addressing different aspects of the railway system. A fifth Sub-Project, SP5, had the role of driving the overall approach and ensuring that the project adopted a whole systems approach. The structure of the project and the underlying concept is set out in Figure 1.

An earlier deliverable from SP5, D5.1.1 'Railway Road Map' provided preliminary versions of five high-level roadmaps, setting the 2050 targets for an affordable, adaptable, resilient, automated and high capacity European railway. Definitions of the five aspects of the 2050 railway were derived as part of that work and these are included in the Appendix. The roadmaps addressed the targets and goals identified in the White Paper on Transport and were developed following a detailed literature review including examination of published strategies of national railway administrations in Europe. A workshop was held with representatives of all the C4R Sub-Project teams to ensure that any relevant information derived from the state of the art reviews within the Sub-Projects were given due consideration. This included key metrics and published targets towards delivering the vision, as well as research activities planned to be undertaken in the four Sub-Projects (on infrastructure; new

[1] White Paper on Transport (2011). *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system.* COM(2011) 144 FINAL. Brussels 28.3.2011

[2] Challenge 20150 (2013). The Rail Sector Vision. http://www.cer.be/publications/charters-and-agreements/challenge-2050-rail-sector-vision

concepts for freight; operations to deliver enhanced capacity; and advanced monitoring) of the C4R project.

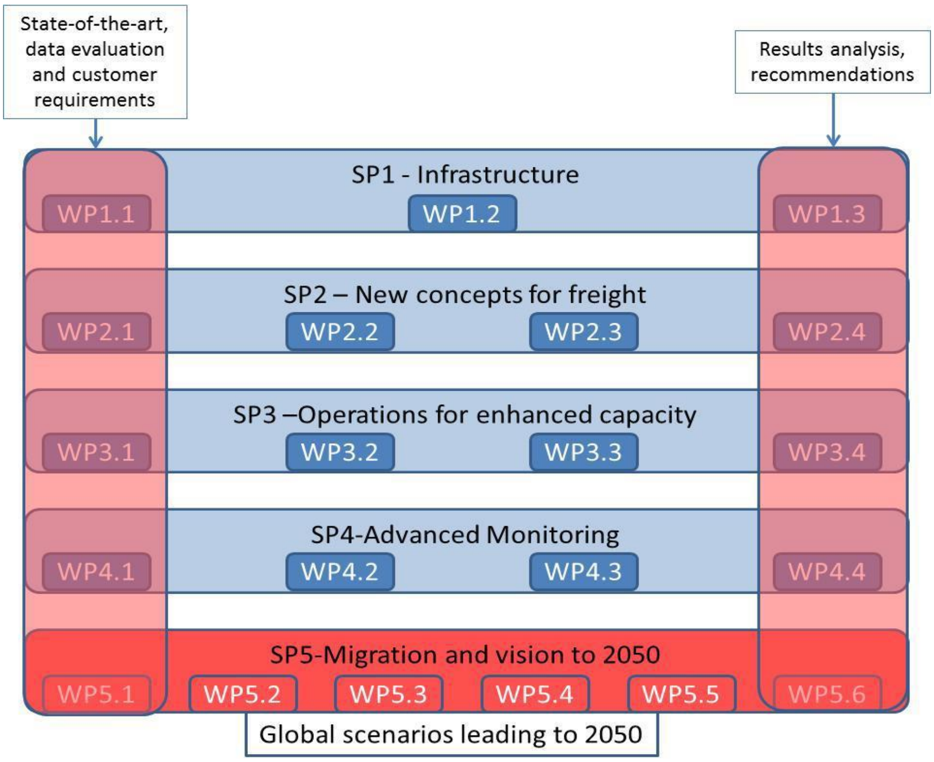

FIGURE 1 CAPACITY4RAIL STRUCTURE/CONCEPT

RESEARCH AND DEVELOPMENT

A number of parallel initiatives are underway, supported by the EU and also the National Governments, to support the growth of railways and there are indications of progress in several areas. However, there is limited data on the impact of the various initiatives that have been implemented in the period 2013 to 2017 (i.e. the life of the C4R project) on the 2030/2050 targets; this is to be expected as transport projects take time to implement and the impacts take time to become apparent.

Some examples of research and development carried out that are particularly relevant to the targets for rail set by the EU 2011 White paper include:

- Shift2Rail (on-going programme):
  - A public-private partnership, supported by the Horizon2020 programme, was formally launched in 2014;
  - The programme co-ordinates European rail research and innovation to develop new technologies with capabilities to deliver the 2050 vision at TRLs close to market exploitation. This includes reducing life cycle costs of railway assets and operations

by at least 50%, doubling capacity and increasing reliability and punctuality by at least 50%.

- Rail Technical Strategy, Europe (2014)
  - The strategy, developed by the Railway Operating Committee, sets out the means to achieve the 2050 vision of European Railways set out in the business led document 'Challenge 2050';
  - The aim is to use a Systems Engineering Approach to systematically develop standardised systems and deliver improvements in reliability, availability, maintainability and safety (RAMS).
- SUSTRAIL (June 2011 – May 2015):
  - The objective of the EU project SUSTRAIL (Sustainable Freight Railway) was to deliver innovations to support the European rail freight system and make progress towards delivering the commission's targets to transfer freight from road to rail;
  - The project delivered a package of innovations (covering wagon-track systems)that together demonstrated the capability to deliver lighter and more energy efficient wagons with higher speeds and loading capability;
  - Implementation and realisation of benefits are still dependent on achieving lower Track Access Charges and lower capital cost to build the 'SUSTRAIL' wagon.
- Research undertaken in the UK by sustainable transport charity Transform Scotland found that:
  - Overall air and rail travel between Scotland's Central Belt and London is increasing and carbon emissions are falling as more people are choosing rail;
  - Virgin Trains' growth on the west coast route between Glasgow and London over the last decade has saved CO2 (332,208t) that is equivalent to taking 145,000 cars off the road network for a year;
  - Further passenger growth on the east coast route between Edinburgh and London can be accommodated whilst still cutting carbon from the ambitious plans by Virgin Trains to win a 50% market share against airlines.
- Expansion of the high-speed rail network in Spain[3]:
  - A new section of high-speed line, 166 kilometres in length, between the cities of Valladolid and Leon opened to traffic in September 2015. The new line has been designed for speeds of up to 350km/h with double standard gauge track and 25 kV 50 HZ electrification;
  - Adif (Infrastructure Manager in Spain) manages a total 3,150km of high-speed rail lines in Spain (making it the largest national high-speed network in Europe);

[3] https://www.globalrailwayreview.com/article/25581/developing-a-sustainable-spanish-high-speed-rail-network/

- Use of new technical solutions has enabled Adif to ensure high quality of services at lower cost.
- Digital Railway
  - An initiative led by Network Rail, in collaboration with the UK Department for Transport and industry, to accelerate the introduction of digital systems to support the rapidly growing demand for greater capacity and deliver on the 4C targets (halving Carbon emissions and Costs, doubling Capacity and improving Customer satisfaction by 2050) defined in its Rail Technical Strategy;
  - The focus of the initiative is to improve Capacity, performance and connectivity in the UK Railways.
- Closer Running of trains to increase capacity
  - Closer running of trains has been identified as a key enabler to meet the target for increase in capacity (of passenger and freight trains) at an affordable cost. As a first stage of the research, RSSB[4] has carried out research to establish the relevant background information to support the development and launch of an appropriately structured programme of work that can support the reduction of the headway of individual trains;
  - The work has shown that increasing network capacity through a reduction of headway, or closer running, is technically possible; it will, however. require a combination of enhancements to technology already used in the rail industry and the utilisation of systems used in other industries;
  - The research has delivered a technology roadmap for 'closer running, identified the technology dependencies and made recommendations for future work streams, including opportunities for technology transfer from other industries;
  - Closer running is supported by other research. For example, research on the concept of integrating ‘relative braking distances’ with ERTMS level 2, proposed by ALSTOM[5], called ERTMS boost, uses real time dynamic data of the train to allow shorter separation between trains on high speed lines. Combining the real time dynamics of two trains allows a ‘relative braking distance’ of the following train to be calculated by the difference between the ‘best case braking’ distance of the lead train and the ‘worst case braking’ distance of the following train. Leveque states that ERTMS boost could provide a potential improvement in track capacity of up to 50%.

COMPETITOR TRANSPORT MODES

The major challenges of capacity, congestion, environmental impact and provision of accessible transport are common to all the transport modes. Due to the significant levels of CO_2 and other particulates emissions, the need to reduce the environmental impact has been and continues to be an area of specific focus for the automotive and aviation sectors, both in terms of improving their

[4] https://www.rssb.co.uk/pages/research-catalogue/t1095.aspx
[5] (Leveque, O. (2012). ERTMS boosted. ALSTOM)

environmental credentials and preserving (and if possible increasing) their competitive advantage over rail. While it is clear that the rail sector is on track to achieve its low carbon goals, the automotive and aviation sectors have, over the last decade, made substantial progress in developing and adopting new initiatives to deliver significant reductions in the use of fuels generating CO_2 as well as their capability to deliver greater capacity from the existing networks. Some examples of recently completed and on-going research to significantly deliver greater capacity from the existing network (thereby ensuring affordability) while also reducing environmental impacts are described in the following sub-sections.

Automotive sector

- Autonomous road vehicles – there are a number of projects being carried out worldwide that are investigating and researching autonomous vehicles. Progress with the development of autonomous cars has progressed exponentially over the last decade with a number of national governments as well as private sector organisations (e.g. Ford, Google, Tesla, and Apple) testing autonomous vehicles (albeit with different levels of automation up to 'fully automated') and the technologies within them. They utilise similar systems where sensors (LIDAR, Radar, Cameras) on the vehicle are used to map the vehicle's surroundings and the information is combined with a learnt model to identify and execute suitable navigation routes. Two examples of autonomous vehicle projects from the UK are given below.
    - Mobile Robotic Group, University of Oxford: is researching technologies that can be used in autonomous cars with the aim of greatly improving efficiency. The Group is operating an automated Nissan LEAF called ROBOTCAR[6]. The use of scene recognition distinguishes the ROBOTCAR from the Google self-driving car but also limits operations to 'familiar' routes. The use of sensors in determining vehicle location is vital to autonomous driving as the current status of GPS is not accurate enough to be used on its own, especially in some circumstances where signals could be blocked by existing infrastructure, e.g. tall buildings. The use of GPS alone is also not ideal as GPS signals can be jammed;
    - GATEway (Greenwich Automated Transport Environment)[7] is an industry/Innovate-UK jointly funded project to develop understanding and overcome the technical, legal and societal barriers of implementing automated vehicles in an urban environment and demonstrating the integration of a zero emission fully autonomous transport system in a smart city environment. The aim is to demonstrate the use of automated vehicle technology to improve public understanding and acceptance, and allow manufacturers to develop and assess their technology in real world situations. The project has been using an adapted version of the automated shuttles used at Heathrow Terminal 5 for trials on predefined routes within a live highway network.

[6] http://ori.ox.ac.uk/application/robotcar/
[7] https://gateway-project.org.uk/

- Convoy / Platooning of vehicles - is a process where a formation of vehicles travel together behind a manually controlled lead vehicle. The lead vehicle is driven by a professionally trained driver assisted by driver aids and warning technologies. The following vehicles use laser sensor technology (lidar) to identify and maintain the required separation distance from the vehicle in front (Jootel, 2013[8]; Chan et al, 2014[9]). Through this method, separation distances of 1m to 6m between consecutive vehicles can be achieved at speeds of up to 90km/h. This delivers significant increase in capacity and decrease in fuel consumption.
  Current roadmaps predict lorry platooning (with small convoys of around 3 vehicles) on motorways in Europe by 2020 and being rolled out more extensively by 2025
  - SARTRE (SAfe Road TRains for the Environment) Project [10]was a collaborative European project which developed strategies and technologies that would allow vehicle platoons to operate on public highways. The reduction in fuel consumption was found to be significant, leading to potentially large savings in the cost of transportation and a decreased CO^2 footprint . The estimated benefits were found to include ~50% reduction in highway related accidents, and ~10% reduction in fuel consumption;
  - Following on from the EU project, the UK's Department for Transport is currently funding the world's first real-world trial (to be carried out between 2017-2019) of heavy goods vehicles operating in a digitally linked platoon of lorries on UK's dual carriageways and motorways;

Aviation sector

Currently a number of collaborative projects between ANSPs (Air Navigation Service Providers) and aircraft operators are underway to increase capacity (e.g. better use of the infrastructure and allocation of tracks for flights) and improve efficiency (e.g. reducing delays and cancellations, flying times, fuel burn and CO2 emissions). Improvements in air traffic management technologies, accuracy of aircraft positioning and Vehicle to Vehicle communication systems have successfully enabled a reduction in the separation between aircraft, both longitudinally and laterally, on one of the world's busiest flight paths over the North Atlantic

Laterally, extra flight lane was added (implemented in November 2016) by reducing the lateral separation from 1 degree of latitude (~60 nautical miles) to 0.5 degrees. Further increase in useable capacity is being planned through further reductions of separation between 2016 and 2022 (aiming for 15 nautical mile separation). Decreasing the longitudinal and lateral separation also allows flights to take more direct routes and thereby reduce flight times, fuel consumption and CO_2 emissions (estimated at more than 52,000 tonnes of Carbon):

- Time Based Flow Management

[8] Jootel, P S. (2013). Safe Road Trains for the Environment (SARTRE) project final report. Ricardo
[9] Chan E, Gilhead P, McCarthy M. (2014). Heavy Vehicle Platoons on UK Roads Technology review. Ricardo & TRL
[10] http://www.roadtraffic-technology.com/projects/the-sartre-project/

- Time based separation during landing (as opposed to fixed distance separation) safely recovers most of the capacity that is lost during strong headwind conditions during approach (already in use at London Heathrow); This optimises runway utilization, enables planes to fly closer together during descent and allows improved sequencing and reduces airborne holding delay minutes (in adverse weather conditions);

- Reduced lateral separation (RLat) Project – An initiative by the International Civil Aviation Organisation, jointly implemented by NATS (UK) & NAV CANADA and is based on improved communication and positioning technologies:
  - Reducing lateral separation from 1 degree (60 NM) to ½ degree (30 NM) is essentially the equivalent of turning two lanes into 3 lanes without expanding the infrastructure);Following trials in 2015, ½ degree has become the standard minimum separation in Nov 2016 on the organised track structure on the North Atlantic route;
  - Aireon project: Space based Automatic Dependent Surveillance (Iridium Technologies, NAV CANADA, European ANSPs) has a target date of 2018 to deliver further improvement in capacity:
    - Aircraft can be spaced even more closed together, ¼ degree (15 NM) separation; In addition, greater security provided through better tracking of aircraft globally through space-based Automatic Dependent Surveillance.

SUMMARY

Over the last two decades, following several years of relatively low levels of investment, the approach to the rail sector has changed significantly and has been accompanied by growing levels of investment. The EU White Paper on European Transport has identified specific goals for rail and this has given further impetus. C4R is an important research project in this context and is part of a number of initiatives underway to support the growth of rail, sponsored by the EU, National Governments and the private sector. Meeting the capacity requirements at an affordable cost continues to be a challenge.

Over the same period, both the automotive and aerospace sectors have made significant progress in increasing the capacity capability of their infrastructure and improving their environmental performance through adaptation of existing and use of new technologies. Both sectors are increasingly showing that they can deliver a transformational change in responding to the challenges of capacity, cost and environmental impact.

