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Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations

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Exploitation of results from CAPACITY4RAIL

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Executive Summary

CAPACITY4RAIL, a project included in the Seventh Framework Programme (7PM), and co-funded by the European Commission, aims at bringing today's railway system to this future vision for 2030/2050, wants to bring together a wide range of stakeholders, in an ambitious partnership, encompassing them also from across the railway sector, subsequently making the results from this project beneficial for a wide spectrum of organisations.

Therefore, it is paramount that a clear and effective plan is developed in order for the results of the projects to be exploited and implemented in an optimum manner. Without such a strategy outlined the full potential benefits of the project may not be realised.

Dissemination of the project's outputs will facilitate the wide-spread of information and knowledge from the results created by Capacity4Rail stakeholders beyond the members of the consortium and will also help to draw interest.

Exploitation of CAPACITY4RAIL aimed to have partners of the project as well as external organisations implementing results derived from the project. The strategy of how this will be done is fundamental in order for the full value of the project to be attained.

Capacity4Rail main scope has been to offer, within the frame of an integrated vision of the different railway subsystems, a coordinated approach needed for combined progresses in freight system, operation techniques, infrastructure and monitoring technologies, which were defined and pushed further in this system vision, to achieve an affordable increase of capacity, availability and performance to the whole railway system, by developing a holistic view on the railway as a system of interacting technical components driven by customer demand.

The results of the project have been demonstrated and thus validating the results to aid implementation.

This document consists of:

- A summary of the main results that will be publicly available, including the project aim, expected results and the guidelines and standards that can be developed
- a general SWOT analysis of the project which will need to be considered in order for the projects outcome to be successfully implemented and exploited, also business cases and perspectives derived from the analysis
- a general strategy for the use of expected project results, comprising an overview of the consortium strategy and strategic impacts, amongst the stakeholders, divided into different sectors: railway undertakings (RUs) and infrastructure managers (IMs), rail

supply industry, academia and sector associations, and set in different timeframes, short-term actions after the project end and long-term actions.

The strategy will include the proposals to be made to ERA, regarding recommendations to be proposed for the update/modification of the Infrastructure TSI's and also others.

- Guidelines and actions, in order to go further on the research of the tasks and activities already developed.
- A series of conclusions regarding the project outcomes to be successfully implemented and exploited.

The document also highlights the political and legislative aspects which ought to be considered by the CAPACITY4RAIL project.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
C4R	Capacity4Rail project
SP1	C4R-Subproject 1 "Infrastructure"
SP2	C4R-Subproject 2 "New concepts for Efficient Freight Systems"
SP3	C4R-Subproject 3 "Operation for enhanced capacity"
SP4	C4R-Subproject 4 "Operation for enhanced capacity"
SP5	C4R-Subproject 5 "System assessment and migration to 2030-2050"
SP6	C4R-Subproject 6 "Management, Dissemination, Training and Exploitation"
3MB	C4R-1st slab track concept, Multi Moulded Modular Slab Track
7FP	7th Framework Programme
AMS	Advance monitoring system
CER	Community of European Railway and Infrastructure Companies
DG RTD	Directorate general for research and innovation
DGs	Directorate general
EASME	Executive Agency for SMEs
EC	European Commission
ECM	Entity in charge of maintenance
EIM	European Infrastructure Managers

Abbreviation / Acronym	**Description**
EoT	End of train (devices)
EP	Electronic pneumatic brake system
EPF	European Passengers' Federation
EPTTOLA	European Passenger Train and Traction Operating Lessors' Association
ERA	European Union Agency for Railways (before, the European Railway Agency)
ERCEA	ERCEA
ERFA	European Rail Freight Association
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ESC	European Shippers' Council
ETCS	European Train Control System
EU	European Union
F&L	European Freight and Logistics Leaders Forum
FRE	Subsystem FRE-Freight System > Rolling Stock and Terminals
H2020	Horizon 2020, "The EU Framework Programme for Research and Innovation" 2014-2020
HS	High-speed (line)
IM	Infrastructure Manager
INF	Subsystem INF-Infrastructure
IP	Integrating Project
IT	Information technology
ITU	Total Transit Time

Abbreviation / Acronym	**Description**
KPI	Key performance indicator
LCC	Life cycle cost
LPWAN	Low power wide Area networks
L-Track	C4R-2nsd slab track concept, Ladder Track
OPE	Subsystem OPE-Operations
PoC	Proof of concept
R&D&I	Research, development and innovation
RAMS	Reliability, availability, maintainability and safety
RCF	Rolling contact fatigue
RFC	Rail freight corridors
REA	Research Executive Agency
RFID	Radio-frequency identification
RU	Railway Undertaking
S&C	Switches and crossings
S2R	Shift2Rail
SC	Societal challenges
SHM	Structural Health Monitoring
SME	Small and medium-sized enterprises
SRRIA	Strategic Rail Research and Innovation Agenda
TEN-T	EC Trans-European Transport Network
TEU	"Twenty-foot Equivalent Unit2
TiT	Tunnel-into-tunnel technology

Abbreviation / Acronym	**Description**
TRL	Technology readiness level
UIC	International Union of Railways
UIP	International Union of Private Wagon Owners
UITP	International Union of Public Transport
UNIFE	The Association of the European Rail Industry
USP	Under sleeper pads
VHST	Very high-speed track (/traffic/train)
WP	Work Package

1. Main results that will be publicly available

1.1 Project Aim

CAPACITY4RAIL's main aim and purpose is to investigate and demonstrate innovative concepts for increased capacity of the whole railway system, with infrastructure sustainability by introducing innovative concepts of infrastructure, that are enforcing the use of components based on low carbon and recycled materials, with self-monitored integrated elements, and also conceptual designs of flexible, market oriented, efficient and environmental friendly vehicles and train compositions.

Intermodal integration within the global transport system will be improved through enhanced transhipment of passengers and freight, and increased automation in operations and facilities.

The subprojects that form the initiative:

- SP1 Infrastructure
- SP2 New Concepts for Efficient Freight systems
- SP3 Operations for enhanced capacity
- SP4 Advanced monitoring
- SP5 System assessment and migration to 2030/2050
- SP6 Management, dissemination, training & exploitation

are all aimed at bringing today's railway system to its future vision for 2030/2050, with, a coordinated approach in which combined progresses in freight system, operation techniques, infrastructure and monitoring technologies were defined and pushed further in this system vision.