While rail still has the advantage with regards to its mass transit aspects and environmental friendliness, the threat from the highways sectors in particular, with the growth in autonomous and connected automotive vehicles is real. It is therefore clear that focused effort will be required to ensure that the growth in rail seen in recent years is maintained.

2. Objectives

The main objectives of this report are to:

- Revisit the 2030 and 2050 targets for rail to confirm any changes (e.g. resetting of targets, introduction of new targets etc);
- Contribution of C4R Innovations to achieving the targets;
- High-level review of other progress in the rail sector that will help to meet the targets;
- Report on progress in competitive sectors (e.g. automotive, aerospace) in transport with potential to impact on the achievement of the 2050 targets and vision for railways;
- Report on the gaps and identify next steps.

The Structure of Report is provided in Table 1

Chapter	Title	Content of Chapter
1	Background	
2	Objectives	The objectives of SP5 and this report.
3	2030/2050 Vision - Revisited	The development and definition of the 2030/2050 Rail targets against the C4R context, the key trends and anticipated changes in the transport sector over that period and a discussion of the R&D required to achieve the targets.
4	C4R Progress	A summary of progress achieved within the C4R project work packages.
6	Roadmaps – Progress towards Rail 2050	The roadmaps – as A3 fold-outs.
7	Next Steps	The work necessary to achieve vision – what and where are the gaps.
	Appendix	Definitions of C4R Aspects of Rail 2050

Table 1 Structure of this Report

3. 2030/2050 Railway – Vision revisited

Transport is operating in an era of unprecedented levels of social, economic, political and environmental change catalyzed by the incredible pace of technological change. For example the disrupting technologies from the communications and digital sectors have changed user expectations of the sort of services users expect to receive, such as reliable and comfortable journeys, accurate real-time information, seamless intermodal travel, paperless integrated (across modes) tickets etc.

Rising demand for passenger and freight services coupled with world-wide concerns about CO2 and NOx emissions, climate change, all favour the rail sector, an environment friendly mass transit mode, over the automotive sector. However as discussed in Section 1, the automotive sector is fighting back by unlocking significant additional capacity and reducing negative environmental impacts through the adoption of next-generation technology (e.g. electric vehicles, battery operated cars, autonomous vehicles, lorry platoons, digital controlled traffic management systems etc). At the same time, rail which has received and is receiving unprecedented levels of investment (e.g. large scale infrastructure projects, new freight and passenger rolling stock, adoption of new technologies to enable smart infrastructure, smart rolling stock, smart ticketing etc) from public and private sector organisations is still seriously impacted by the apparent lack of capacity and the high cost to increase network capacity. Figure 2 encapsulates current thinking on the major milestones in achieving the 2050 Railway.

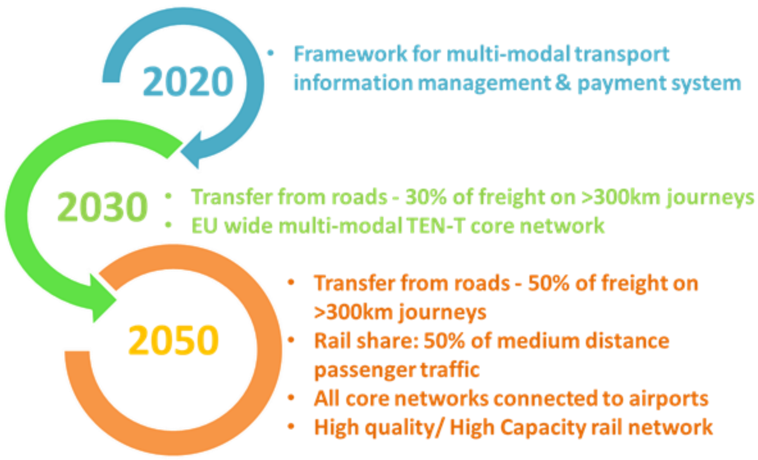

FIGURE 2 EUROPEAN RAIL JOURNEY TO 2050 RAILWAY

An important part of determining what needs to be done to achieve the targets defined in the EU White Paper and other supporting national strategies, is looking at the targets within the context of the changing landscape within which European railways is and will be operating over the next few decades. This includes aspects such as the technological developments, the evolving requirements and expectations of customers (freight and passengers), impacts of climate changes as well as any policy and regulatory changes. The key aspects that need to be addressed therefore are:

i. The targets defining the 2030 and 2050 vision for the railways
ii. The key trends and anticipated changes within the transport and other 'influencing' sectors
iii. The Research and Development needed to drive the changes and enable the transformational change in the railways.

The three aspects have influenced the activities undertaken in the C4R project and are discussed in the following sub-sections.

2030/2050 Railway - TARGETS

The targets for 2030 and 2050 derived from the EU white Paper, Rail Route 2050 and other relevant studies through a review of published literature, collated and set against the five C4R aspects (Affordability, Adaptability, Resilience, Automation and High Capacity, are summarised in Table 2.

		Target Year	2030	2050
C4R aspects	**Sub-groups**	**Indicators**	**Targets**	
Affordability	Economic (Initial and whole life, absolute & relative to other modes)	Mean Access charges		No increase in real terms
		Mean operating costs		50% decrease
		Infrastructure maintenance		50% decrease
	Environmental	Specific mean CO_2 emissions	30% decrease from 1990 levels	50% decrease from 1990 levels
		Total CO_2 emissions		50% decrease from 1990 levels
		Specific energy consumption		50% decrease from 1990 levels
		Total energy consumption		50% decrease from 1990 levels
		Exhaust emissions (NO_x, PM10)		40% decrease from 1990 levels
		Noise levels		Eliminate problem zones by all measures
	Safety	Equivalent fatalities		50% decrease
Adaptability	Interoperability	Cross-border restrictions on rail movements		Unrestricted, seamless
		Bundling of freight rolling stock		Fully interoperable
		Standard freight		No access

		Target Year	2030	2050
C4R aspects	Sub-groups	Indicators	Targets	
		containers		restrictions
	Service demands	Freight demand		Demand is met without increase in freight access charge
		Passenger overcrowding		Less than 10% at peak times
	Climate change	New rail infrastructure		Adapted for 50-year forecast
		New rolling stock		Adapted for 25-year forecast
Resilience	Extreme weather	Train delays (due to EW)	Reduce by 40%	Reduce by 80%
		Train cancellations (due to EW)	Reduce by 30%	Reduce by 60%
	Accessibility	TEN-T core network	Accessible by all new rolling stock	
		TEN-T comprehensive network		Accessible by all new rolling stock
	Infrastructure failure	Train delays (due to IF)	Reduce by 40%	Reduce by 80%
		Train cancellations (due to IF)	Reduce by 30%	Reduce by 60%
Automation (GoA levels and intelligent Systems)	Signalling & communications:	ERTMS Level 2	Deployed across the whole network	
	Intelligent Transport System	Multi-modal information management and payment system	Fr in place	
		Euro-wide standard system	Completed	
	Intelligent monitoring & diagnostic systems	Rolling stock	All new rolling stock equipped	
		Infrastructure		Maximised on infrastructure
High Capacity (Useable network capacity, Modal shift to rail)	Network extent	High-speed	300% increase	Completed
		TEN-T (core)	Completed	
		TEN – T (Comprehensive)		Completed
	Inter-modality	High speed rail links to TEN-T		Completed

		Target Year	2030	2050
C4R aspects	Sub-groups	Indicators	Targets	
		core airports		
		Rail freight links to TEN-T core seaports		Completed
		Multi-modal information, management and payment	Framework in place	
	Modal transfer to Rail	Road freight over 300 km	30% shift	50% shift
		Passenger traffic – medium distance travel		Rail market share: at least 50%

TABLE 2 2030/2050 RAILWAY TARGETS

The targets themselves have not changed since the earlier deliverable SP5 D5.1.1 was produced. The targets described in Table 2 therefore continue to be relevant and provide the goal posts for railway strategies across European Rail organisations.

2030/2050 Railway – key trends and anticipated changes

The "mega trends' in the transport sector that are expected to influence the sector include factors such as globalisation, liberalisation, climate change, resource (financial, skills & people) constraints and demographic changes. These are in general addressed through long-term European and National strategies. For the rail sector specifically, the trends and drivers that are relevant to the operations of the railway and can be expected to strongly influence the steps and activities over the next few decades in relation to the 2030/2050 targets are described in Table 3. The potential of the trend/factor to influence the five C4R aspects (affordable, adaptable, resilient, automated and high-capacity railway) as well as comment relevant to the particular trend/factor are also described in the table.

2030/2050 Railway R&D & Outcomes

Research and Development (R&D) is fundamental to providing the foundation for tackling the technical, operational and cultural challenges inherent in the design, construction and operation of an affordable, highly automated and high capacity European passenger and freight rail network that is resilient and adaptable to evolving changes. Clearly this has to be achieved taking into account the large differences in the 'current state of the railways' as well as the priorities between the different European countries. The priority areas for research cover a broad swathe of areas such as infrastructure and rolling stock, intelligent mobility, energy and environment, personal security, safety and homologation, competiveness and enabling technologies, and strategy and economics.

Horizon 2020 is the EC's latest and largest research and innovation framework programme. One of the aims of this R&D programme is to put Europe at the forefront of innovation in many R&D and

Innovation stream that has been set up to promote the competitiveness of the European rail industry and meet the changing EU transport needs. Specifically this initiative aims to support the delivery of the EU white Paper targets of doubling the capacity of the European rail system, increasing its reliability and service quality by 50%, while halving life-cycle costs.

Particular areas of research that would contribute to the C4R aspects of Affordability, Adaptability, Resilience, Automation and High-capacity are described in Table 4 (This is not intended to be a comprehensive list but a selection of the key areas where progress is needed).

Despite the budgetary constraints of recent years, most European countries have set out ambitious investment plans for their railways and a significant body of research on the potential future of rail and the contribution of new technology to delivering the next generation of rail have been carried out/are underway. A few selected examples include:

- 2030 Rail Network Strategy (Irish Rail, 2011)[11] – Irish Rail's plans for the medium and long-term development of the intercity passenger network and the freight network have been outlined in their strategy, taking into account the country's economic circumstances. The key objectives of the strategy reflect the wider EU railway vision, e.g. enabling modal shift to rail from the highways sector to reduce congestion and environmental pollution, reducing journey times and improving frequencies on high-volume for commuter and inter-city lines, facilitating long-term growth of rail, electrification of the core network and providing a real alternative to road travel.

  Irish Rail's Rail Review (2016) Report has in fact confirmed that the rail network has started showing increasing passenger numbers year on year since 2014 (following the large decrease since 2007). The actions from the Rail Strategy are being acted upon (e.g. longer freight trains were introduced in 2016) but a very significant challenge that could potentially derail progress still exists, significant gap in funding to catch up on asset management and investment for growth.

- Rail Technical Strategy Capability Delivery Plan[12] - Following on from the publication of the Rail Technical Strategy in 2012 and the Network Rail Technical strategy in 2013, the Capability Delivery Plan (2017) developed by the Rail Delivery Group and the Rail Supply Group together with the UK Department for Transport set out the 'capabilities that will enable the railway to offer better transport opportunities for passengers and freight'. The 4Cs (halving Costs, doubling Capacity, reducing Carbon and improving Customer satisfaction) remain the strategic goals for 2050 and reflect the EU White Paper goals. The Capability Delivery Plan sets out a list of twelve key capabilities to enable GB railways to meet the strategic goals.

[11] http://www.irishrail.ie/about-us/rail-vision-2030
[12] Rail Technical Strategy Capability Deliver Plan (2017). www.rssb.co.uk/rail-technical-strategy

- Future of rail 2050[13] – a thought piece by a private sector consulting organisation setting out a forward looking vision for rail, focusing on passenger and user experience to energise innovative thinking to meet the significant challenges and potential opportunities facing rail.

- Unlocking the Potential of Railways: A Railway strategy for CAREC, 2017 - 203014 - the objective of the strategy is to make 'rail the mode of choice for trade'. The development plan of improving rail and multimodal infrastructure aims to commercialise and reform railway activities to enable better capture of evolving trade flows and contribution to regional economic development.

- The trains, planes and automobiles of 2030[15] - The Japanese next generation high-speed trains which achieved a record top speed of 374 miles per hour during testing is expected to go into service in 2027; while the affordability of the Maglev technology is currently perceived as a significant barrier, the Japanese are hopeful that a wider market uptake (in particular the USA) will help to make the technology more affordable.

- Rail Freight Strategy – The European Court of Auditors[16] has reported that rail's market share of European Union (EU) freight has fallen since 2011 despite the EU contributing €28bn to rail projects between 2007 and 2013 and a concerted long-time effort (since 1992) to encourage a shift of freight from road to rail. There are several underlying reasons including the higher priority to passenger trains so that path allocation and price are issues and freight trains average speeds of only around 18km/h on many international routes. The decline in the use of coal that historically contributed to a high-volume, high-tonnage rail freight means that new core high-volume markets are needed to fill the gap.

  However progress has been made in a number of areas related to freight. While Austria, Germany and Sweden are reported to have achieved better results than the EU as a whole, there are several examples of some progress being made in other countries/routes through individual initiatives:
    - Rail freight between the Netherlands and Italy has surged between 2010 and 2016[17]. The Netherlands shipped twice the amount of freight by rail than by road transport to Italy in 2016. The opening of the Gotthard terminal has facilitated this change for example by enabling shorter journeys, longer trains and higher speed;
    - The introduction of new locomotives between the Spanish Port of Santander and the station of Mataporquera has delivered a by 12 per cent increase in freight traffic;

[13] http://www.arup.com/homepage_future_of_rail
[14] https://www.adb.org/documents/railway-strategy-carec-2017-2030
[15] http://www.alphr.com/the-future/1001886/the-trains-planes-and-automobiles-of-2030
[16] http://www.railjournal.com/index.php/freight/rail-freight-still-losing-market-share-in-europe.html
[17] https://www.railfreight.com/business/2017/08/03/rail-freight-netherlands-italy-surged-with-two-thirds/

- GB Railfreight (GBRf) in the UK is investing in new lidded biomass wagons[18] with a capacity to carry a higher payload of 70 tonnes (from current capacity of 53 tonnes) and auto-loading and discharging capabilities. This will enable GBRf to carry more biomass while reducing its carbon footprint and emissions; iGBRf has also been developing alternative core commodity markets such as intermodal freight; [19]
- There is growing recognition of the considerable potential for rail to serve as the carrier of high-value freight , e.g. a trial set up by the Eurocarex consortium in 2012 at St Pancras using SNCF Postal TGV (used to carry postal traffic on the French rail network) successfully demonstrated the feasibility of the concept;
- A new rail freight connection between the Spanish city of Salamanca and the Portuguese port of Aveiro is planned for completion in 2021. This railway will form a strategic component of the Atlantic Corridor in the Iberian Peninsula, situated as it is in an area with very high traffic from and to the ports;
- Researchers at the University of Huddersfield[20] in the UK are looking into the possibility of manufacturing lighter weight bogies for the rail freight industry. With a reduction in weight, track damage, energy consumption and carbon emissions could be lowered and opens up the possibility of lower track access charges.

The examples described form just a small snap shot of the work being carried out. They form a part of the large number of smaller enhancements and innovations being deployed across the European rail network that are supporting progress towards Rail 2050. Clearly progress is being made but it is still too early to measure the collective impact of the investments.

SUMMARY

The 2030/2050 vision and the associated benefits of an effective trans-European passenger and freight railway are recognised by the member countries. The particular environmental benefits of the railways over the automotive sector and its superior capability for the provision of mass transit are the other significant factors influencing significant investment into the railways, both at the national and international levels.

While traditionally railways have been slow to respond to change (in relation for example to the automotive and the aviation sectors), over the last decade this has also changed. This is demonstrated by the significant body of R&D and innovation that has been carried out and outcomes implemented. The targets of the 2030/2050 Railways are extremely challenging and while progress in achieving the environmental targets appears to be on target, there are some key areas where

[18] https://www.railbusinessdaily.com/news/new-hoppers-will-allow-gb-railfreight-to-carry-one-third-more-biomass/?utm_medium=email&utm_campaign=11117%20-%20e-newsletter&utm_content=11117%20-%20e-newsletter+CID_769cfdaeda229de5dc33a175f756d54a&utm_source=Email%20marketing

[19] https://www.railbusinessdaily.com/news/gb-railfreight-delivers-christmas/?utm_medium=email&utm_campaign=91117%20-%20e-newsletter&utm_content=91117%20-%20e-newsletter+CID_3e961c58916f7dbb22b23a29b2b9fdad&utm_source=Email%20marketing

[20] https://www.railfreight.com/business/2017/08/10/lighter-weight-bogies-to-change-rail-freight-industry/

sufficient progress has not been made. For example, three areas where progress has been significantly low are:

- Modal shift from road to rail: The main reasons appear to be the high cost of rail freight relative to road freight (both in terms of current operations and upgrading the freight network, rolling stock, interchanges and terminals); In addition, there are difficulties in allocating train path for freight and often at times of conflict, passenger trains are given priority resulting in low average freight train speeds;
- Electrification of network and upgrade of signalling: The overall progress on the electrification of the network and the change from traditional signalling to ERTMS has been far slower than originally planned. Once again the high cost of implementation has been the significant barrier. This also has major impacts on delivering greater capacity from the existing railway network
- Higher levels of Automation: While progress is being made in discrete areas and within specific parts of the networks, increasing the grades of automation on railways has not kept up with the apparent progress on the automotive sector.

This again shows the important role that the H2020/Shift2Rail programmes can play in supporting the achievement of the 2030/2050 rail vision.

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
1	Growth in rail traffic • Passengers • Freight • High-speed lines	✓	✓	✓	-	-	Across EU-28, rail passenger levels have registered a small but consistent growth (under 2%) in the last few years; however not all countries have registered an increase in numbers; Growth in rail freight has been more or less stagnant or in fact showing signs of decreased activity overall. The average trend also masks the fact that while some EU countries have experienced strong growth in rail freight (e.g. Germany, Baltic countries), a number of other countries have experienced a sharp decline (e.g. France, Bulgaria, Slovenia). Based on current levels of usage and growth, the 2030/2050 targets are challenging.
2	Rail freight Corridors & Container traffic	✓	✓	-	-	✓	Historically rail freight has been driven by high-volume, high tonnage goods. Decline in commodities such as coal and steel are changing the rail freight landscape. Unlike passenger trains that run to timetables, freight trains run in response to customer and supply chain demands. Significant improvement of the availability of train path for freight trains and flexibility of the container designs are required. Currently rail freight is not competitive with other freight transport modes. Some of the factors underlying this are the lack of capacity and the low overall speeds of freight trains (caused mainly by the prioritisation of passenger trains on the network, the high cost of rail freight interchanges and quality of the freight rolling stock)

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
3	Expansion of rail network	✓	✓	✓	✓	✓	The overall length of the European rail network has remained more or less unchanged in recent years. By contrast, the road network has continued to grow, in particular the motorway (roads with grade separated junctions) networks that carry a significant proportion of highway traffic.
4	Expansion of rolling stock fleets (passenger & Freight)	✓	✓	✓	✓	✓	An important measure of the potential to provide capacity is the rolling stock available to run services. While rail passenger vehicles have shown a small overall increase, there has been a significant decline in the number of freight vehicles.
5	Electrification of rail network	✓	✓	✓	✓	✓	Electrification of the rail network is another fundamental enabler of the 2050 high-capacity / low emissions network. However the rate of electrification has been slow, with an increase of just 0.5% over the 2 year period, 2012 – 2014. The proportion of electrified network varies significantly between countries, between 85% (Luxembourg) and 24% (Denmark).
6	More demanding customer (passengers & freight) expectations	✓	-	-	✓	✓	There is growing requirement for the railways to keep pace with the improved and innovative services offered by other customer facing industries; this is driven also by the exponential growth in mobile devices and the constant flow of real-time information. There is therefore a very strong market requirement for rail operators to significantly

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
							increase the rate of automation to provide the levels of service customers expect.
7	Competitiveness of air/road/water travel	✓	-	-	-	✓	Rail, in particular rail freight, continues to lag behind road and water in terms of cost competitiveness. It is particularly less competitive on routes shared with passenger trains due mainly to the lack of flexibility and the higher priority accorded to passenger trains. It is generally accepted that for journeys <200km, road is the mode of choice. For journeys of over 200km the costs of rail freight start reducing and over 300km rail is more cost competitive. Any increase in fuel cost can affect the competitiveness of roads but on the whole the road sector is more responsive to changes in the economic cycle and market requirements. The lack of flexibility is a key barrier for rail freight, particularly on routes shared with passenger traffic.
8	Energy - costs and availability	✓	-	-	-	-	The availability of different types of energy can have significant impacts on the transport sector. While road transport represents the largest consumer of energy, that sector is also investing heavily into looking at alternative sources of energy (e.g. electricity/battery) as well as improving the energy efficiency of road vehicles. Progress is also being made in the rail sector, e.g. the light-weighting of bogies, use of regenerative braking. However progress is relatively poor, e.g. the rate of electrification of

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
							the European rail network is progressing far more slowly than originally planned
9	Demand for interoperability	✓	✓	✓	✓	✓	Interoperability is seen as a key driver in promoting a single cross-boundary market to improve efficiency, gain economies of scale and increase the competitiveness of rail with other modes of transport. While significant progress has been made in the development of standards, due to the complexity of the railway system, the implementation of interoperability is a continuing challenge. Progress on some of the enablers of interoperability such as the TEN network is on route to meet targets while others such as the implementation of ERTMS is continuing to lag.
10	Urbanisation & Demographics	✓	✓			✓	Increasing urbanisation (leading to growth in the already crowded commuter traffic market) and changing demographics (decrease in overall population but an increase in the number and share of the elderly in the population) leading to changes in the expectations of customers about the type of services. Adaptability to enable a service that is responsive to rapidly changing customer requirements is therefore of critical importance to achieving the target of making rail the ‘transport mode of choice’.
11	Intelligent Transport Systems (ITS) including modal shift	✓	✓	✓	✓	✓	ITS is vital to the development of sustainable transport

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
							systems in Europe, an objective that underpins the targets for modal shift set out in the 2011 EU White Paper. For example, ITS can enable better planning by providing passengers with up to date and integrated information. A number of European (& national) projects have been carried out to support the White Paper objectives. Digital innovation in particular is becoming more widespread across all modes. In rail significant progress has been made in areas such as smart ticketing, open data systems and big data analytics enabling greater choice and efficiency for passengers and freight, use of sensors and intelligent systems to improve asset data collection and management etc. ITS is a key enabler of automation and has the potential to deliver the transformation required by the 2050 targets.
12	Technology step changes	✓	✓	✓	✓	✓	Internet of Things - – Enabling use of sensors, big data analytics, Machine learning etc can increase the pace of change and support the drive to decrease cost, increase efficiencies; this is being adopted across various rail disciplines, engineering, maintenance, signalling, communications, ticketing
13	Environmental requirements & Climate change	✓	✓	✓	-	-	Climate change impact is one of the main threats to ensuring a reliable railway. Railway assets are long-life assets and this makes change more difficult and expensive.

	Trends / Influencing factors	Relevant to					Comments
		Aff	Adap	Res	Auto	Hcap	
							However over the last decade the need to ensure that the various systems are resilient to the 'new' extremes of climate change effects have been recognised and have resulted in a considerable body of R&D to find appropriate solutions.

TABLE 3 TRENDS AND FACTORS INFLUENCING FUTURE RAILWAYS

Key:

Aff: Affordability;

Adap: Adaptability

Res: Resilience;

Auto: Automation; and

HCap: High-Capacity

Affordable	Adaptable	Resilient	Automated	High-capacity
Infrastructure and Rolling stock				
1. Design and construction of cost-effective rail infrastructure, including track, stations, bridges and depots 2. Optimized inspection/maintenance of rail infrastructure 3. Design, construction, certification and acceptance of safe, quiet, energy efficient, high speed rolling stock 4. New rolling stock designs (passenger & freight) – flexible, ergonomic, 5. Inspection and maintenance of rolling stock 6. Design of smart (electricity) grids 7. Alternative fuel for infrastructure & rolling stock (e.g. photovoltaic cells, hydrogen trains etc)	1. Design and construction of rail infrastructure with standardized interfaces 2. Design, construction, certification and acceptance of high speed rolling stock (passenger and freight) 3. Design, construction, certification and acceptance of (passenger and freight) – flexible designs responsive to changing requirements (e.g. freight container designs, passenger train interiors adaptable to carry high value freight) 4. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options	1. Design and construction of rail infrastructure, including closure/replacement of level crossings 2. Design, construction, certification and acceptance of high speed rolling stock 3. Design, construction, certification and acceptance of rolling stock resilient to climate change impacts 4. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options	1. Sensor technologies and monitoring systems for infrastructure and rolling stock 2. Design and construction of rail infrastructure, including track, stations, bridges and depots 3. Design, construction, certification and acceptance of high speed rolling stock 4. Design and implementation of Euro-wide secure signalling and communication systems 5. Digital rail – modern digital signalling and train control systems 6. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options	1. Design and construction of rail infrastructure, including track, stations, bridges and depots 2. Automated inspection/maintenance of rail infrastructure 3. Identify land-use and planning requirements for rail infrastructure 4. Design, construction, certification and acceptance of safe, quiet, energy efficient, high speed rolling stock 5. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options

Affordable	Adaptable	Resilient	Automated	High-capacity
8. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options				
Operations				
1. Noise measurements and mapping adjacent to railways 2. Whole life operating cost model for rail transport 3. Safety analysis models for rail transport 4. Infrastructure enabling implementation of ERTMS level 3 – 5. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options	1. Command and control system to optimise capacity on rail network (e.g. ERTMS level2 and Level 3) 2. Bottlenecks – identification and removal 3. Border restrictions – identification and removal 4. Depot/freight terminals – optimal capacity and operating protocols 5. Risk analysis and contingent planning systems for climate change adaptation 6. Development of appropriate tools (e.g. models, simulators) to	1. Command and control system to optimise capacity of rail network 2. Modelling the operation of depots/freight terminals to optimise safe capacity 3. Modelling the operation of stations to optimise safe capacity 4. Risk analysis and contingent planning systems (including flexible timetabling) for recovering degraded modes 5. Modelling and analysis of extreme weather events 6. Safety and security systems at Member	1. Develop automatic data collection and analysis models for maintaining rail infrastructure 2. Develop automatic data collection and analysis models for maintaining rolling stock 3. Design and implement Euro-wide information system and common data structure for rail users 4. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options	1. Command and control system to optimise capacity of rail network 2. Bottlenecks - identification and removal 3. Modelling the operation of depots/freight terminals – to optimise safe capacity 4. Modelling the operation of stations to optimise safe capacity 5. Safety and security systems at Member State borders 6. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment

Affordable	Adaptable	Resilient	Automated	High-capacity
	support evaluation, appraisal of investment options	State borders 7. Development of appropriate tools (e.g. models, simulators) to support evaluation, appraisal of investment options		options
		Documentation		
1. Develop common metrics and data model, operating protocols, safety authorisation and certification procedures, information management systems, specifications, standards etc.	1. Develop common metrics and data model, operating protocols, safety authorisation and certification procedures, information management systems, specifications, standards et	1. Develop common metrics and data model, operating protocols, safety authorisation and certification procedures, information management systems, specifications, standards etc	1. Develop common metrics and data model, operating protocols, safety authorisation and certification procedures, information management systems, specifications, standards etc	1. Develop common metrics and data model, operating protocols, safety authorisation and certification procedures, information management systems, specifications, standards etc

Table 4 Research to enable 2030/2050 Railway

4. Capacity for Rail Progress

The fundamental aim of the C4R project was to support the vision of making rail the 'mode of choice for transport' for passengers and freight by contributing to the research, development and innovation activities towards the achievement of a high-capacity and responsive to demand (passenger and freight) railway that is affordable, adaptable, resilient and automated.

The work carried out in C4R represents some of the initial steps in moving towards the 2030/2050 vision for Rail and meeting the targets set in the European White Paper. While it is acknowledged that additional work is required to progress the innovations to higher TRLs and closer to market, they provide the necessary foundation to deliver Incremental enhancements based on the underlying principle of taking a whole systems approach to delivering some of the necessary solutions for rail. The research underpins the requirements of the future railway such as more passenger & freight trains, higher use of the available capacity of the infrastructure without compromising on performance such as:

- infrastructure and rolling stock designs for speeds up to 480km/h enabling high-speed trains and thereby delivering greater capacity outputs;
- longer and lighter freight trains with capability to carry higher loads (tonnage) and thereby reducing costs, reducing environmental impacts and supporting modal shift from road to rail;
- improving formal & unified process for disruption management and recovery from extreme weather events / incidents on the European rail network for passenger & freight trains and thereby improving reliability and resilience;
- making better use of available capacity through improved operations and responsive timetabling, effective use of large and diverse sources of data, tools to support evaluation and appraisal of investments and thereby delivering more useable capacity efficiently and eligibly.

C4R Research, Innovations and Outputs

Research, innovations and outputs from the C4R project fall into four main categories:

V. Infrastructure: covering selected topics in Track, Bridges, Switches & Crossings and Advanced monitoring techniques; the outputs are a mix of new products (at demonstration level), decision support tools, guidelines and framework;

VI. Rolling stock - Freight: covering selected topics related to innovative wagon designs (maximising useable lengths, increased flexibility), Automatic couplers and improved designs for interchanges in terminals; the outputs are in the form of conceptual designs, guidelines and guidance for future actions;

VII. Operations: covering selected topics related to enabling faster recovery from extreme weather events, faster and responsive timetabling, common data architectures to enable integrated and effective use of data sets; the outputs include Guidelines, Process diagrams, Simulations tools, Common data architecture and Roadmaps;

VIII. Railway system: covering selected topics related to the use of a whole system approach; outputs include scenario analysis tools and results, decision support tool for evaluating alternative options to increase network capacity.

A breakdown of the innovations and outputs from C4R, and brief indications of their potential to contribute to the Rail 2050 targets are given in Table 5 (infrastructure), Table 6 (Freight), Table 7(Operations) and Table 8 (Railway System).

The potential of the outputs from C4R to contribute to the high level targets of reducing cost, environmental impacts, modal shift to rail, reducing disruption (from incidents, extreme weather events) and contributing to overall increase in capacity are proposed. A rough estimation of the relative levels of contribution is given in terms of: high - ✓✓✓; medium - ✓✓, and low - ✓.