Some of the benefits that CAPACITY4RAIL will bring are listed below:

- provide an overall increase in railway capacity by developing a holistic view on the railway as
- a system of interacting technical components driven by customer demand
- develop the vision and requirements of the railway system in 2030/2050 including environmental and socio-economic aspects in terms of infrastructure and operation (adding a provision for an increase of freight traffic)
- identify the technologies and development/implementation steps in short-, medium- and long-term, necessary to move towards the railway system for 2030/2050
- develop new concepts for railway track of the future, in view of potential application for mixed traffic, but also very high-speed (over 350 km/h), that encompasses cost savings, rapid construction, resilience and enhanced maintainability
- provide general track design guidelines for very high-speed with identification of limiting factors especially in terms of admissible track irregularities and transition zones demonstrate, in real rail freight corridors, the feasibility of the most promising designs
- specify the requirements of an efficient freight rail freight system 2030/2050 to fulfil the EU targets

- provide a conceptual design for the rail freight vehicles (wagons and trains) of the future design transshipment technologies and interchanges of the future (rail yards, intermodal terminals, shunting facilities, rail-sea ports, etc.),
- design modern fully integrated rail freight systems for seamless logistics and network-based performance and develop their catalogue, standardisation pack and technical spec;
- develop modelling and simulation tools for high volume traffic management
- derive joint requirements, European standards and testing for incident management plans
- develop new concepts for railway structural and operational monitoring to enhance the availability of the track
- elaborate a system for a fast-check of track and structures after natural hazards

1.2 Main Results

CAPACITY4RAIL has provided an integrated optimisation approach looking for potential increased capacity research developments and actions that includes multiple elements, the complete railway sector technical and operational subsystems, providing a combined approach for all these aspects in dynamic forecasting supply-demand scenarios, technological readiness levels and cost-benefit analysis considerations to support their effectiveness for the implementation and operational decision-making processes.

CAPACITY4RAIL has progressed for 48 months to provide, among other results:

- ✓ New infrastructure and track processes of work and systems (SP1). – slab track prototypes, new switches concepts, very high-speed superstructure and upgrade/adaptation works and processes for existing infrastructure– which have already been designed and prototyped to provide greater reliability through focusing on designs targeted to the actual and expected railway use and much lower maintenance, building a new infrastructure capable to afford also a medium/long distance mixed traffic as well
- ✓ the requirements of an efficient freight rail freight system 2030/2050 to fulfil the EU targets (SP2), regarding proposals for new wagons design, including automatic couplers, and train configurations with maximum speed increased to 100-120 km/h, maximum lengths of 1000 m (even up to 1500 m) or improved braking capabilities the use of P-brakes with EoT (End of Train) devices or EP-brakes on all wagons (and trains), specific train services (such as small liner trains), but also automation models for marshalling yards and terminals to optimise transhipments
- ✓ developments in modelling and simulation ad-hoc tools for high capacity management (SP3), dealing with traffic capacity computation, data gathering, analysing and utilizing, and collecting real-time data on the train operation, and planning aspects allowing the interleaving of slower freight trains, but also being able to respond to incidences, with incident management planning, working with degraded mode operations, with the ability to forecast delay propagation and the flexibility to adapt traffic management slots to that situation

- ✓ Besides, innovative concepts for railway structural and operational monitoring have been developed (SP4) to be integrated since manufacturing of components in order to review aspects of structural health monitoring reliability for operational condition, thus enhancing the availability of the track, combined with automated maintenance forecasts and a prediction of the structural lifetime

Furthermore, demonstration activities have been developed in the framework of this project. They play a crucial role as they enable the assessment of the innovations and the most promising designs developed in the project. Most of the demonstrators have taken place on operated railway infrastructures (i.e. IP in Portugal) or in specific laboratories with real-scale test facilities (i.e. CEDEX Track Box in Spain).

The work of SP5 has driven the overall system approach, ensuring CAPACITY4RAIL to adopt this comprehensive view, and been acting as a "container" for all the work:

- Ensuring the synergies between the different SPs in the project
- Completing the identification of the TRL Technology Readiness Levels that can point out the field for future research and making possible the total comparison between the target and actual performance,
- Enhancing the Cost-Benefit Analysis (CBA), that will put into a clear economical scale the pros and contras of the implementation of such technologies, being cost effective.
- Evaluating the migration of new technologies in existing systems, which is a key factor for successful implementation and improvements
- Proposing more advanced guidelines for future deployments in the mid-term, and better adjusted recommendations for technologies to be developed and deployed in the long-term

1.3 Guidelines and Standards

CAPACITY4RAIL will also deliver the necessary guidelines for the systems to be implemented in the railway domain, combining the technical developments with new business models that would enable and foster their application.

The **guidelines** were identified in the deliverable D56.2

G-INF-x, Guideline number "x", subsystem INF-Infrastructure,

G-INF-1 – Criteria for a LCC analysis of a new concept of slab track

G-INF-2 – S&C, Rail inclination and rail grade for minimizing the degradation in the switch panel

G-INF-3 – S&C, Geometry optimization of the crossing

G-INF-4 – S&C, Use of rail pads and USP for dynamic load mitigation in crossing panel

G-INF-5 –Use of rail pads and USP for a track design optimization under VHST (very high speed traffic)

G-INF-6 – Three stage approach methodology for track upgrading

G-INF-7 – Upgrading of tunnel gauge by the TiT tunnel in tunnel system

G-FRE-8 – Introduce potential network improvements for new freight catalogue

G-INF-9 – Functional and technical requirements for monitoring and inspection techniques

G-INF-10 – Key recommendations for next generation monitoring and inspection technologies in the infrastructure

G-INF-11 – Application of SHM-Structural Health Monitoring system in infrastructures components

G-INF-12 – Requirements for AMS-Advanced monitoring systems integrated in the infrastructure

G-INF-13 – Use of RFID technology as AMS- Advanced monitoring systems embedded in the infrastructure

G-INF-14 – Use of retro-fit kits for selected applications in existing infrastructures

G-INF-15 – Monitoring of rails

G-INF-16 – Decision tool for S&C maintenance based on track geometry

G-INF-17 – Inspection of ballast drainage and frost resistance

G-INF-18 – Finite Element Modelling

G-FRE-x, Guideline number "x", subsystem FRE-Freight,

G-FRE-1 – Needs for actual infrastructure gauge and applied improved developments of Infrastructure Components

G-FRE-2 – Operate Longer Trains on Ten-T Corridors

G-FRE-3 – Considerations for Freight Services on the Control Command Signalling Subsystem

G-FRE-4 – Incentives for Track-Friendly Running Gear and Improved Braking Performance and Installation of On-Board and Track Wayside Monitoring

G-FRE-5 – Use of Heavier and Duo-Locomotives in General Operation and Terminals

G-FRE-6 – Introduction for Intermodal Traffic of Liner Trains for Containers

G-FRE-7 – Recommendations to Freight Train Operators

G-FRE-8 – Electrification of Terminals/Last Mile Services

G-FRE-9 –Measurement of vertical loads to avoid overloaded/imbalanced wagons or malfunctioning running gear

G-FRE-10 –Monitoring of vehicle curving, traction and braking performance

G-FRE-11 –Monitoring of wheel profile

G-FRE-12 –Use of axle box and hot wheel detectors

G-OPE-x, Guideline number "x", subsystem OPE-Operations,

G-OPE-1 – Use and Sharing of a Web Train Schedule within IM's, FOC's and TOC's

G-OPE-2 – Use of the SysML Schematic disruption Management Process

G-OPE-3 – Integration of Weather Forecast Models in Railway Operation

G-OPE-4 – Use of a Global Matrix of Grades of Automation (GoA)

G-OPE-5 – Use of ESB (Entreprise Service Bus) as Architecture of Choice for TMS

G-OPE-6 – Improvement of Management and Technology of Data Resources Including Ontology

G-SYS-x, Guideline number "x", subsystem SYS-Railway System - Assessment and Migration to 2030/2050