In addition an indication of the potential timescale (in terms of short-term (by 2025), medium-term (by 2035) and long-term (beyond 2035) is given. For each output, brief descriptions are provided in the comments column. Detailed descriptions of the outputs are provided in the detailed task reports.

				Potential to contribute to Rail 2050 targets												
No	**INFRASTRUCTURE - C4R Innovations / outputs**	Type	Usability	Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
	Track															
1	**Design requirements (functional and technical) and improved guidelines for design (new track concepts) – plain lines and differentiated for high speed, mixed traffic** a) Track loading b) Greater resilience to climatic impacts c) Costs and RAMS oriented	Knowledge Guidelines for new designs better able to meet future needs	**LT**	✘	✓✓	✓	-	-	-	✓	-	✓	✓✓	✓✓	-	The guidelines have been produced by drawing together current knowledge and expert analysis and developing new track designs that have the potential to meet both the functional and technical requirements of a railway carrying significantly more freight within a mixed high-speed traffic environment. The guidelines provide a robust foundation for further development, through other R&D programmes (e.g. Shift2Rail) of rail tracks that can deliver a more affordable railway through the reduction of whole life costs; a railway that is appropriate for the one envisioned for 2050 with a higher market share of freight traffic (through increased capability). While the designs represent tracks that require less frequent and more easily implementable maintenance (e.g. shorter possession time, modular set up with standard parts), in the short-medium term, the cost of new construction is expected to be higher than current norm. This can, however change with time, greater take up of the designs and the building up of more experience within the industry.
2	**Computer Model for track design optimisation; the model can be used to examine &/or predict** a) Effects of increasing train speed to 400kmh & 40 MT/yr. tonnage b) Instantaneous dynamic response of track to passage of a train c) Cumulative dynamic response of track to passages of trains d) Long-term geometric deterioration of track	Knowledge Computer Model DST	**ST**	✘	✓✓	✓	-	-	-	✓	-	-	-	✓✓	✓✓	The computer model enabled numerical analysis of alternative track design solutions to examine the impacts on performance of rail pad and USP vertical stiffness variations. The numerical modelling analysed only the instantaneous response aspects and more work is required to extrapolate the results to provide information on long-term performance & enable a robust LCC evaluation. The selected theoretical solution itself has not been validated through laboratory testing in the CEDEX Track Box (due to logistical issues with the test box). However Pass-by tests on the impact on ballasted track on the Madrid-Barcelona High-speed lines have been carried out to provide a database of results for validating the results from future tests on the CEDEX Test Box. The tool can support the development of a more efficient maintenance management strategy based on predictive maintenance and thereby deliver cost savings, better performance and improved services for passengers and freight. This will contribute to the policy objective of a modal shift of passengers and freight from road to rail.
3	**Innovative Modular slab-track concept (1) - RAMS oriented design** **Moulded Modular Multi-blocks slab track (3MB): Guidelines for Assembly and Construction** a) Mixed traffic & high-speed traffic b) Construction – facilitated by inherent properties e.g. does not require precise sub-grade levelling, realignment due to soil setting is easy c) Asphalt subgrade d) Potential to standardise production process & mechanise installation process e) Standard elements (completely modular) f) Potential to standardise production process & mechanise installation process g) Elements can be maintained separately and do not require heavy machinery h) Block replacing possible	Product Laboratory validation completed	**MT to LT**	✘	✓✓	✓	-	X	-	✓	✓	-	-	✓	✓	The modular slab track design has been selected from a number of innovative designs developed as part of workshop discussions. A demonstrator version of the 3MB design has been developed and installed at the CEDEX test site . Laboratory trials of the prototype have been completed (at CEDEX, Track Box sections with granular sub-ballast). The initial construction cost of the modular slab track is expected to be higher than the ballasted track that can be used within the same context (e.g., high-speed passenger and freight); however, the potential for reduced maintenance costs (less frequent interventions & faster maintenance) is also high. Of particular importance is the increase in the availability of the track to traffic, better use of the high-speed potential of the infrastructure. While it is clear that the operating costs are lower than for ballasted track, further work is required to develop the Business Model that is needed to attract further investment. The design has specific advantage in addressing areas of the network that are critical to route performance and there is need to minimise maintenance and avoid the creation of bottle neck resulting in delays to passengers and freight trains.
4	**Innovative Modular slab track concept (2) - LCC oriented design** **L-Track concept: Guidelines for Assembly and Construction** a) Mixed traffic & high-speed traffic b) Construction – facilitated by inherent properties e.g. does not require precise sub-grade levelling, realignment due to soil setting is easy c) Asphalt subgrade; Continuously supported rail d) Potential to standardise production process & mechanise installation process e) Standard elements (completely modular) f) Potential to standardise production process & mechanise installation process g) Elements can be maintained separately and do not require heavy machinery h) Block replacing possible	Product	**MT to LT**	✘	✓✓	✓	-	✘	-	✓	✓	-	-	✓	✓	The modular slab track design has been selected from a number of innovative designs developed as part of workshop discussions. A demonstrator version of the L-Track design has been developed and installed at the CEDEX test site . Laboratory trials of the prototype are underway (at CEDEX, Track Box sections with granular sub-ballast). The initial construction cost of the modular slab track is expected to be higher than the ballasted track that can be used within the same context (e.g., high-speed passenger and freight); however, the potential for reduced maintenance costs (less frequent interventions & faster maintenance) is also high. Of particular importance is the increase in the availability of the track to traffic, better use of the high-speed potential of the infrastructure. While it is clear that the operating costs are lower than for ballasted track, further work is required to develop the Business Model that is needed to attract further investment. The design has specific advantage in addressing areas of the network that are critical to route performance and there is need to minimise maintenance and avoid the creation of bottle neck resulting in delays to passengers and freight trains.
	Bridges															
5	**Modelling of dynamic response of bridges to very high speed trains** a) Up to speeds of 480km/h b) Impact of vibration on passenger comfort c) Alternative options to reduce vibration levels d) Recommendations for further research & updating Eurocode (related to bridge requirements for very high speed trains)	Knowledge	**LT**	-	✓	✓	-	-	✓✓	-	-	-	✓	-	-	This early-stage research carried out train-track-bridge dynamic simulations to get a better understanding of the dynamic response of bridges to very high speed trains (up to 480km/h) in order to improve the designs and increase the reliability and resilience of these services. This is particularly important as there are a large number of bridges on the very high speed lines and current EUROCODE requirements do not cover speeds over 350km/h. The desk-top research covered short-span beam bridges and frame bridges. Full-scale trials have been carried out on an 8m portal frame bridge on the Madrid-Barcelona high-speed line. While the simulated response showed good agreement with the experimental results, further field trials and research are needed to better understand the dynamic behaviour under different circumstances and develop robust & implementable bridge designs that can cope with the dynamic impacts of very high speed trains.
	Switches & Crossings															
6	**Resilient S&Cs (Simulations & numerical modelling)** a) Proposed short-term solution (Obj: reduced loads. rail profile degradation & wear) b) Proposed medium-term solution (Obj: improving the performance of the crossing panel & optimising rail pad stiffness) c) Proposed long-term solution (Obj: Moving away from the current incremental approach to S&C design; Whole system approach, e.g. pre-fabricated ballast-less modular track design, providing greater efficiency & lower cost) d) Weather resilience (Obj: Preventative measures to reduce buckling due to high temperatures) e) Condition monitoring (Obj: mitigate failure impacts - switch blade movement, dynamic forces, switch heating)	Knowledge	**LT**	-	✓	✓	-	-	-	-	-	✓	✓	-	-	Early stage of research - concept building. Further validation (of models), laboratory tests and field measurements are needed to realise improved performance. Improving the resilience of S&Cs has the potential to contribute significantly to reducing disruptions to services due to infrastructure issues.

				Potential to contribute to Rail 2050 targets												
No	**INFRASTRUCTURE - C4R Innovations / outputs**	Type	Usability	Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
7	**S&Cs - innovative concepts to improve performance** a) Use of alternative material (bainitic frognose & R350 head hardened steel) b) Material testing with new disc equipment c) Laser profiler measurement equipment for crossings	Product	**LT**	-	✓✓	✓	-	-	-	-	-	-	-	-	-	Live trials have been carried out on the rail network in Sweden. One aim of the demonstrator was to confirm the capability to identify the exact positions of S&Cs, establish the correlation between track geometry in the S&C and corresponding maintenance data and thereby improve the accuracy of the predicted need for and timing of tamping. Improved planning for preventative maintenance will enable a more reliable network and lower maintenance costs while also delivering improved performance. Evaluation of the performance of crossings with new materials (bainitic frognose & R350 head hardened steel in the wing rails) are on-going. Results from the early part of the trial has shown that hardness has increased and there is no wear on the material. It is expected that the relative short installation time (~3.5h) making in-track repair feasible and the increases hardness of the material will improve internal quality, increase the lifetime of the asset and reduce maintenance costs.
	Sensors for Advanced Monitoring															
8	**Embedded sensor: Passive RFID tags** a) SHM monitoring b) Strain gauges c) Environmental parameters (e.g. temperature, moisture)	Product	**MT to LT**	-	✓✓	✓	-	-	-	-	-	-	-	-	-	Trials of sensors embedded in slab track have been carried out.- this has shown that live data from SHM is recoverable. Also, the use of the sensor will deliver savings on work & reduce possession time. The results are extendable to other used of RFID tags (e.g. continuous monitoring).
9	**Embedded sensor: Accelerometer on sleepers (wireless vibration monitoring)** a) Low cost, low power b) Easy installation c) Use of energy harvesting (e.g. solar), long-life battery d) Remote access e) Weather-proof	Product Technology Evaluation framework	**MT**	-	✓✓	✓	-	-	-	-	-	-	-	-	-	Vibration based 'track movement system' sensor was chosen following an analysis using a 'Technology Identification Framework' that looked at the Drivers, Barriers, Capabilities and Applicability of the technology being investigated. The framework itself forms a useful tool to enable a systematic early stage identification, evaluation and selection of technologies that have the potential to deliver benefits. Following laboratory trials (on test track), live trials of the vibration based track movement monitoring sensor have been carried out on high speed lines (HS1 in the UK and a transition zone onto a bridge in Portugal). The trials have confirmed that the low-cost sensors are easy to install, require low power, an energy harvesting system (e.g. solar panel) can be used to power the sensor and data can be accessed remotely. Also that the sensor are a cost-effective addition to the monitoring toolbox.
Key	DST: Decision Support Tool; Usability - ST: Short-term (within 5 years); MT: Medium term (5 to 10 years); LT: Long-term (more than 10 years); Potential to contribute to targets - x: negative; -: not relevant or no impact; ✓: positive impact															

TABLE 5 RESEARCH, INNOVATIONS & OUTPUTS FROM C4R : INFRASTRUCTURE

No	FREIGHT - C4R Innovations / outputs	Type	Usability	Potential of the innovations to contribute to Rail 2050 targets: Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
Gap analysis and requirements specifications																
1	**Freight system requirements of the 2030/2050 European Railway (meeting the EU White Paper targets)** a) Evaluation of development trends in Europe b) Requirements to deliver incremental & system changes c) High level analysis of the measures and costs of the proposed 2030/2050 freight system	Advisory Note	LT	✖	-	✓	✓✓	-	-	✓✓	-	-	-	✓	-	A critical review of the current state of play with regard to rail freight in Europe followed by a detailed analysis of the freight market and the competitive and regulatory environments in which rail freight is operating and has to operate in the future. This provides the base point from which a transformational change will need to be achieved the meet the rail freight targets and deliver on the stated objectives to reduce operational costs, carbon and noise emissions and incentivise the modal shift of freight from road to rail. The reported data on the achieved growth in rail freight (including inherent rail growth and transfer from road to rail) shows that the continuation of current trends are insufficient to meet the targets set for rail freight (both in 2030 and 2050). A strong commitment and significant investment in infrastructure as well as rolling stock is a critical requirement to change the current trends and improve the potential to achieve the required trajectories of rail freight growth. Changes needed to infrastructure, rolling stock and signalling to achieve the change from small incremental steps to strong system level growth are described.
Delivering Greater Efficiency - Freight Rolling Stock (Wagons) Designs																
2	**Concepts & innovations in wagon design to enhance rail freight efficiency** a) Technical feasibility of new designs b) 12-axle bogie wagon with Jacob-bogies for five 45 ft containers c) 12-axle wagon with 4 pocket frames & Jacobs bogies d) 6-axle wagon for transport of cars b) Electronically controlled pneumatic brakes, electric line along the train, End-of-Train device	Conceptual designs (higher reliability, lower cost)	LT	✖	✓✓✓	✓✓	✓✓	✓	-	✓✓	-	-	-	✓	-	The new designs have been developed to enable greater flexibility in the container configuration allowing more efficient use of the train length and greater load carrying capability. This can translate into lower unit costs and thereby improve rail freight's competitiveness against road freight. Drawings of the new designs are provided supported by a detailed analysis of the technical feasibility (using mathematical programs/expert opinion) of the designs proposed by assessing against a defined list of criteria (greater reliability at lower cost & lower noise levels, lower unloaded weight of wagons, greater usable length, in-built flexibility to enable carrying of different types of loads, higher maintainability and increase in manoeuvrability (e.g. better brakes). CBA, roadmap for introduction, impact on network operations & logistics. Expected impacts have been assessed (e.g. increase in usable length, carrying capacity, operating cost, manoeuvrability, The initial technical feasibility analysis (of proposed designs) using analytical methods (e.g. from Queuing theory & discrete event modelling) and high-level CBA (for the case studies considered, (i.e. Car transportation business & container transportation) indicate potential reduction in transportation costs alongside a significant increase in the efficiency of operations. Further work is needed to define the overall benefits, technical & contextual feasibility of the designs and their contribution to rail freight system performance.
Terminals & Interchanges																
3	**Concepts/innovations of transhipment technologies & interchanges to handle future freight (different levels and types of freight)** a) Interchange types: Rail to road (long-distance & shorter range units transfer); rail to rail(shunting &/or gauge interchange) , rail to waterways (sea & inland) b) Three Case studies for evaluation of future scenarios (Overall performance of the terminals & performance of its components): • Rail - rail (Terminal in Munich), • Rail - road (3 terminals in Antwerp) & • Rail - port (Port of Valencia); Hallsberg (Marshalling yard in Sweden) c) Technological & Operations innovation to improve terminal performances: • Information & Communication • Intelligent Transport Systems	Conceptual designs (Reducing cost, increasing efficiency) Making freight more competitive	LT	✖	✓	✓	-	-	-	✓✓✓	-	-	-	✓		The inefficiencies in the operation of terminals (resulting in time delays and cost increases) have been shown to be a key barrier to the making rail the transport 'mode of choice' for the carriage of freight; Intermodal termini are currently large, high-cost and space intensive. The concepts and designs have been developed to enable the use of technology to improve the efficiency of freight handling at terminals and also provide the requirements to ensure that the terminals can handle all the different types of freight and respond quickly to the changing nature of freight. The case study approach has been used to demonstrate the evaluation of the performance of the typologies of terminals - to deliver operational & logistic improvements. Further work is required to assess the improvement in performance of terminals and its contribution to making rail freight more competitive (through lower cost & higher efficiency) with regard to rail freight; work is also required to evaluate and implement appropriate technologies to enable greater automation of the activities (e.g. loading/unloading) within the terminals/interchanges. Proposed potential innovations to deliver on factors such as reducing cost, energy consumption & GHG emissions, easier access, include: • Silent trains + last minute electric road vehicles (or other) enabling end-to end freight • Linear traffic (load & unload trains at high speed, horizontal transfer systems, avoiding need to part (lower cost to customers and society) • Cheaper, smaller but more frequent & more automated terminals • Replace hub & spoke terminal with Liner trains with wagons picked-up & dropped at stations along the way • Automation of marshalling yards
Rail freight systems for 2050 - requirements and standards																
4	**Catalogue of rail freight systems for Rail 2050 - requirements to deliver incremental change & transformational system change** a) Modal shift from road to rail b) High-speed rail network c) Multi-modal TEN-T Core network d) Traffic Management Systems e) Long-term comprehensive TEN-T network f) Multi-modal transport information	Guidelines for future actions	LT	-	✓	✓✓	✓	✓	-	✓✓	-	-	-	✓	-	Report provides a catalogue of requirements related to the different aspects making up the rail freight system in order to meet the EU White paper target for rail freight. It addresses issues such as: • The sub-systems of rail freight - wagons, locomotives, trains, infrastructure, the traffic system, IT & monitoring systems • Processes and timeframes for development and implementation • Barriers to achieving the rail freight targets • Industry surveys reporting on industry views on needs and priorities • Innovations, technologies and Operational processes
5	**Impacts on TSIs and requirements for new/revised Standards** Standards for fully integrated new rail freight systems based on evaluating requirements resulting from: a) New wagon designs b) Longer freight trains c) Providing new gauge d) Gradients and curves - revised standards e)Energy requirements & availability f) New network/train operations g) New train management system	Guidance	LT	-	✓	✓✓	✓	✓	-	✓✓	-	-	-	✓	-	This is initial work on establishing what is required to meet the requirements of existing standards and where new/revised standards would be required; establishing where compliance can be achieved within existing standards. The report aims to help develop a common understanding of the impacts of the proposed innovations on existing and future Railway Standards. Not a comprehensive document yet - but offers guidance to stakeholders and other organisations on what will be required to ensure compliance to regulations etc. Improved Standards and better compliance will support interoperability and improve the competitiveness of the rail freight sector. Standards are proposed for: new wagons & locomotives, gauge, trains. infrastructure design (to reflect the needs from the other proposed innovations), train & infrastructure management.
Key	Usability - ST: Short-term (within 5 years); MT: Medium term (5 to 10 years); LT: Long-term (more than 10 years); Potential to contribute to targets - x: negative; -: not relevant or no impact; ✓: positive impact															

Table 6 Research, innovations & outputs from C4R: Freight

				Potential to contribute to Rail 2050 targets												
No	**OPERATIONS - C4R Innovations / outputs**	Type	Usability	Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
	Operational Strategies															
1	**Improving tactical and operational processes for Infrastructure Managers** a) Simulations and models to support Infrastructure Managers (IMs) in evaluating enhanced line and train capacities (from innovations) of rail networks, including longer trains and more efficient freight wagons b) More efficient linking of the timetable planning (generally carried out on an annual basis, tactical level) & operational planning (generally 3 days to 8 hours prior to actual traffic, short-term rescheduling & dispatching) c) Models & simulations that can be used to asses innovations to increase capacity d) Gap Analysis to identify further development needs (including need to harmonise planning systems across European countries e.g. for international path requests)	Review: Models & tools, Best Practice, next steps for improving tactical & operational planning	**ST to MT**	-	-	✓	-	-	-	-	-	-	-	✓	✓	Scenario for improved optimised control has been defined; A set of potential scenarios to validate the proposed approaches have been developed and shared. The scenarios have taken account of the scope and size of the network underlying the scenario and its capabilities (traffic homogeneity, signalling system, current levels of traffic control) as well as the availability of data List of models and tools currently used by different IMs The critical gap is the discrepancy between existing tools for real-time traffic control and practical operational requirements; need for open-source software and open access to data held by national railways; gaps in timetable planning & operational control that are barriers to achieving higher capacity Use of mathematical modelling to introduce greater flexibility in timetable planning Best practice from the planning processes used by IMs in Great Britain, Sweden and Germany (lessons learnt, barriers identified and planned innovations) have informed the developed of the generic framework
	Simulations & Timetabling - Better use of Useable Capacity															
2	**Modelling and evaluating the impacts of innovations on capacity** a) Models/simulations framework requirements - to accommodate improvements in infrastructure, signalling, timetabling principles, train operations & control b) Innovations to improve current framework includes: ● Integrating uncertainty in traffic control and delay managements into current models ● Feasibility of microscopic simulation in a real-time environment	Guidelines To enable greater efficiency in the use of existing networks	**ST to MT**	-	-	✓✓	-	-	-	✓	✓	-	✓	✓	✓✓	Theoretical impacts on capacity - Integrating uncertainty within the traffic control framework; examining the impacts of different levels of automation in traffic control on capacity consumption. Uncertainty modelling with Bayesian networks - of train delays (application to a 180km railway corridor, Stockholm to Malmo in Sweden); demonstrated validity of approach to use live delay data to predict delay propagation along the route. Potential applications of proposed approach: ● Provide updates on evolving traffic conditions to traffic controllers to support improved decision making; ● Enable evaluation of consequences of the actual decisions adopted; ● Provide up to date information on train delays to passengers and freight operators
3	**The LIU optimisation model** a) A statistical model to predict delay propagation on the rail network (based on Bayesian networks) b) Evaluate impact on capacity /performance from the addition of a train path c) Data requirements - stations and timetable for the trains on the simulation network	Tool Simulation and evaluation of delay propagation	**ST to MT**	-	-	✓✓	-	-	-	✓	✓	-	✓	✓	✓✓	LiU Model is an analytical tool to evaluate impact on performance when some of the parameters used in developing the timetable are changed. The tool can be used for planning and for providing up to date delay information on predicted performance to passengers & freight operators following an initial delay. Model output: Predictions of delays on the simulation network (probability of the occurrence of a delay event, predicted delays for arrivals at destination station, total delay on the simulation network).
	Operational Planning															
4	**CAIN (CApacity of the INfrastructure) - Demonstrator (IT Tool)** a) Has been developed by extending an existing system KADR for timetable and operational traffic to link with the statistical model LIU (Timetable evaluation) b) CAIN - software system has been designed to: ● Incorporate additional train paths into an existing timetable (e.g. to meet specific & temporary requirement) ● Optimise the existing timetable (e.g. impact on the performance of the trains in the timetable) ● Simulate and evaluate different options for additional paths	Tool Simulation and evaluation of impact of the provision of additional ad-hoc train paths	**MT**	-	-	✓✓	-	-	-	✓✓	✓✓	-	✓	✓	✓✓	The development of the CAIN Demonstrator has created a tool with the ability to: ● Establish a link/bridge between the two IT systems (KADR & LIU models) and enable interaction between different data exchange standards ● Transfer data from the Open source systems Railsys/Rail ML ● Create and display virtual networks The CAIN - LIU model output: Timetable robustness and impact on performance of the timetabled trains following the introduction of temporary additional train paths. CAIN-LIU Model scenario analysis: Malmo to Hallsberg corridor: ● Options to meet freight operator request for an additional train path; impact on delay of two alternative slots for the freight train have been examined
	Managing Disruptions															
5	**European practices and levels of automation for management of large disruptions** a) Current practices in and case studies from European countries (UK, Spain, Czech Republic, Slovakia, Sweden and France) for managing large disruptions caused by internal (e.g. infrastructure failure) or external (severe weather) events; b) Existing data for use in operations to communicate real -time information about traffic conditions, infrastructure issues, incident status c) State of the art on levels of automation defined in IT systems (general) and specially within the railway operations; detailed analysis of current and future levels of automation for managing disruption d) Railway infrastructure data formats in existence and their usability for disruption management, now and in a future with high levels of automation	Knowledge Collation of practices from several European countries to enable a single formalised process for disruption management	**LT**	-	-	✓	-	-	-	-	-	✓✓	✓✓	✓	✓	Aim is to inform the rail industry about current practices for small & large disruptions and also inform the development of a process based on a whole systems approach to better manage traffic operations during unexpected and severe disruption conditions. Enabling the network to return to regular operations as quickly as possible will contribute significantly to improved performance and making rail the mode of choice for passengers and also freight: ● Open source systems engineering modelling language SysML - potential to enable the development of a standardised process for European railways ● Analysis of disruptions caused by extreme weather events; disruption management processes in use ● Definition of current and projected levels of automation that can enable traffic management activities to improve the disruption management process ● Building on work carried out in an earlier FP7 project (ON-TIME); ● In-depth analysis of 'activities' making up the disruption management process (including examination of human-machine interactions);
6	**Network disruption management process** a) Use of a standardised and open source system engineering modelling language, SysML b) Integrates extreme weather event management process c) Support the Infrastructure Manager and Railway Undertaking	Process diagram: a decision support tool to enable IMS and RUs in making the decisions best able to speed recovery from disruption events	**LT**	-	-	✓	-	-	-	-	-	✓✓	✓✓	✓	✓	Use of SysML platform enables a systems approach to be used; Decision support tool - for both the IM & the RU actions covering freight. Addresses aspects such as monitoring and predicting state of infrastructure and operations (current & evolving), resource allocation, rescheduling, communication between the UM & RU (to ensure effective decision making), communication with other relevant stakeholders (passengers, freight operators, external data providers weather forecasts, etc), recovery plan (including creating revised timetable as appropriate) for use during degraded conditions. KPIs for delivering and measuring improvements in disruption management. Results of validation of the Disruption Management Process by comparing with processes used by IMs in France and UK. Impact of proposed disruption management process on the improvements proposed to improve and grow rail-freight operations (e.g. longer trains) . Developing contingency plans appropriate to freight including rerouting, greater use of electronic monitoring systems.

TABLE 7 RESEARCH, INNOVATIONS & OUTPUTS FROM C4R: OPERATIONS

				Potential to contribute to Rail 2050 targets												
No	**OPERATIONS - C4R Innovations / outputs**	Type	Usability	Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
Roadmap - Increased Automation To ???																
7	**Roadmap for automation strategies** a) Role of automation in the management of large disruptions, in particular extreme weather events b) Envisaged levels of automations within the different railway sub-systems (e.g. trains, command & control systems, stations, infrastructure signalling, power systems etc) c) Impact of different levels of automation	Knowledge / Guidelines Planning support for necessary developments to achieve 2030/2050 targets	**ST**	-	-	-	-	-	-	-	-	✓✓	✓✓	✓	✓	Recommendations for increasing levels of automation that will contribute to faster recovery and reduced impacts of disruptions as well as delivering increased capacity: ● Integration of weather forecast models to improve preparedness to extreme weather events and their consequences for railway operation ● Instantaneous and automated sharing of information between all interested parties enabling prompt and correct response to evolving condition ● Automated DSTs for optimising resource allocation ● Automating process to monitor and report on changing traffic conditions so that decisions are made with accurate and timely knowledge of the state of operations
Improving Capacity through Better Use of Data																
8	**Ubiquitous data for improving railway operations and enabling a high-capacity railway** a) Review of existing models and emerging approaches for data exchange used by the European Railway organisations b) Data formats (especially open data formats that can substitute proprietary data in the future) and models for data exchange in railway operations c) Collection, storage and effective utilisation of data (large data sets, from diverse sources internal & external to railways) d) Data models, resources, interpretation to support the C4R visions of the 2030/2050 railways	Review Data architectures to support future TMS, Improve railway operations, Meet evolving requirements	**MT to LT**	-	-	-	-	-	-	✓	✓	✓✓	✓✓	✓✓	✓✓	Data usage is critical to optimising the capacity utilisation; innovations are related to the use of data to enable more effective use of capacity and delivering a better service to users Relevant data formats, models, concepts - visions for 2030, 2040, 2050 railways. Current gaps: (Priority areas for modelling) - architecture recommendations - how proposed data sets in proposed formats and models can interact to enable scenario orientated software solutions. ESB architecture can provide an appropriate foundation for future Traffic Management systems. Improved integration of data can improve efficiency in the sector (~1 to 2% of annual revenue is lost due to poor data integration). Improved management and integration od data is key to improving the efficiency (& thereby increasing its competitiveness) of the railways Harvesting and using data from external public sources can contribute significantly to improving disruption management (e.g. through providing greater situational awareness) Suggestions on how the 'Data' world may be evolving over the short/medium term (e.g. can help the railway community to better position itself within the competitive multi-modal transport environment, in the rapidly changing business environment of the industry). Proposed architectures - greatly improving the maintainability, extensibility and lifecycle costs of large ICT deployments; also new challenges to overcome. Candidate architecture for future TMS platforms, the Enterprise Service Bus (ESB Model being looked at in Shift2Rail & by UK's Digital Railway Programme. ICT and data resources that could be used in the short to medium term . Candidate architectures for future TMS - The enterprise Service Bus. Semantic data models & supporting architectures; how the concept of ontology can add value to railway operations by decoupling software applications from the data they operate on - demonstrated adding value to railway operations through a case study; leveraging diverse data sources; Candidate architecture for handling high-velocity data within a reasoning framework; potential costs and benefits of the semantic approach to data integration plus limitations . Using data from external sources to improve operations/disruption management.
Key	Usability - ST: Short-term (within 5 years); MT: Medium term (5 to 10 years); LT: Long-term (more than 10 years); Potential to contribute to targets - x: negative; -: not relevant or no impact; ✓: positive impact															