G-SYS-1 – Introduction of "Capability Trade-Offs" Tools

G-SYS-2 – Development of a Network Traffic Simulator to Test Impacts On Capacity

G-SYS-3 – GIS Visualisation Tool For Existing Data and For Innovations

G-SYS-4 – Priorisation of upgrading freight services investments based on case scenarios and CBA results

See D56.2 Guidelines for further research and development activities

For the Infrastructure technical subsystems, the following **standards** were identified in need of review or elaboration:

- For Track design general questions:
  - EN 13803 "Railway applications - Track - Track alignment design parameters - Track gauges 1 435 mm and wider"
- For rail fastening design:
  - EN 13481 series on "Railway applications. Track. Performance requirements for fastening systems"
- For the use of Under Sleeper Pads:
  - EN 16730 "Railway applications - Track - Concrete sleepers and bearers with under sleeper pads"
  - IRS 71301 “Under Sleeper Pads (USP) Recommendations for Use”.
- For Ballastless track system design questions:
  - EN 16432 series on "Railway applications. Ballastless track systems"
- For Line Categories on load limits (concerning VHST and mixed freight services):
  - EN 15528 "Railway applications - Line categories for managing the interface between load limits of vehicles and infrastructure"
- For design bases on structures and dynamic factor application for VHST:
  - EN 1990 "Eurocode - Basis of structural design"
  - EN 1991-2 "Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges"
  - EN 1992-2 "Eurocode 2: Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules"
  - EN 1993-2 "Eurocode 3: Design of steel structures - Part 2: Steel bridges"
  - IRS on "Exceptional and Over-Loads on Existing structures"
- For design optimization of switches and crossings (S&Cs):
  - EN 13674-2 "Railway applications - Track - Rail - Part 2: Switch and crossing rails used in conjunction with Vignole railway rails 46 kg/m and above"
  - EN 13232 series on "Railway applications. Track. Switches and crossing"
- For RFID technology standards:

  - ISO/IEC 18000 series on "Information technology - Radio frequency identification for item management", especially Part 6
  - prEN on RFID in Railway Applications as required by TC225/WG4 to be developed
- For general use as on-site measurement systems:
  - prEN 15654-1 "Railway Applications - Measurement of vertical forces on wheels and wheelsets: Interoperable On-Track measurement sites for vehicles in service"
  - prEN 15654-3 "Railway applications - Measurement of vertical forces on wheels and wheelsets: Approval and verification of on-track measurement sites for vehicles in service"
- For specific use as "Wheel Impact Load Detector (WILD)" or "Weight in Motion (WIM)":
  - IRS on "Exceptional and Over-Loads on Existing structures"

For the Freight system capabilities, the relevant standards to be reviewed or drafted were identified:

- For brake systems and performance in train compositions:
  - EN 14198 "Railway applications. Braking. Requirements for the brake system of trains hauled by locomotives"
  - EN 14531 series on "Railway applications. Methods for calculation of stopping and slowing distances and immobilization braking"
  - EN 15625 "Railway applications. Braking. Automatic variable load sensing devices"
  - EN 15612 "Railway applications. Braking. Brake pipe accelerator valve"
- For operational static brake testing:
  - EN 15806 "Railway applications. Braking. Static brake testing"
- For brakes components specifications:
  - UIC Leaflet 541-1 "Brakes - Regulations concerning the design of brake components"
  - UIC Leaflet 541-03 "Brakes - Specifications for the construction of various brake parts - Driver's brake valve / Driver's brake controller"
  - UIC Leaflet 541-04 "Brakes - Regulations concerning the manufacture of brake components - Self-adjusting load-proportional braking system and automatic "empty-loaded" control device"
  - UIC Leaflet 541-6 "Brakes - Electropneumatic brake (ep brake) and Passenger alarm signal (PAS) for vehicles used in hauled consists"
  - UIC 541-2 "Dimensions of hose connections (brake hoses) and electric cables; types of pneumatic and electric connections and their positioning on wagons and coaches equipped with automatic couplers of the UIC and OSJD Member Railways"
- For Structural design of freight wagons:
  - EN 12663 series on "Railway applications. Structural requirements of railway vehicle bodies", especially for part 2 Freight wagons

- For wheelsets and bogies design:
    - EN 13749 "Railway applications. Wheelsets and bogies. Method of specifying the structural requirements of bogie frames"
- For buffers and couplers design:
    - EN 15551 "Railway applications. Railway rolling stock. Buffers"
    - UIC Leaflet 524 "Wagons - Technical specifications governing spring devices for wagons fitted with automatic couplers belonging to the UIC and OSJD member railways"
    - UIC Leaflet 577 "Wagon stresses"
- For vehicles reference masses:
    - EN 15663 "Railway applications. Vehicle reference masses"

2. Market Analysis

2.1 SWOT ANALYSIS

A SWOT analysis has been performed based on a general overview of the Strengths, Weaknesses, Opportunities and Threats of the C4R project, according with the general aspects of the project and the sector reflected in the deliverables and, taking into consideration the opinion of the stakeholders of railway system, some of them already participating as members of the C4R project. A questionnaire was prepared to pick up the aims and objectives perceived by each individual member to do so.

2.1.1 STRENGTHS

- As demonstrated in the C4R project, the Railway sector is a well-defined system and thus gives the possibility for a high degree of automatization in most of the processes. A basic strength of the railway sector is that it is a transportation system that responds precisely to the needs of decision makers and several stakeholders of the transport sector, compared to other alternatives, for example, in terms of:

    - Lower costs per ton transported compared to road
    - Higher energy efficiency in general
    - Higher speeds compared to road
    - Generation of production and research resources
    - Development of necessary knowledge based on background
    - No possibility of delay by road traffic jams
    - PAP (Pre-arranged train paths)

- The main aspects of rail transportation system related to infrastructure subsystem, including track and earthworks, traffic management terminals and their operations, and the freight railway system with their main characteristics are addressed. The project has had an especially multidisciplinary character and looked at the interfaces within the railway system as well as the interfaces external of the rail system.

- C4R combined IMs/RUs/Academia/Industry partners and thus this sum of forces, and the "know-how" generated in the initiative has been powerful to come to results which will provide a high commercial and industrial benefit of the sector, apart from profiting the increase of capacity and sustainability of the whole transport system, envisioned in accordance to the White Paper of the European Commission.

Special mention must be made that through UIC and UNIFE, among other associations an excellent output for dissemination is available. In addition, through these channels external stakeholders also have some access to the project

This output goes beyond the common approach of research activities and developed a common understanding of the key issues European Railways are facing

- The industry partners are leaders in railway technologies and the technical subsystems and therefore have been able to bring an excellent knowledge base into the project

- Good level of participation from Railway Operators and Infrastructure managers has ensured that customer needs are carefully considered by the industrial partners

- Collaborative actions already exist between some partners. Some partners are already involved in integrating technologies which will be beneficial during the integration and implementation phase of the project. Some of them remain evolving their developments through other on-going initiatives such as Shift2Rail and their lighthouse projects.

  To be based on the outcomes and relationships that have been developed in previous projects (e.g. OnTime, Innotrack, etc...), helped also to align the thinking and to target outcomes already from an early phase of the project. The proven and tested research co-operation of the involved partners (IM, RU, System suppliers, Academia) even facilitates the currently ongoing collaboration and follow-up of activities into Shift2Rail.

- This current project is based on latest research and recommends an optimised work process for most areas. Also gives references to state of the art examples, that already prove the realistic and pragmatic approach in the innovation and optimisation fields.

- Through the analysis performed, as well as simulations and demonstrators C4R has given the opportunity for the results generated to be validated against real-life applicable scenarios. C4R will bring together the knowledge of equipment, devices and technology, both for those that are now in use, and for those that will be necessary to use in the future with the aim of managing the railway system in the areas covered in a more efficient way.

  Solutions are intended to be flexible and will consider:

  - Monitoring technology
  - Availability of smart technology

- Interoperability
- Scalability

- Relevant areas, so, have been quickly identified in the development of monitoring equipment and according applications, that can potentiate the level of automatization.

  As an example, the project responds to the existing market need for sensors for detection of failures and their propagation, damaging effects and deterioration of components that can be used in diverse environments and multiple cases. The possibilities to develop preventive strategies based on failure prediction are very promising and the project results contribute to that evolution.

- A lot of knowledge about sensors and monitoring is available, and the potential in this field is already high and further increasing. Simulation models, data analysis and digitalisation are under permanent development, and so methods and automation are improved (and will be) continuously at a high pace.

- Roughly the same situation appears in the case of upgrading of freight lines and the operational capabilities: much research and knowledge is already available and thus provide opportunities to improve capacity. The guidelines developed in C4R for the upgrading of freight lines or to provide an optimised level of operation, close a wide gap and will be of a great advantage for the dissemination and exploitation of the results of C4R.

- The increased level of automation, optimisation of processes and technical systems upgrading will become a very well-defined line of action to reduce costs and promote environmental sustainability. Several documented examples developed in the project have already shown this, such as:

  - Improved design, maintenance and operation with cost optimisation for S&C
  - Self-monitored components
  - Optimised freight wagons and train design and operation capabilities
  - Implementation programs to develop future timetable optimised processes
  - Creation of rules and procedures to deal with traffic disruptions (due to extreme weather conditions or other causes)

2.1.2 Weaknesses

- The weaknesses reflected in the C4R project are very similar to those already existing in the railway sector in the EU, amongst others, that have been mainly identified within the frame of this project, and are related to:

  - High fixed costs of the system, even with the innovations
  - Schedule and network inflexibility for the full capacity use scenarios
  - Railway system that may be unsuitable for specific types of transport
  - As well, underused capacity in some corridors
  - Still limited geographical coverage of rail networks, and need of reinforcing intermodality
  - Current reliability of freight transport
  - Large investment needed for infrastructure and rolling stock innovations
  - Still long innovation cycles
  - Actual interoperability scenarios
  - Vibration and noise issues not so extensively covered

- Apart from these weak points, which are not very surprising as being traditional problems of the railway system, currently the lack of standards for data presentation, data-exchange/-communications, the interpretation of data and the related processes is difficult to solve, as the development of standards is a very slow and consensual process. This is becoming another major problem, because some of the capabilities that the Internet of Things (IoT) resources and "big data" tools required for the optimisation and automation of processes, to ensure achieving the increased capabilities and minimisation of disruptions, are to be based on such structure of formal standardisation.

  The development of clear guidelines by C4R for the upgrading of freight lines or traffic management, covering the data flows, parameters and exchange of useful communication, even if providing a great progress in this area, need more development.

- Another existing weakness that continues to persist, not only inside the C4R-project formulation and framework, but in the whole system, is not only the lack of structure but of a relevant part of the necessary data. The data requirements of researchers are not fully met by existing IM and RU systems. Also, Industry needs to understand that the overall system could be profited via a shared "know-how" management and the availability of data.

- Thus, developing and implementing robust demonstrators can be delayed because of the necessity to collect missing data to prepare the demonstrators to be fit for operational conditions. Particularly in comparison to the automotive sector, the overall progress made in the railway sector is relatively slow.

- Besides, an important point of weakness is the Many of the innovations are difficult to justify based purely on LCC and financial terms. The partners investing may not recover their investment because of the structure of the supply chain.

  This implies a necessary shift of the added value between partners and the only ones that may assume this role are the IMs. The highest priority is still to convince the IMs and to match their constraints. Then through adapted tolls with bonus and malus they may help to speed up the market uptake

- Most of the IM experience a high influence by differences in regional policies, different rules and regulations for competitive mobility providers. Significant differences can be observed in the priorities of the different national railways, as well.

  As a result, railways work as a cost driven industry in different environments. Higher investments for a general optimisation of the network are often depending on the willing of politics to restructure and create a firmer and more homogeneous ground for these activities in the frame of the EU, according to harmonising European directives and regulations, creating a more open, and at the same time competitive, access to the market.

- An important remaining basic question in this context is the willingness of society to move to a more sustainable transport system. The connected change-process needs also clear political decisions to promote a sustainable model for the society.

2.1.3 Opportunities

- Most opportunities referred in the C4R project are linked to new service levels, market and environmental demands, that have been covered by the stakeholders:
  - New markets
    - Trends
    - Life style
    - Technologies
    - Niches
  - Use of reliable assets and models
    - Trains

    - Infrastructure (Tracks, installations, freight and passenger terminals...)
    - IoT/IT 4.0

- Increasing interoperability

    - ERTMS deployment
    - Harmonised power supply on important corridors

- Increasing demands for sustainability

- In relation to the emergence of technologies, the project could be instrumental in the development of new standards and technical recommendations or extensive, useful reviews of the existing ones

- The necessary growth of participation of the railway system in the quotas of transportation in the EU, will require in the end the necessary incremental and step system changes addressed and identified in the European Commission’s Transport White Paper, and in coherence with visions for 2030/2050, and thus developing products and components from both public and private investors

- The opportunity also exists to follow the development of implementation plan for railways of legislation relating to the liberalisation further established in the Fourth Railway Package, in both technical and market pillars

- Co-operation with other research projects covering similar fields: new components or optimisation for infrastructure components, terminals operation, upgrading of freight systems and optimisation of traffic management systems and processes.

  This is joined to the application of new technologies and operational criteria that may derive to global cost-saving in the railway sector. This knowledge will suppose new opportunities for the stakeholders inside and outside of the C4R project (within the confidentiality limits of the project)

- Further relation with Horizon 2020 initiatives, especially with the Shift2Rail Joint Undertaking including its Innovation Projects (IPs) and its lighthouse projects, should be explored in order to continue with the development of the major findings from C4R. Liaisons should be made with any PPP initiatives inside H2020

- In terms of general service, the C4R project provides solutions to the growing demands of railway capacities for import and export of products, that help to face the requirements of the likely future growing demands for both passengers and freight service, but specially in the latter which goes mainly together with the actions necessary for increasing axle loads in rolling stock (and support by the infrastructure) and making possible longer trains operations

- The demands are also for higher frequencies of traffic and increased numbers of PAP (Pre-arranged train paths) on corridors. All these requirements are relevant in the regional networks but even more important for the traffic in Trans-European Network (TEN-T) and Rail Freight Corridors (RFC)

- Developments coming from C4R should be further evaluated outside the EU frame of the project in order to explore the possible application to new markets other than Europe

- The commitment required for many of the National Railways, Infrastructure Managers (IMs) and /or Railway Undertakings (RUs), is to improve performance and capacity on their networks, building on the base for the development of already agreed solutions.