TABLE 8 RESEARCH, INNOVATIONS & OUTPUTS FROM C4R: RAILWAY SYSTEM

No	RAILWAY SYSTEM - C4R Innovations / outputs	Type	Usability	Potential to contribute to Rail 2050 targets: Reduce Cost			Reduce env. Impact			Support modal shift to rail		Reduce disruption (lower delays)		Increased Capacity		Comments
				Constr.	Maint.	Ops	Carbon	Noise	Vib	Fr	Pass	Major	Minor	Fr	Pass	
Whole Systems Approach - Options to deliver Value for Money																
1	**Capability Trade-offs tool** A Decision Support Tool to help IMs and RUs to obtain Value for Money from investments to increase capacity of the rail network: a) An on-line high-level tool to evaluate rail capability trade-offs when considering different options to increase the capacity of a route b) The tool enables a whole-systems approach when planning upgrades to ensure early consideration of a full range of options c) The tool allows the user to input data related to the infrastructure, rolling stock and operations related to the route under reinvestigation d) While the fundamental objective of the tool is to help compare different options to increase capacity on a route, the tool has been designed to look at the (qualitative) impact on the other four C4R characteristics, affordability, resilience, adaptability and automation. This gives the user the flexibility to prioritise solutions that meet the particular needs of the route being considered.	Product On-line tool to support IMs and RUs to make comparative evaluation of alternative investment options to increase route capacity	**ST to MT**	✓	✓	✓	-	-	-	✓	✓	-	✓	✓✓	✓✓	Early definition is especially important as railways are a complex system and there are great risks and opportunities at stake when changes are made to any part of the system, infrastructure, rolling stock or operations. There is currently a lack of the right models and tools that can be deployed to support the early stage of concept development. The tool can encourage and facilitate early engagement between the different railway stakeholders (e.g. IMs, RUs) and can serve a critical role in identifying the cost-effective whole-system solutions. The tool is a decision-support tool and can help to focus investments to obtain the best value solutions by evaluating the relative effectiveness of different capacity enhancing measures. The main benefits of this high-level tool are to: ● Change current mind-sets and move away from specific sub-system solutions ● Whole-systems approach to generate and evaluate options ● Early robust identification of go/no go options for capacity enhancement of particular routes The tool can be accessed through the link: http://c4r.jerid.cz/ ; a User Manual is included in the Final Report an the tool in the Capacity for Rail website.
Investment Appraisal - Life Cycle analysis & Multi-criteria Analysis																
2	**Evaluation of innovations and new technologies** a) Review of tools and methodologies to evaluate innovations and technologies and their potential applicability to evaluate options against the C4R objectives to deliver an affordable, adaptable, resilient and automated high-capacity railway	Knowledge Decision support tools to improve overall efficiency of operations		-	-	-	-	-	-	-	-	✓	✓	✓	✓	The aim was to make best use of knowledge already available and get value from earlier investment by the EU and national governments. The review included assessment of relevant methodologies developed as part of earlier EU framework project (including MARATHON, INNOTRACK, ON-TIME, AUTOMAIN, SUSTRAIL, SMARTRAIL, INFRAGUIDER, MAINLINE, D-RAIL. The review also looked at other guidelines and processes in use such as RAILPAG, Network RAIL's GRIP (Guide to Rail Investment Process), UK Government's Green Book for the appraisal and evaluation of transport schemes, Transport for Scotland's Carbon Management System, RSSB's Whole Life Carbon Footprint of the Rail Industry, TRANS-TOOLS (Tools for Transport Forecasting ANd Scenario testing - a EU transport network model), TREMOVE , EMMOSS. The applicability and the capability of the different models and processes to support the requirements of the C4R project (i.e. to evaluate the contribution of the C4R innovations and technologies to the defined 2050 affordable, adaptable, resilient and automatic high-capacity railway) are described.
3	**Scenario Analysis - impact of new technologies and innovations** a) An integrated methodology for scenario evaluation based on Multi-criteria Analysis (MCA) and Cost-Benefit Analysis (CBA) b) The MCA is built around the five key aspects of the C4R project, Affordability, Adaptability, Resilience, Automation and Capacity c) The CBA is based on standard life cycle cost analysis methodology, taking into account direct and indirect costs and benefits	Framework Framework MCA and CBA of the impacts on European railway corridors of investment in infrastructure & freight	**ST to MT**	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	The framework incorporating the two methodologies (MCA and CBA) have been developed to take into account the challenges associated with evaluating the impacts of innovations that are still at low Technology Readiness Levels (less than 4). The aim is the report on the potential of the innovations from C4R to contribute to the 2050 vision for EU Railway Network. The methodologies take into account the constraints posed by the limited information available, e.g. on the costs of the implementation of the innovations, the migration path to deliver the network level changes and the uncertainty associated with the costs and potential benefits A Monte-Carlo based simulation analysis is proposed to address the high degree of uncertainty. The evaluation has taken into account the innovations from C4R related to infrastructure (slab track, new Switches & crossing), advanced monitoring systems and new concepts and structure for freight design and operations. Results are presented from case studies based on two railway corridors: Swedish sections of Scandinavian-Mediterranean corridor and Montpellier-Perpignan section of the Mediterranean corridor.
Roadmap to 2050 Rail																
4	**Roadmap - 2050 Rail** a) High-level roadmaps setting the 2050 vision for European Railways based on a review of published literature , including amongst others, for example EU White Paper 2011, European Transport Platforms (ETP) roadmaps, National Railway strategies and targets, TEN-T corridors, implementation of ERTMS, ECTP Roadmap for cross modal transport infrastructure innovations etc. b) Definitions and targets for the C4R characteristics, Affordability, Adaptability, Resilience, Automation and High-capacity c) Contribution of the research and development work in C4R to achievement of the targets	Guidelines Planning support to support for necessary developments to deliver the 2030/2050 Railways	**ST / MT / LT**	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	The roadmap, which is a high level statement, sets out the vision for the 2050 Rail as well as: ● A time frame showing the targets that are apposite to the achievement of the targets ● Relevant outputs that can contribute to the achievement of the targets, including relevant transport industry trends and drivers (facilitators and disruptors) that will impact on the progress ● Subjects for R&D broken down into three broad categories (infrastructure & Rolling Stock, Operating Models & Documentation) ● The deployment of ERTMS on the European rail network is currently well behind the planned schedule and on current progress, there is a very high risk that the 2030 target will not be achieved; this forms one of the main barriers to the achievement of the required increased capacity on the existing network, in terms of running more trains, reducing costs, improving reliability and increasing automation; the opening up of more freight paths and increasing the performance of freight trains that is crucial to enabling transfer of freight from road to rail is in particular dependent on the greater deployment of ERTMS across the network.
Key	Usability - ST: Short-term (within 5 years); MT: Medium term (5 to 10 years); LT: Long-term (more than 10 years); Potential to contribute to targets - x: negative; -: not relevant or no impact; ✓: positive impact															

5. Roadmaps - Progress towards Rail 2050

Progress towards Rail 2050

Key findings from the latest EU-wide progress report on renewable energy, published in 2017 (based on the 2015 national reports and other data)[21]:

- In its final energy consumption, the EU as a whole achieved a 16% share of renewable energy in 2014 and an estimated 16.4% share in 2015.
- The vast majority of EU countries are well on track to reach their 2020 binding targets for renewable energy, but all countries will have to continue their efforts to meet these targets.
- The transport sector achieved a 6% share of renewable energy in 2015, so some EU countries will have to intensify their efforts to reach the 10% binding target for transport by 2020.
- In 2015, renewables contributed to reducing greenhouse gas emissions by the equivalent of Italy's total emissions.
- Transport is the only sector which is currently below aggregated NREAP trajectories at EU level – making slow progress towards the mandatory 10% by 2020.

The findings essentially show that challenging targets are not particular to the railways. Within railways, progress has been made in a number of areas but, as with the renewables, the need to maintain and in some areas intensify efforts continues to be necessary.

C4R research has made some important contributions. As indicated as part of the development of roadmaps for achieving the vision of the 2050 Railways, the four steps on the journey are:

i. Research and Development;
ii. Demonstration /validation /applicability on railway networks;
iii. Standards. legislation, regulations etc where necessary and as appropriate;
iv. Implementation and realisation of benefits.

The research from C4R has resulted in the development of some 'products' and 'tools' that are potentially at low Technology Readiness levels, (potentially around 4).

- Products that have reached the early demonstration stage and with further testing, development and validation could progress to higher Technology Readiness Levels. These include:
    - Rail track: Two modular slab track designs aiming to reduce life cycle costs. It is also clear that wider implementation that can help to reduce initial implementation costs

[21] http://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports

(e.g. through economies of scale and improved skills in the use of this product) will be necessary to deliver on this objective;
    - Switches & Crossings (S&Cs): Innovative concepts to improve performance by supporting better timed and more accurate preventative maintenance. This improvement has the potential to contribute to improved performance as currently maintenance of S&Cs form a significant part of the IMs maintenance costs
    - Embedded Sensors – Low cost and contribute to continuous remote condition monitoring.
- Tools/models that are decision support instruments and have been used with case study data to show their applications and how they can be used to improve aspects of the railway system include:
    - Computer model for track design optimisation (rail pad and vertical stiffness variations) covering instantaneous response. Further R&D is required to process information on long-term performance;
    - The LIU Optimisation Model is an operations planning tool and evaluates the effects of changes to timetable development parameters on performance (e.g. prediction of delays);
    - Capacity of the Infrastructure (CAIN) – Demonstrator Model to examine options for incorporating additional train paths into an operating timetable to meet specific and temporary demand; Scenario analysis on the Malmo-Hallsberg corridor (Sweden) has been carried out;
    - Process diagram for Network Disruption Management – a decision support tool to support IMs and RUs in making speedy recovery from disruption events; process has been validated by comparing with processes in the UK and France;
    - Capability Trade-off tool is an on-line tool to help IMS and RUs to take a whole systems approach when evaluating investment decisions to increase route capacity; the tool allows the consideration of the inherent trade-offs between railway capabilities associated with any changes made to parts of the railway system;
    - A framework for LCC and Multi-criteria Analysis to evaluate the impacts on cost (affordabiity) and capacity of railway corridors from investments in infrastructure and freight.

A significant proportion of the remainder of the work in C4R has focused on early stage research and development, supported by some analyses (e.g. LCC, multi-criteria, scenario) to show the validity of the research and its potential (with further development) to contribute toward the progress to 2050 Rail.

A brief case study building on the results of a detailed LCC and Multi-criteria analysis of investment in infrastructure (slab track) and freight (longer and faster trains) and contribution of C4R projects to the qualitative roadmaps (developed as part of early work on SP5, and Deliverable 5.1.1) are provided in the following sub-sections

Case study – meeting freight market share targets

Two case studies have been developed, based on parts of the rail network on two European TEN-T corridors (Swedish sections of the Scandinavian-Mediterranean corridor and the Montpellier-Perpignan section of the Mediterranean corridor) to illustrate the contribution of the C4R project outputs to 2030/50 vision of an Affordable, Adaptable, Resilient, Automated and High Capacity European rail network. The detailed descriptions of the case studies including the different scenarios considered are provided in SP5, Task 4.2.3). Results from some of the scenarios are presented here for illustrative purpose.

The competitiveness of rail transportation is, to a large extent, dependent on its affordability. The data and inputs collected for the detailed Cost Benefit Analysis (CBA) carried out in another task (SP5, Task 4.2.3) have been used to develop some additional indicators that might support some of the assertions regarding the 2030/50 Vision for the European rail network. Both case studies have focused on the innovations from C4R that have contributed to aspects related to improving rail freight efficiency and increasing its modal share. The focus of the analysis was driven mainly by the available data and consequently the two aspects that have been examined are “Affordability” and “High Capacity” and the case studies have examined investment in track, switches and monitoring systems, as well as the effects of that investment on availability and fixed and variable maintenance costs. Infrastructure LCC, evaluated based on the CBA inputs and intermediate calculations, and normalised to gross traffic is shown in **Figure 3** for the Sweden case study.

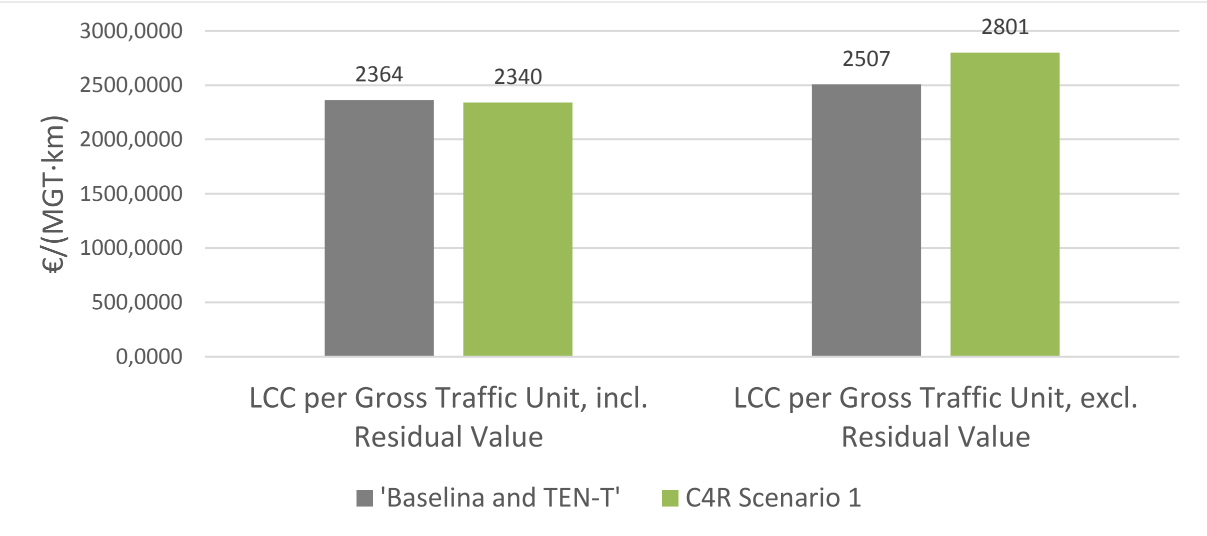

Figure 3. Comparison of Infrastructure Life-Cycle Costs (LCC) between “business-as-usual” and C4R Scenario with full implementation of infrastructure innovations. Results are for the Sweden Case Study, with and without taking into account residual values. LCC is normalized to Gross Traffic measured in Million Gross Tons (MGT).

The results show a marginal reduction of LCC (around 1%) when the track across the corridor is upgraded from current ballasted track to Slab Track (based on the modular design, a C4R innovation). This value takes into account the residual value at the end of the analysis period, which has been evaluated through the application of linear depreciation of asset value assuming a 60-year life for slab track and a 30-year life for standard ballasted track. If residual values are excluded from the evaluation, and considering only initial investment and maintenance costs in the 40-year evaluation period of the CBA, the slab track design leads to an increase in of 18% in the total costs. The analyses were carried out assuming a 1000 €/m target installation cost for slab track and innovative switches at 1.5 times the cost of standard ones. It is clear that a strong business case for slab track is dependent on further developing the innovations in a way that would significantly lower the initial costs.

Train operating costs are a key component of the overall affordability and, indeed, the CBA results have shown that they are crucial to the main benefits generating mechanism. In almost every one of the tested scenarios, the largest positive contribution came from the savings in the overall operating costs resulting from modal transfer from road to rail, further supported by savings on the existing rail traffic.

Average operating costs for the assumed traffic mix in the different scenarios that were considered in the assessment were extracted from the available data. The Swedish case study, as illustrated in **Figure 4**, showed that, even after including the reductions in operating costs, the overall cost reduction is still far from the ambitious 50% reduction to be attained by 2050. The conceptual designs proposed as part of the 'freight' innovations in C4R, enable the lengthening of freight trains to 1000m. Applying this to half the freight trains on the network, delivers a 10% decrease in costs relative to the current situation. Even in the so called "Rail Positive" Scenario (C4R Scenario 4), which simulates a total migration to innovative rolling stock, as well as terminal and feeder train automation, the average costs savings are not dramatically larger.

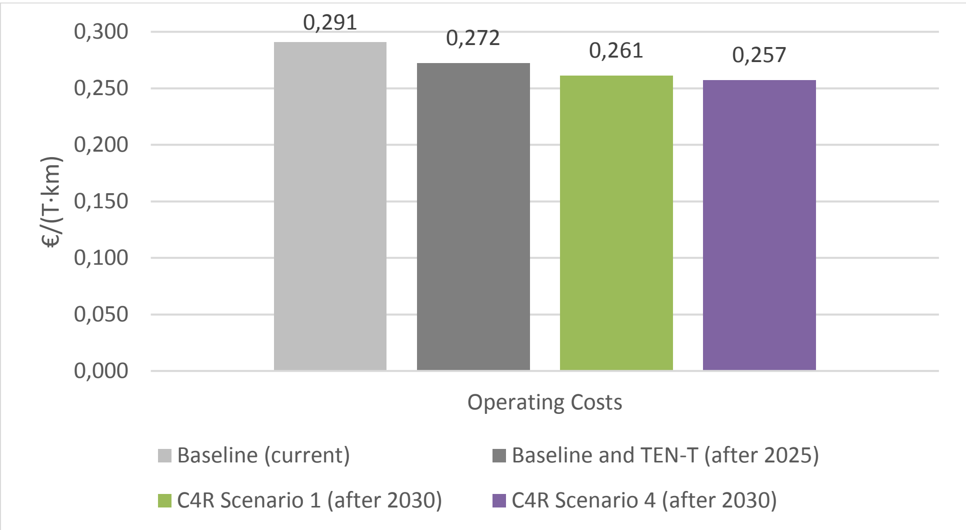

FIGURE 4. AVERAGE TRAIN OPERATING COSTS PER LOAD UNIT FOR CURRENT AND FUTURE RAIL FREIGHT TRAFFIC MIXES ASSUMED IN THE SWEDEN CASE STUDY. "BASELINE AND TEN-T" ALLOWS TRAINS UP TO 750 M, "C4R SCENARIO 1" ALLOWS TRAINS UP TO 1000 M IN LENGTH AND "C4R SCENARIO 4" FURTHER ASSUMES FULL ADOPTION OF AUTOMATIC COUPLERS, EP BRAKES AND TERMINAL AUTOMATION.