- C4R provides clear guidelines to upgrade freight lines, which have not been the focus in the past, but whose rearrangement constitute a key piece of the railway system change, and via a common approach can raise the opportunity to achieve a general increase of capacity. The upgrading of freight lines comprises considerable chances to have substantial cost savings. Import and export of products can be considerably increased by reinforcing the infrastructure of corridors in a concerted and coordinated geographically upgrade activity

- Railway can take profit also of the weaknesses of other transport modes like road transportation that suffers from regular traffic jams and less reliability, higher fuel costs and lower security level.

  The general development of society to more sustainable modes also plays into the hands of railway industry. Providing a transport mode with less emissions, not only regarding greenhouse gases (GHG) but also emissions of noise and vibration, offers an opportunity of overall acceptance by the society

- The deployment of the ERTMS in combination with a harmonised power supply policy for traction on important corridors, will play a fundamental role to enhance the interoperability of the system and promote its use.

- In that scenario, the increasing of transport-capacity will also be driven by the other new developed technologies like improved terminals, enhanced breaking systems, new track design, IT-Evolutions and new monitoring systems for vehicles and track-components, as:

    - Improved terminals help to optimise the loading and unloading processes and are necessary to allow longer trains
    - New braking systems optimise the existing braking capacity and the braking process and allow the secure transport of higher loads
    - New track design adapts to the future demands while giving opportunities for lower noise emissions, reduced maintenance, higher availability and increased resilience

- The developed solutions for measurement and monitoring of the infrastructure and rolling stock help to optimise not only the operation process but also the necessary maintenance activities. A precise prediction of maintenance needs helps to optimise the planning of the works to carry out

- In combination with preventive strategies it reduces the loss of operation time and at the same time saves capacity of maintenance staff. Thus, monitoring strategies provide opportunities to employ monitoring as cost efficient support for railway maintenance and operational control

  The guidelines on how to relate monitoring possibilities to the evaluation of relevant parameters of railway operations or diagnosis of condition of critical components have a further and broader field of appliance. The results can be applied to other needed above-mentioned areas of work

  Aeronautical companies for example have needs for the sensors that are in many aspects like the railways ones. So, any development applied and implemented in this railway system can be easily applied to the other

- As already seen, the possibilities to improve the interaction between IM's and RU's, with system suppliers and the Academia, are important in fields such as digitalisation of timetable planning and operational traffic.

- The increasing part of the mobility market for the railway systems, will only consolidate if railways get a better image due to achieving better punctuality, more integrated and quicker logistic chains, etc. The passenger must "feel" a modern technology, not only the historic and traditional railways

- Finally, there's a significant possibility of investment into railways not only to evolve and get more mature solutions or implement them, but to develop new ones. The follow-up activities and new R&D programmes and initiatives such as those included in the mentioned Shift2Rail initiative will help the chances to make it true.

2.1.4 THREATS

- New and old threats combine in the C4R project and could menace not only the developments achieved, but the future of the railway system, where a non-extensive list can cover:

  - Environmental demands
    - Sulphur directive
    - Noise regulations
    - Vibration regulations
    - Energy policies
  - Governmental
    - Politics
    - Legal demands
    - Local decision on European corridors
  - Market demands
  - Financial-budgetary issues
    - Economic crisis
    - Change of markets
    - Local change of customers
  - increased competition of other modes
    - Large trucks
    - Inland waterways
    - E-mobility
  - Inflexibility of rail transport
    - Services
    - Ideas

- One of the main threats to be seen in the C4R project is the quick change of the boundary and environmental conditions for operation in the transport system.

The improvement of concurring transport modes but also the change of society requirements has a high influence on the current conditions. For example, the accelerated improvements of the automotive sector technology in regard of environment awareness, addressing of climate change effects and autonomous driving must be considered and respected

- Society requirements are changing to more comfort, better accessibility of transport and are demanding successively higher restrictions of emissions as greenhouse (GHG) gases, noise and vibrations. Intermodality is another social demand subject to be covered, as users are requiring clear information via IT solutions to be provided advice for decision-making of routes and combined use of different transportation modes. To achieve a system change, to focus only on the railway system could be a mistake from the view of final users

- There may be difficulties in integrating developed solutions with legacy systems. A very specific threat of this type is in relation to the upgrading of freight lines addressed in the C4R initiative, due mainly to the high investment cost for the new developed systems. Lack of political support and of clear leadership based on well-analysed concepts for upgrading could minimise and even cut this very important activity to be done for the current assets

  Within this field, lack of well-defined operator needs, and requirements may make the results uninteresting for both RU's and IM's, and also political views

- As for the monitoring strategies, the risk of uncoordinated development of components must be addressed to avoid unstructured and non-communicating monitoring systems

  To avoid this threat, it is recommended that new technologies like advanced monitoring must be included in the whole production chain of the infrastructure

- Only bringing additional useful information will increase the effort of the operational staff of the railway system. Advanced monitoring and optimised automated traffic management dispatch must be welcomed by maintenance and operational planners, because these tools will help him to do their work better, but as well they should feel and be correctly informed and trained to understand the level of improvement and be convinced before implementation

- Poor information sharing outside the consortium could lead to confusion and misinformation which ultimately lead to poor outputs on achieving further results when the project has ended

- There is a need to look closely after the cost efficiency and the technological viability of the project results before its implementation, as the ambitious scope of C4R project might lead to difficulty in implementing them in the near future.

2.2 Business cases and perspectives

2.2.1 C4R general perspective – CBA Cost Benefit Analysis

In Capacity4Rail, one of the main scopes has been to define the scenarios and migration paths from existing railway system to the future one considering the innovations and technologies identified/validated in the project, and **to assess them through a Cost-Benefit Analysis (CBA).** This methodology has been also supplemented by a Multi-Criteria Analysis (MCA) that help take into account non-economic aspects that are usually not captured in a CBA.

The **Cost-Benefit Analysis (CBA),** based on a tool developed in the project, was performed for two case studies. The first case study is built on the Swedish sections of the Scandinavian-Mediterranean TEN-T Corridor. A second case study was based on a more detailed analysis of a smaller corridor section in southern France. The analysis is made through a **set of Scenarios** where different sets of C4R Innovations, operational or market conditions changes are modelled.

The two case studies presented (see D54.2/3 *"Assessment of technologies, scenarios and impacts"),* although different in scope, both produced very rich results and allowed for interesting analysis related to the **economic impacts of the innovations that have been considered in the context of the Capacity4Rail project.**

The main innovations considered are the new slab track, new switches and crossings (S&C) with enhanced tolerance to failure and higher availability leading to less delay minutes, new freight wagons with higher axle loads (25 t/axle), terminal upgrades and new monitoring. The several different scenarios have been built with different combinations of conclusion and implementation of these innovations.

Deep infrastructure investments **may or may not be profitable, depending on the conditions of the corridor**. There is a much higher chance of large investments, such as upgrade to slab track, being profitable in capacity constrained sections. However, local boundary conditions, which have big impact on investment cost, complexity of upgrade and operational risks must be necessarily considered in decision making. It should, however, be noted that the biggest share of the benefit is generated by **gains in availability leading to increased capacity.**

Besides, the **introduction of innovative operational concepts** may have a very high profitability. These can be **rolling stock innovations**, such as automatic couplers, EP brakes, often combined with modest infrastructure investment in siding extensions to allow for longer and heavier trains.

In both the preceding issues, the main benefits generating mechanism is the modal transfer from road to rail that is allowed by the **increased carrying capacity**. Benefits in other categories are usually small in comparison. Still, some of the analysed scenarios show that improvements in delays or reductions in travel times can have significant positive impacts through savings in value of time.

2.2.2 Infrastructure – Business case for the development of the innovative concepts of slab track

Certain specific areas in the project have studied business cases, as in the **Infrastructure subproject** for the development of the **two innovative slab track concepts.** The business model supports the viability of the business regarding the new concepts developed. The business model includes **different approaches** in which the external and internal factors, purpose, goals, and on-going plans for achieving them, are analysed.

At the level of develop of the new concepts of slab track reached at the date of publishing of this deliverable, it has been not possible to analyse with the level of details the entire variable involved in the business and decision support model. Besides, some of the different stages of the business model require a particular analysis by every one of the partners related with its internal costs and business strategy. However a global and well-oriented analysis has been possible to perform where different internal and external factors has been detected, analysed and a number of strategic decisions has been proposed.

The approaches followed in the Infrastructure subproject to build a Business case are:

- A **PEST** “Political – Economic – Social – Technological” analysis
- A **SWOT** “Strengths, Weaknesses, Opportunities and Threats” analysis,
- A **CAME** analysis
    - ✓ **C**orrect the weaknesses
    - ✓ **A**dapt/adjust to the threats
    - ✓ **M**aintain the strengths
    - ✓ **E**xplore the opportunities
- A **CANVAS** model

The main conclusions are summarized.

PEST Political – Economic – Social – Technological analysis

PEST analysis develops a framework of external environmental factors used in the environmental scanning component of strategic management. It is a widely used tool that let analyse the political, economic, social and technological environments related with your business. Normally, it is part of a wider analysis which finalizes with the business operation and management plan.

As a result, a global idea or 'big picture' is obtained that helps corporations or businesses to understand the changes which they are exposed to, and from this, exploit the opportunities that they present.

(See D11.3 *Design requirements, concepts and prototype test results (Final)*)

Political,

Current political world situation lives a turbulent period. All these facts draw a demanding scenario of uncertainty and instability where it is not easy to have a clear idea about the national infrastructures plans forecast in the short and mid-term.

Economic,

Global economic environment has suffered relevant changes in the last times. The uncertainties surrounding the forecast are high. The analysis offers an uncertain outlook for the future of infrastructures plans.

Social,

Social demands play an important role in the infrastructure plans. Not only from an economical point of view, but also considering the environment, the sustainability, the efficiency, the security, the smart and green transport, social inequality or climate action.

Due to the financial and economical restrictions, one of the most important demands in our society is the efficiency of the new infrastructures. These must be useful and economically sustainable at the same time. They must be accurately adapted to the current and future needs, but not be over dimensioned. Besides, the cost should not be only evaluated in matter of money but also in societal benefits.

Technological,

Slab track represent a major challenge in the development of the railway system.

SWOT and CAME analysis

Correct the weaknesses and maintain the strengths

Modular system used by the models of slab track designed during the project represents one of the most advanced technologies developed regarded with the slab track systems. This technology will mean an important reduction of the maintenance tasks in matter of time and costs.

The lack of experience in the construction and exploitation of this typology of track supposes other of its great challenges to overcome in order to get the access to the market. The construction of demos where the technology will probe the developments and achievements in the field of the slab track systems are other relevant way of overcoming the reservations at the time of implement the system in real tracks.

The monitoring system installed in the different models of slab track represents a notably differentiating factor over the rest of technologies which could raise the promotion of the system in the near future.

Adapt/adjust the threats

Threats are mainly related with the economic and unstable framework worldwide situation. However, it is possible to deal with this fact paying attention over the areas where the investments in infrastructures are still powerful. Some countries have extensive infrastructure plans for the next decades which includes important investments in matter of railway infrastructures. This fact could represent important possibilities in order to access to important engineering rail projects.

Explore the opportunities

The systems developed in C4R project could be not only use in the construction of new infrastructures. The field of renewal and upgrading of the existing ones should be put in value at time to market the designed models of slab track. The raise in the loads and the speeds of rolling stocks requires new capabilities. This one linked with the raise in the comfort and safety demands by passengers and the reduction of operational costs by the administrators, supposes a great opportunity to commercialize a new system of track which help to carry out all this new prescriptions and societal and economical concerns.

CANVAS model

Among other approaches, the subproject has followed a **CANVAS model,** which consist in the analysis of key blocks which can be clustered in major blocks which meet and associate activities with strong links in common; these are,

- Infrastructure: key activities, key partners and key resources.
- Offer: value propositions.
- Customers: customers segments, channels and relationships.
- Finances: cost structure and revenue streams

Infrastructure, key activities

- To complete the design.
- To check optimal functionality (verifying all requirements are satisfied)
- To contact targeted manufacturers.
- To make the railway sector aware of the new product. Publicity & dissemination.

The production process will depend on the business model of every one of the partners involved in the developments of new systems.

Infrastructure, key partners

Despite of the fact that the consortium is solid and robust in its own composition, some key partners could be required in order to speed up the process to get the market. On this subject, the active and strongly participation of some additional recognized prestige construction and engineering firms as associated partners will help to include the new concepts of slab track in the new rail engineering project. In addition, the involvement of some additional administrator could be relevant, so the development could be tested in different demonstrator before reach the market.

Infrastructure, key resources

Being able to keep the existing consortium as a multidisciplinary team.

R&D departments of the different members of the consortium plays a relevant role in the process of development and technical support regarding the new models of slab track designed in the project. They should support the technical viability and solve all possible doubts and uncertainties about the implementation of this technology in real conditions. In addition, one of their most crucial tasks is the transference of information from them to the **engineering** departments, which must be involved and are in charge of include the new solutions in the rail engineering projects.

Commercial departments are the key factor of the partners which is crucial to be included at the time of spreading the developments reached in the project. In order to get an strengthen of the market links between the customers, i.e. infrastructure managers, railway administrator, and the designers and owners of the new designs, will be needed to arrange technical meetings, close contacts and any other type of relationship.

Publicity and commercialization of the results will require a strong investment in publicity in order to get and consolidate the distribution channels which will serve as ways to achieve the total commercialization of the designs and developments of the project.

The **protection** of results will require the previous definition of who are the co-owners of the developments achieve during the project. Once this will have been done, the partner should decide the need to come to a join ownership agreement. This ownership agreement could represent the more appropriate solution when a consortium is not sufficiently specific. This mean of protection has associated a set of costs which will be shared between the parties.

Offer – value proposition

The proposal at the time to offer the new systems must be aligned with the advantages and benefits which the system brings over the rest of existing slab tracks systems. These benefits are previously detected in the SWOT analysis

Customers

The innovative designs developed requires the need of a close relationship with the potential customers to spread the benefits in the use of these ones and to solve the possible doubts in relation with them.