Affordability is not limited to economic and financial issues. Environmental affordability can be assessed, for example, by evaluating specific Greenhouse Gas Emissions. Once again, the targets for 2050 are very ambitious, aiming for a 50% reduction by 2030 (although this reduction is of course from across the railway sector). The available data does not allow the computation of embodied carbon, but the emissions from the operation itself have been computed and are shown in Figure 5 for the Swedish case study. As illustrated, there is a 25% reduction in specific emissions by 2030, which is a significant contribution for the target. These figures reflect only the rail sector, since it is to this mode that the target concerns. The overall reduction from transportation will be significantly larger owing to the effect of modal transfer.

It is worth noting that, after monetisation, GHG emissions have relatively small impact on the overall CBA results. This component, the only one included in the computation of externalities, did not significantly shift the overall results in terms of Net Present Value (NPV) or Internal Rate of Return (IRR). The monetisation however based on an arbitrary conversion factor, since it is extremely difficult to accurately even to assess the true impacts of climate change, let alone set a value to them.

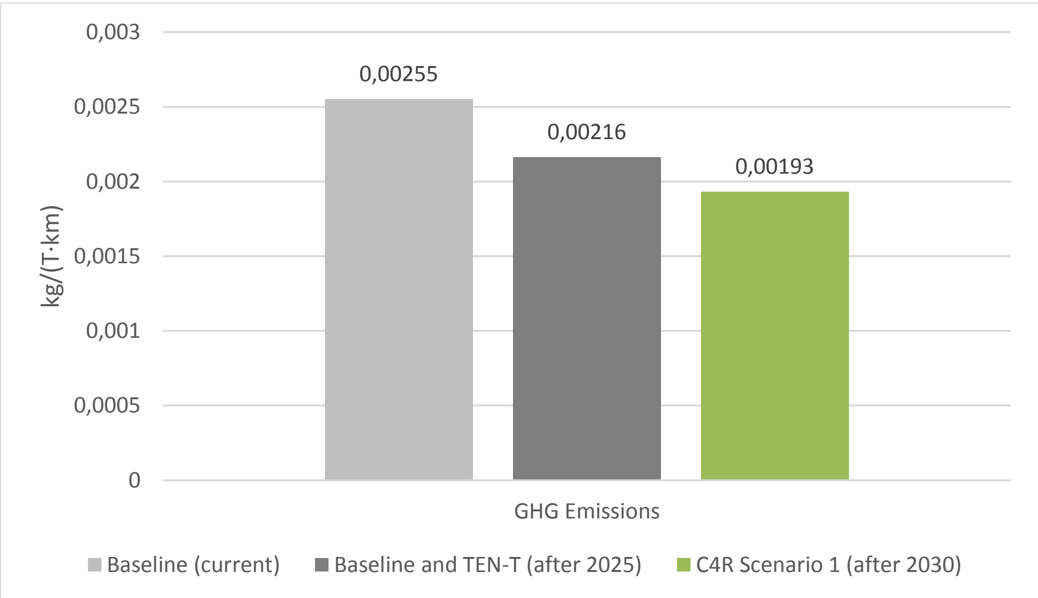

Figure 5. Average Greenhouse Gas Emissions per load unit for current and future rail freight traffic mixes assumed in the Sweden case study. "Baseline and TEN-T" allows trains up to 750 m and "C4R Scenario 1" allows trains up to 1000 m in length.

Regarding Adaptability, it is worth pointing out the results from the "Rail Positive" Scenario (C4R Scenario 4 in **Figure 4**, for example) in the Swedish case study, as well as Investment Level 2 in the Montpellier-Perpignan case study. Both these Scenarios assumed complete migration to a freight rolling stock fleet based on the innovative freight rolling stock design concepts and new technologies resulting from C4R Sub-Project on Freight. The technologies included end-of-train device, automatic couplers and Electro-Pneumatic (EP) brakes which, not only enable the deployment of longer freight trains, but also improve performance in terms of speed and braking and thereby result in more efficient terminal operations. The two scenarios mentioned are among the few that presented positive NPVs, as discussed in detail in D5.4.2/3. The designs and technologies provide additional benefits in terms of interoperability and coping with more varieties of container types, contributing to meet the 2030/50 Vision targets.

Another important aspect that became evident in one of the scenarios analysed in Swedish case study was the significant impact of and cost associated with train delays. The results showed that the benefits of an overall 80% reduction in delays would be sufficient to offset the negative balance from the remaining categories and return a positive outcome. This is an illustrative example of the importance of ensuring a resilient rail network.

While many of the CBA scenarios resulted in negative NPVs, the analyses did not incorporate the impacts of changes in market share. The "business-as-usual" scenarios present a progressively declining rail market share. This reflects reality and to some extent is due to network capacity constraints for freight paths. In the Swedish case study, for which market share projections are shown in Figure 6, this decline is just reversed by 2030, but then declines again over the period to 2050. What we gather from the other scenarios shown is that Scenario 1, which is based on a complete migration to slab track, shows the biggest growth in market share. Overall all the scenarios indicate only modest increase in market share, significantly short of the modal transfer targets.

A similar analysis on the Montpellier-Perpignan corridor, a section that is already capacity constrained, shows a decline in the "business-as-usual" situation that is more pronounced. The impacts of the C4R innovations on market share are not qualitatively different from the Swedish case study, exhibiting, at most, only a modest increase in market share, as shown in Figure 7. The modal shift achieved through the implementation of C4R innovation essentially appears to reflect the expected losses to the road sector in the coming decades.

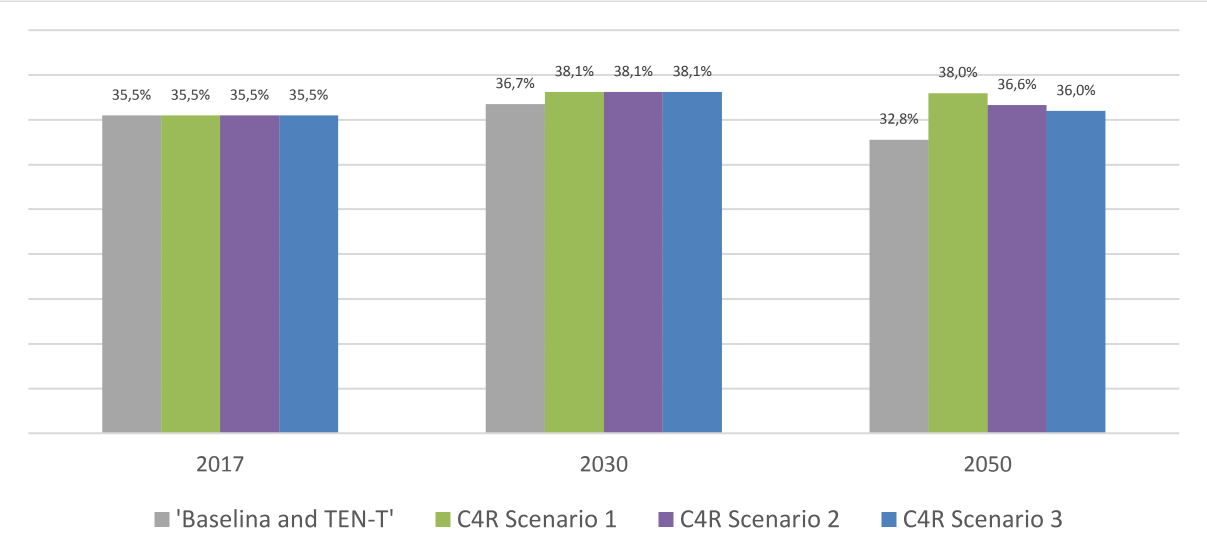

Figure 6. Predicted market share evolution for some of the C4R Scenarios from the Sweden case study in D5.4.2/3.

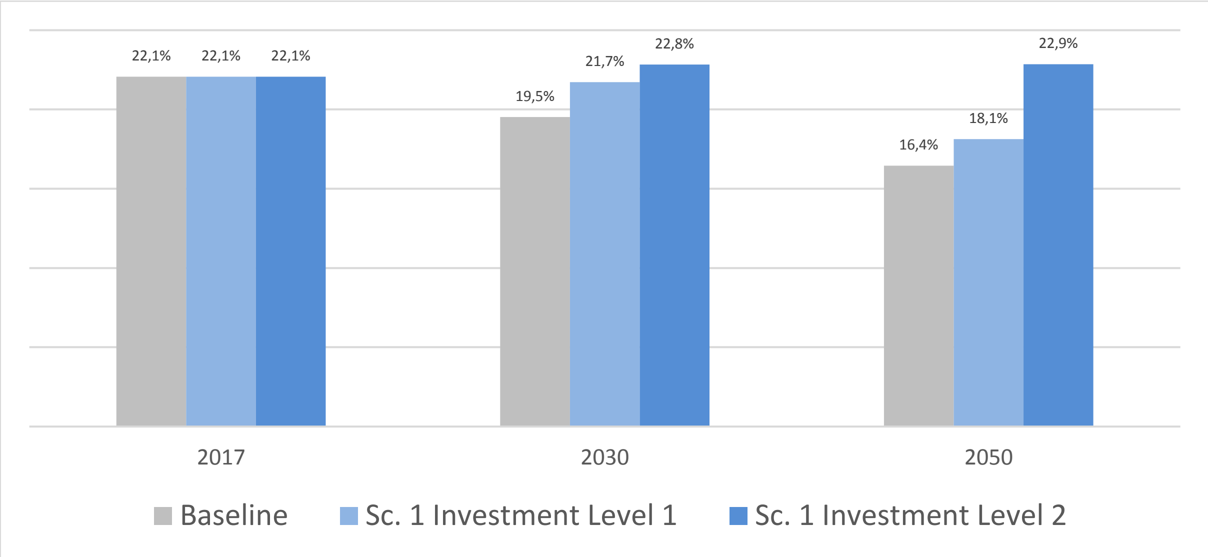

Figure 7. Predicted market share evolution for some of the C4R Scenarios from the Montpellier-Perpignan case study in D5.4.2/3.

One key issue connected to the market share evolution in the tested scenarios was the capacity on the routes analysed. The Perpignan-Montpellier section of the Mediterranean corridor is already a bottleneck on the route; two potential mechanisms to increase capacity are (i) an increase in train length and (ii) an increase in track availability through the implementation of Slab track, switches and crossing and monitoring systems. The scenario with maximum investment and innovations, called "Scenario 1 Investment Level 2" (cf. D5.4.2/3 for detail), assumes that freight trains up to 1500 m will start running from 2025 and achieving up to half of the traffic share in some market segments, in terms of the number of trains. In terms of average load per train, this represents a 40% increase, keeping load factors constant. On the infrastructure side, the combined innovations are assumed to provide a 16% increase in track availability, which translates to a similar growth in capacity measured in number of trains. Combining this with the carrying capacity increase from longer trains, results in a 62% increase in overall freight carrying capacity, which is almost two thirds of the way to the target of doubling overall capacity. However, we recall that this assumes passenger traffic remains constant, allowing all new capacity made available to be allocated to freight traffic, which is clearly unrealistic.

C4R contributions to roadmaps to 2050 Rail

The roadmaps presented in the earlier report, SP5, D5.1.1 have been revised to show the areas where C4R has contributed to the five aspects, Affordability, Adaptability, Resilience, Automation and High Capacity.

Keys to the map:

	Areas of C4R contribution
	R&D (carried out)
	Demonstrator developed and tested
	Further R&D has to be carried out
	Demonstrator to be developed and R&D outputs validated
	Legislation, Standards, regulations – need to be addressed
	Implementation and benefits realisation

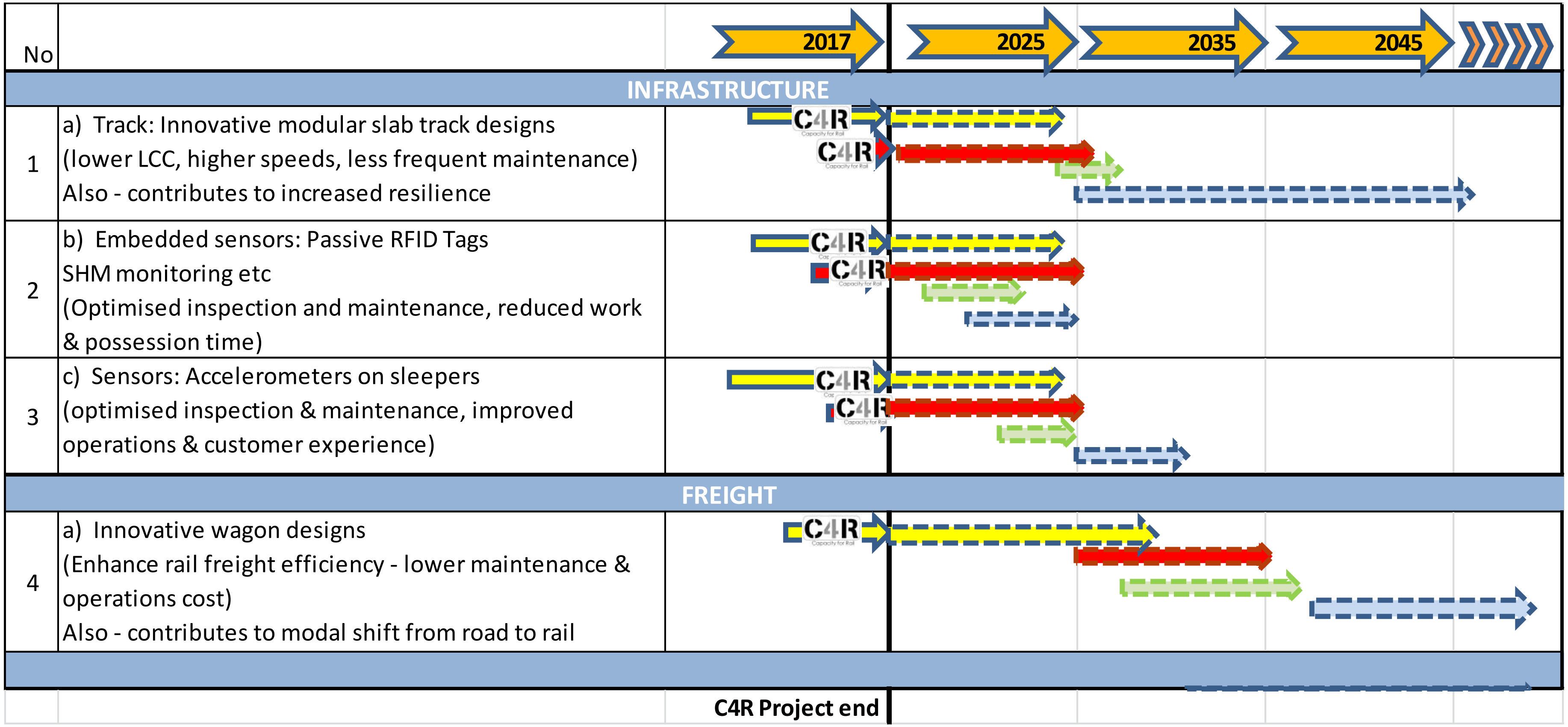

FIGURE 8 C4R R&D – ROUTE TO AFFORDABLE RAIL 2050 RAIL

(FIGURE CONTINUED IN NEXT PAGE)

No		2017	2025	2035	2045	
DECISION SUPPORT TOOLS /MODELS						
5	a) Cost appraisal model (Databases, Life cycle & Multicriteria analysis - infrastructure upgrades)	C4R				
6	b) Modelling & simulations (Track design optimisation; dynamic response of briges to very high speeds, Resilient Switches & Crossings)	C4R				
DOCUMENTATION & GUIDELINES						
7	2030/2050 freight system requirements, Future freight systems, Impacts on TSIs of new freight systems)	C4R				
		C4R Project end				

FIGURE 8 (CONTD): C4R R&D – ROUTE TO AFFORDABLE 2050 RAIL

No		2017	2025	2035	2045
	INFRASTRUCTURE				
1	a) Track: Innovative modular slab track designs (Completely modular, Standardised production process & mechanised installation, block replacement) (Also contributes to affordability and resilience)	C4R			
2	b) Track: Imroved Design Guidelines (Differentiated for high-speed & mixed traffic;) (Increased resilience to climatic changes & affordability)	C4R			
	FREIGHT				
3	a) Innovative transhipment technologies & interchanges (Handle different levels & types of future freight) Intelligent transport Systems Case studies - evaluation of future scenarios	C4R			
4	b) Rail freight systems for 2050 (Requirements to enable incremental & transformational change) (Modal shift, high-speed freight, TM & Intelligent	C4R			
5	c) Need for new/revised Standards & impact on TSIs (Facilitates takeup of new designs, longer trains, infrastructure upgrades, new management systems etc)	C4R			
		C4R Project end			

Figure 9 C4R R&D - Route to adaptable 2050 rail (Contd in next page)

No		2017	2025	2035	2045	
DECISION SUPPORT TOOLS /MODELS						
5	a) Concepts, scenarion analyses (new technologies & innovations) (Databases, Life cycle & Multicriteria analysis - infrastructure upgrades)	C4R C4R				
6	b) Modelling & simulations (Track design optimisation; Dynamic response of briges to very high speeds, Resilient Switches & Crossings)	C4R C4R				
DOCUMENTATION & GUIDELINES						
7	a) 2030/2050 freight system requirements (Advisory Note) (Future freight systems, Meeting incremental and system requirements	C4R				
		C4R Project end				

Figure 9 (Contd) C4R R&D - ROUTE TO ADAPTABLE 2050 RAIL

No		2017	2025	2035	2045
	INFRASTRUCTURE				
1	a) Track concepts: Design requirement & guidelines (Greater resilience to climatic impacts)	C4R			
2	b) Resilient S&Cs (Simulations & modelling) Proposed solutions for potential applications in short-, medium- & long- terms Proposed preventative measures to enable weather resilience	C4R			
	FREIGHT				
3	a) Advisory Note on Freight System requirements for 2030/2050 Rail Rolling Stock designs (for recovering from incidents)	C4R			
	DECISION SUPPORT TOOLS /MODELS				
4	a) Improved tactical & operational planning for IMs Enables (responsive) timetabling, Routing	C4R			

FIGURE 10 C4R R&D - ROUTE TO RESILIENT 2050 RAIL (CONTD IN NEXT PAGE)

No		2017	2025	2035	2045	
DECISION SUPPORT TOOLS /MODELS						
5	b) Planning systems for recovery from incidents (Process diagram: Decision support tool (using standardised and open source systems) to help IMs & RUs in making decisions for speedier recovery from incidents	C4R C4R				
DOCUMENTATION & GUIDELINES						
6	a) Modelling and Analysis of extreme weather events Collation of practices from several European countries; Improves resilience - Paves the way for a single formalised process for disruption management	C4R				
7	b) Roadmap for automation strategies Role and impact of different levels of automation Guidelines: Planning support for management of large disruptions.	C4R				
8	c) Ubiquitous data - improving operations Data architecture to support future TMs, operations and evolving requirements of 2030/2050 railways Data models, resources etc. to support 2030/2050	C4R				
		C4R Project end				

FIGURE 10 (CONTD) C4R R&D - ROUTE TO RESILIENT 2050 RAIL

No		2017	2025	2035	2045	
INFRASTRUCTURE						
1	a) Embedded sensors (Can contributs to intelligent infrastructure, automated condition monitoring)					
DOCUMENTATION & GUIDELINES						
2	a) Common data structures Data formats, especially open data formats that can substitute proprietary data in the future) and models for data exchange in railway operations					
3	b) Metrics, Operating protocols & Specifications (Decision support tools to improve efficiency, Levels of automation in European practices for managing disruptions, Roadmap for automation strategies)					
		C4R Project end				

FIGURE 11 C4R R&D - ROUTE TO AUTOMATED 2050 RAIL

No		2017	2025	2035	2045
	INFRASTRUCTURE				
1	a) Track: Improved Design concepts & Guidelines (Greater availability of useable capacity - improved performance & resilience to climatic changes)	C4R			
	FREIGHT				
2	a) Innovative wagon designs By contributing to modal shift from road by making rail freight more competitive	C4R			
	DECISION SUPPORT TOOLS /MODELS				
3	a) Modelling & simulations (Track design optimisation; dynamic response of bridges to very high speeds, Resilient Switches & Crossings) (Potential to increase freight & passenger train capacity in combination with rolling stock improvements)	C4R			
4	b) IT Tool - Capacity of the Infrastructure (CAIN) (Incorporating additional train paths to operating timetables, simulating and evaluating options,	C4R C4R			
		C4R Project end			

Figure 12 C4R R&D - Route to High-Capacity 2050 Rail (Contd in next page)

No		
	DECISION SUPPORT TOOLS /MODELS	
5	c) Railway capabilities trade-offs tool On-line tool to evaluate investments to improve capacity using a whole systems approach	
	DOCUMENTATION & GUIDELINES	
6	a) Track: Improved Design concepts & Guidelines (Greater availability of useable capacity - improved performance & resilience to climatic changes)	
7	b) Models and frameworks to evaluate impact on capacity of improvements/implemented innovations (Enabling greater efficiency in the use of existing networks, Integrating uncertainty in traffic management, delay management into existing models)	
8	c) Modelling impacts on innovations (Guidelines to facilitate the implementation of innovations through simulation of their impacts and showing effects on useable capacity)	
9	d) Data usage for optimisation of capacity utilisation More effective use of available capacity & improved service provision	
		C4R Project end

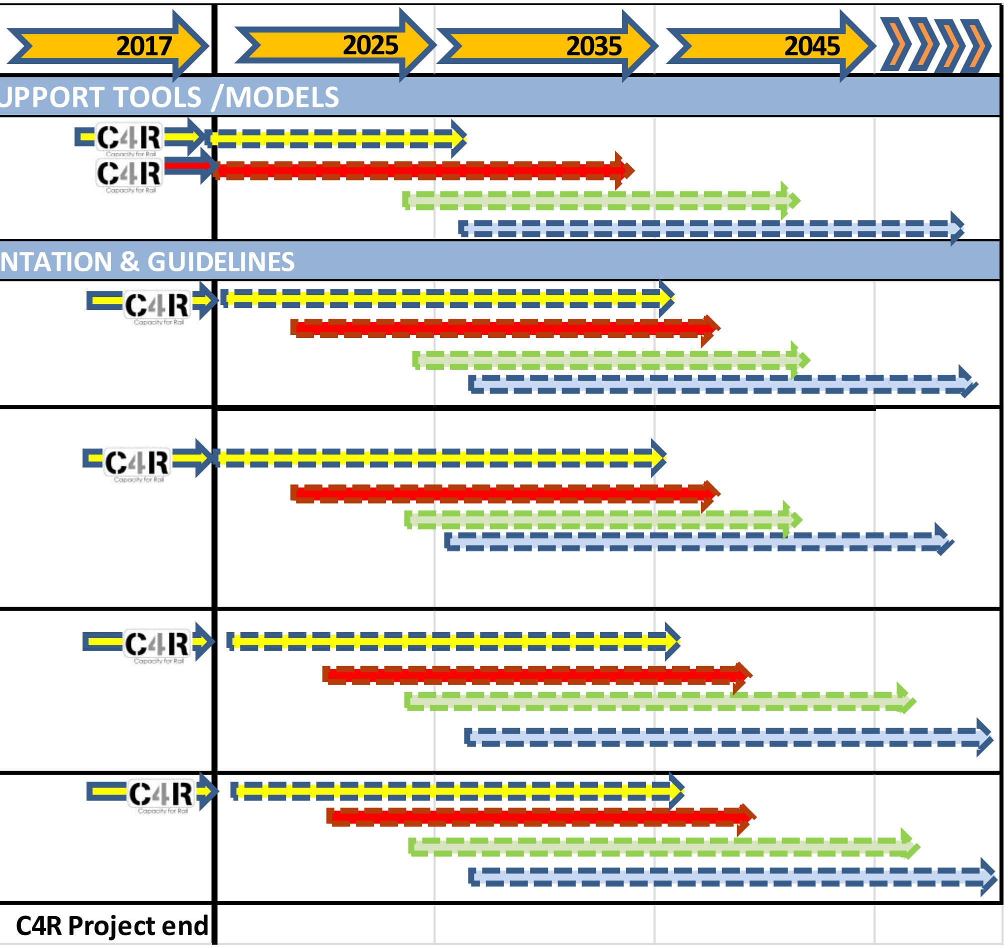

Figure 12 (Contd) C4R R&D - Route to High-Capacity 2050 Rail

6. Next Steps

The major challenges facing transport are lack of capacity, increasing congestion, need to reduce environmental impact and address the mobility needs in a period of changing demographics and exponential growth in the introduction of new technologies. Solutions that are developed for railways have to deal with legacy infrastructure as well as aging rolling stock and the requirement to inter-operate with existing vehicles. While small(er) schemes can start unlocking the potential of the railway system, it is also important to remember that the incremental changes themselves, particularly in selected parts of the railway without taking full account of the whole system impacts, will not lead to the looked for capacity enhancements and reliability improvements.

C4R has laid a very valuable foundation on which success can be built and a key element of the success of the C4R project will therefore lie in the handling of the outcomes and ensuring that the benefits of the research are realised. In addition to the products and tools a significant amount of knowledge, guidelines and advice has been put together.

It is therefore important as a first step to set out the actions that would help to actively pursue the realisation of potential benefits from all of the research, both where there are tangible outcomes such as a product, tool etc as well as the intangible outcomes. Often a key barrier to progress in achieving the benefits of the research is the lack of sufficient resources to take ownership and deliver the end-to-end value stream that encompasses innovative research, ensuring continuity and knowledge retention. It is important therefore to progress projects to the next steps and 'provide the right signals to external and internal audiences'. We are aware that some of the work from C4R (e.g. SP2 work on Freight) is already feeding into the Shift2Rail Programme. Typically the outcomes are at an early stage (low TRL), and thus they need to be developed further by appropriate parties (for which funding is required) prior to implementation. A proactive engagement strategy with both internal and external stakeholders would be beneficial by maintaining momentum and can include activities such as:

- Disseminate research results appropriately so that they can be challenged and built on to achieve strategic objectives;
- Align outcomes with an appropriate strategy and start the dialogue with stakeholders to agree the case for further development, identify route to eventual implementation and the actions and resources needed to achieve this;
- Put in place a mechanism to report progress towards achieving the strategic Rail 2050 objectives.

Appendix

Definitions of the five aspects underlying the 2050 vision

Definitions for the five aspects of the Railway system that have underpinned the work in the Capacity4Rail project were developed as part of the work in SP5 and reported in D5.1.1. These are included below for convenience.

Affordable Railway

An *affordable* railway is the *mode of choice* for investors (public and private) and users (passengers and freight), particularly for medium and long-distance travel. The *affordable* railway:

- Is not just about lowest initial cost, but the total cost of procuring, maintaining and operating the railway based on improved understanding of whole-life, whole-system issues such that lifetime benefits exceed lifetime costs.
- Optimises CAPEX and OPEX (operational expenditure) costs – which are transparent and predictable.
- Is energy efficient and minimises its impact on the environment.
- Delivers lowest Life Cycle Cost while achieving increased reliability, availability, maintainability, safety and quality of the railway system (RAMS performance).
- Meets passenger and freight capacity requirements.
- Minimises barriers to entry and provides effective access to the rail industry.
- Is competitive with other modes for passengers and freight.
- Tries to use innovation to reduce the costs.

Adaptable Railway

An *adaptable* railway is both flexible and extensible so that, with modest and incremental interventions, rail services can be modified to fit a range of future scenarios – including long-term service-levels and ability to integrate new technology developments. The scenarios include changes in the transport market, modal shift and external demands (such as legislation on greenhouse gas emissions). In building an adaptable railway, innovations and processes will need to be phased into existing railway systems in a sustainable way from engineering and operations viewpoints.

AND

An *adaptable* railway is modular and has well-defined (standardised, open) interfaces and standards for interoperability, so that the railway system can respond rapidly to changes in the pattern of demand – such as providing additional trains to cater for surges in demand generated by exogenous factors (e.g. major sporting events). Improved and innovative construction techniques with less complexity (e. g. of the interfaces between railway sub-systems) and high standardisation that reduce costs and disruptions to users.

Automated railway

An *automated* railway is one whose infrastructure and rolling stock are operated and maintained by machines to a degree where the intelligence, speed and scale of operations are no longer correlated with the availability, capacity or capability of human resources. That is, the railway is capable of operating efficiently and effectively without human intervention under normal and (most) degraded service conditions. Automation will cover various aspects such as:

- Construction and renewal
- Monitoring and maintenance
- Operations
- Communications
- Ticketing and pricing
- Inter-modal transfer of passengers and freight.

Resilient Railway

A *resilient* railway is robust, thereby minimising the incidence of infrastructure, rolling stock and operational failures that affect services. Furthermore, a *resilient* railway is one which by design (e.g. of operations, maintenance processes, logistics, tools, equipment) is capable of recovering quickly from perturbations to normal service e.g. as a result of short-term internal events (such as the failure of rail infrastructure) or external events (such as extreme weather conditions, and vandalism).

High-Capacity railway

A *high capacity* railway is one which has virtually no constraints (bottlenecks) on its operation. A *high capacity* railway can accommodate projected passenger and freight demands spread unevenly through the day (e.g. high flows during peak hours and lower flows at other times optimally), whilst meeting customer requirements in terms of defined service levels (such as, reliability, journey time and frequency of service) in an affordable manner.

A high-capacity railway will tolerate interventions from inspection, maintenance and enhancement with minimal impact on the availability of the transport infrastructure network and enable a move towards the achievement of 100% planned availability (perhaps a ‘forever open railway (24 hours/7 days a week)’ depending on demands).

High capacity is addressed by rolling stock, operations, infrastructure and other railway assets.