The existence of a direct assistance line between customers and the consortium of the project is considered crucial at the time to obtain good results in the commercialization of the results. This assistance must be both technical and financial, explaining and solving the advantages and possible doubts and issues occurred during the design and construction process.

It is highly recommended the creation of a technical and commercial committee in order to attend all these possible issues related with the slab track systems developed in the project.

The assessment by the possible customers of the new systems of slab track developed in the project could be done by several ways:

- Standardization: the models developed must comply the current normative and prescriptions in every country where they will be implemented and constructed. The only way to get this is through the test and standardization of the different components which be part of the systems. This procedure will guarantee the post adequate behaviour and the safety prescriptions.
- Elaboration of design guides and engineering solutions where the slab track models developed in C4R project will be included resulted in alternative to the current solutions.
- The execution of demonstrators in rail stretches will help the adequate assessment of the new models of slab track in real conditions.

The commercialization of the new slabs by the consortium must be object of a deep study where every partner will play a role according to its business. In this way, the different partners of the consortium are totally complementary between themselves, and no relevant overlapped are detected. Technical assistance during the different stages of the construction process: planning, design, construction and maintenance will help and speed up the implementation of the new systems of slab tracks developed in C4R.

Among the customers, national governments, infrastructure managers and railway administrators play a primary role as end-users of the developments and designs reached in the subproject of Infrastructure of the project. In addition, the main construction companies along with the engineering design firms must get in touched, can be considered as potential customers.

Cost structure and revenue streams

Cost and revenue structure should be calculated in dependence of the business and engineering sector of every one of the partners in the consortium participating in the development of the slab track designs. The definition of the different costs (fixed costs and variable costs), and revenue streams address the different stages (engineering, construction, technical assistance and maintenance tasks) of the engineering cycle and must be objected of a post in-depth individually study.

In the case of constructors and administrator, the new slab tracks models represent a good chance of improve and upgrade the existing construction methods what could have repercussions in the cost and management structure of the company as well as the rail administrator where the new concepts suppose a crucial opportunity in order to reduce variable costs associated with the maintenance tasks.

On the other hand, the revenue streams will be also very different depending on the kind of business of each partner.

In the case of study, this revenue streams will bring through the commercialization of the new concepts of slab track through the usual exploitation channels. The gateway to new markets and the access to the public administration through the developments of the project will allow the possibility to come to agreements in matter of engineering, construction or maintenance projects which will affect the revenue streams in a positive way.

2.2.3 Freight – perspective and analysis of the economic performance

C4R has focused on **innovations on the wagon, on the train, on the interface with other modes** or internally to promote the future growth in rail transports to meet the requirements for 2030/2050 set by the EC. The technical analysis has been with an economic analysis. The analysis is based on the experience of the partners in the project and on the consultation of various stakeholders to have real economic costs and effective demands of the final customers. The main conclusions are summarized.

There are ongoing plans to permit longer and heavier trucks in Europe. For example, in Germany, the truck length will be extended from 18.75 m to 25.25 m as it already is in Scandinavia. This will *lower the cost* for transport by truck with 26 % and also *lower the market price* for transports.

Proposals to increase the gross weight of trucks, are on long-term to be implemented all along in Europe. In Sweden, increase from 60 to 74 tons which will lower the cost for transport by truck by another 19 %. There are also plans to increase the length from 25.25 to 34 m so it will be possible to handle two trailers by one truck, lowering the cost per trailer by 42 % (KTH calculations).

The way that railway can meet this challenge and improve cost efficiency, can be exemplified: to **introduce longer trains (650 to 750 m) will reduce total operating cost** for long haul by 6 % per t-km.

Length – Axle load and Speed

An increase to 1050m for train length, which is optimal for one high-power locomotive, will decrease the cost with 21 %. Reduction for a transport in a trainload with a full train. For wagon load and inter modal there is also terminal costs and feeder transports which also will not be directly affected so the cost reduction from door to door will be 4 % for the 750m train and 13 % for the 1050m train.

Another measure is **to increase the axle load** from 22.5 to 25 t which **will reduce the cost per ton-kilometres** for heavy freight by 10 %. To extend the gauge from G2 with 7.3 m^2 effective loading area to GC with 10.0 m^2 area will decrease the cost by 23 % for voluminous goods.

Consequences of longer trucks are also that the break-even-point for inter modal transports will increase to longer distances where market is smaller. An increase of the truck length from 18 m to 25.25 m will push the break-even point for a typical intermodal transport from 350 km to 500 km. An increase of truck-length from 25.25 to 34 m will push the break-even from 500 km to 650 km. That means that intermodal will be unprofitable on national markets.

Another measure is **increasing speed for freight trains from 100 km/h to 120 km/h. This may increase operating costs, but at the same time, makes possible operating more freight trains between passenger trains and increase productivity with faster circulation of vehicles and thus lower capital costs.**

New wagon designs to enhance efficiency

The various proposals of **new wagon designs** are very interesting for the car transportation wagons where the benefits appear very significant for certain categories of car lengths.

It is possible to reach around 25% gain in the transportation costs because of asset rotation, with direct gain in capacity in a given length and a reduction of maintenance. **Reduction of the number of axles**, as long as the stability of the wagon is correct and as long as the speed limit does not appear to be penalizing, induces naturally a reduction of the maintenance cost beyond the simple reduction linked to the possible predictive maintenance.

For the container transportation wagons, cost reduction should reach 16% even without introducing better train manoeuvrability. However, gain on maintenance resulting from the reduction of number of axles per container carried (2.4 axel/container versus 3/container) should even reduce it more.

For the container transportation, the proposed solution to have the possibility of a partial flexibility to carry 20´, 40’, 45’ containers applied to 60’ wagons, is applicable for 30% of the containers to be 45’, without an increase of the train length but with a constraint of working by blocks of 3 wagons not able to be uncoupled operationally because of the absence of the free rectangle of Bern necessary for the staff safety when decoupling.

The increase in capacity in terms of units is limited to 7%. But it is also applicable for 80’ wagons on which you can place 2 x 45’ containers every group of 3 x 80’ wagons not to be uncoupled operationally. On trains of 720m (without the locomotive) you could transport 54 units of which 18 could be 45’ units instead of 48 units of which 48 could be 45’ units. The gain of efficiency is 12.5%.

For the crane-able semi-trailer transportation trains the new wagon design creates a little efficiency of 3.4% which would not be sufficient for a positive wagon owner decision of investment.

A **progressive introduction of automatic couplers**, compatible with UIC ones, would give no benefits in the transition period, but its high cost, would push to use it for coupled wagons by drawbars, speeding up their introduction and reducing cost by 50% if the market allows such coupled wagons.

For introduction of longer trains, a significant cost reduction is forecast, due to the single driver, with the second locomotive being remote controlled, and to the infrastructure toll if it is based on the pure network capacity utilization, and not only on the t-km.

The major problem, which is a serious drawback, is the existence of a large available fleet of wagons for which the cost of modifications would be important. So, unless the market increases strongly according to forecasts, the probability of major structural modifications is low.

Based on the estimated cost of these new wagons compared to new standard wagons cost, a little margin may appear also on costs.

For all types of transport, specifically if uncoupling wagons is not frequent, for instance for shuttle trains, the **reduction of time of preparation of the train before departure** is a very positive progress. For that purpose, equipping the train with an electric line and with an End of Train device enables to perform a brake test from the driver’s cabin if sensors have been installed on the wagons. This could be a first step of progress before installing an EP braking system.

The automated brake test with an EOT device and connected devices on each wagon does not need high investment and generates a significant increase of capacity and competitiveness. It is the first improvement to be done together with a lengthening of the train with EOT.

The costs are extremely variable for EP brakes on all train using LPWAN according to the services expected: they can be as low as 30€ per year for a single device using only direct LPWAN for its connection with the base with some latency up to 8€/wagon /day for a full service with 25 sensors, a smart box GSM connected and equipment for automated brake test and accurate positioning.

Innovations in terminals

To improve the competitiveness for inter-modal it is **necessary also to reduce the terminal cost**. If the cost for transfer one container from road to rail will be reduced from 30 € to 10 €, total transport cost can be reduced with 15 % for a for a typical transport.

Regarding terminals, economic estimated analysis has been performed for different terminals, obtaining **average costs, (also NPV & IRR), investments (CAPEX) and operational (OPEX)** costs included.

For conventional terminals, with reach-stackers and gantry cranes, cost per loading unit is in the range 20-30 €/TEU, which is also a common market price for terminal handling. Includes operating cost and capital cost for the technical equipment, a normal charge on the terminal operator side. Cost models include also the basic investments, which is the long-term cost for building new terminals. The total cost is in the range of 30-50 €/TEU. This is normally not included in the market price, because some of the investments have been done long time ago by the state and are not allocated to each terminal.

Scenario analysis was undertaken, implementing KPIs for different improvements of operation and technique in the different terminal typologies. **Technical measures including; fast transtainers, horizontal and parallel handling, automated gates, automatic couplings on locos and operative measures like long trains, H24 working time and automatic ITU and vehicles control and data exchange, were assessed and indicated a better terminal performance.**

These measures showed profitability following an assessment by cost benefit-analysis. Main benefits were identified from **transit timesaving, decrease of external costs and from the extra traffic revenues.**

Analysis of linear traffic showed that it is possible to have more terminals to cover a larger market, in combination with considered new techniques. As horizontal transfer makes it possible to have terminals on an electrified siding, the train can make short stops on intermediate stations. This means that there will be no need for shunting with diesel and parking of wagons, as well as full automation of transfer of loading units will be possible. Cost for a small-scale automatic linear terminal has been calculated to 12 €/TEU for operation and capital costs for technical equipment; including the rail infrastructure the total cost will be 14 €/TEU. The low cost for the linear terminal is due to the absence of shunting engines and dedicated personnel. It ensures a very high benefit/cost ratio.

Handling wagons on a marshalling yard is quite different: operating cost in Sweden is 15 € per wagon. Adding yearly maintenance and operational cost for the IM it will be 52 € per wagon. Calculating the whole cost, it will be very expensive: in this case 96 € per wagon, which reflects the cost to build a new marshalling yard. For marshalling yards, automatic couplers, automatic brakes on wagons, automatic wagon identification, duo locos and driverless locos improved KPI. In this case, the cost-benefit analysis gives a negative result because of the huge investments.

However, the yard is not as a stand-alone business unit, but a pre-requisite for the rationalization of wagonload's transport system within the service production chain. A fully automated marshalling yard is technically possible and potentially strongly effective: the automatic coupler is an ultimate solution for WL, especially if it can be radio-controlled, making longer trains easier to operate and, even if it is a big investment, it can lower long-term costs.

For IMs, **new solutions for high-speed control of the network infrastructure**, inside the structure devices informing regularly on the status of the infrastructure will enable more **intelligent maintenance preventive/predictive programming**, generating significant economies.

Also, **more accurate information on train positioning**, possible train lengthening, getting extremely cheaply accurate information on use of certain sidings will boost the possible use of the infrastructure.

For RUs the main **needs for cost-efficiency on the positioning of their train**, are following the status of their Rolling Stock (Locomotive and Wagons), the efficiency of their operations specifically at the departure of the terminals, the loading status of their wagons to ensure safety. New needs will surely appear with the train automation projects for the marshalling.

2.3 General strategy for the use of expected project results

2.3.1 Consortium strategy and strategic impacts

The results of the C4R project are checked in several ways to prove the viability and validity of the developed solutions. New designs and prototypes of new developed track components combined with elements for monitoring and measurement equipment, designs for freight trains and wagons as well as terminal operations, and traffic management/operation timetable tools are tested under laboratory conditions, simulations of performance, also in several different locations in situ under real traffic and weather conditions.

An increase of the automation levels for the processes in the railway system, joint to the strategy of migration and roadmaps to be followed, mixed with the intense testing, will assure the project acceptance and confidence by the participating stakeholders, as well by the market. This will provide a solid base for the exploitation and implementation of the results into the market.

By integrating a large "bandwidth" of the main key stakeholders in the project, it is ensured that the partners will implement the solutions which are of specific interest for their respective field of activity into their organisations. As a result of the partnership, members who are also in association of other superior level organisations, including UIC and UNIFE, the awareness of the project will be achieved using their habitual dissemination and communication channels.

Further, the C4R project results and knowledge will be incorporated into the Shift2Rail Joint Undertaking and its innovation project (IPs) and its lighthouse/associated projects. This is assured on one hand by the effect that many participants of C4R have been chosen to contribute to Shift2Rail. Thus, participants on "working level" have already acted as a logic link between the projects as soon as Shift2Rail started and will currently be able to introduce the final results of C4R into the ongoing project.

On the other hand, C4R has actively included leading participants of Shift2Rail into the project information to be as transparent as possible about the activities and results and to encourage the transfer of the performed work on management level. To mention an example the project has invited the programme manager of Shift2Rail to participate on the Final Conference in order to get informed and connected to the SP-leaders but also to give the participants of C4R an insight about the proceedings in Shift2Rail.

2.3.2 STRATEGIC IMPACT

Infrastructure and advanced monitoring

Advances in the frame of C4R have been done in the infrastructure, regarding potential that can suppose major steps and so impacts in the technical field of infrastructure design, renewal and maintenance, covered by SP1 tasks and deliverables, and also including advanced monitoring, developed in all its depth within the frame of SP4.

The development of infrastructure solutions that aim at both cost-saving operation by low cost maintenance and extended life-cycle, lowering the total Life Cycle Cost (LCC), have been covered and include two new concepts and prototypes of modular designs of slab tracks ("3MB" and "L-Track") for the railway track of the future and, even with greater initial expenses for investments than the ballasted track, would reduce the cost of installation from on the shelf available slab track models.

Another impact to be considered on their potential is the availability for additional capacity that will be created, based on profiting from originally scheduled intervals on lines that now would require a minimised number of track possessions. These types of solutions increase potentially in each day available from 3 to 5 complementary hours, in which mainly potential new freight services can use the track at their full potential capabilities without crossing or mixing to ordinary or high-speed passenger service.

The investment cost of upgrading to slab track was assumed to be in some scenarios 1.000.000 €/track-km, which is within the typical frame of values for existing slab track designs; this value includes the installation of innovative monitoring systems, as complement to the track's replacement. The main intended effect from the implementation of slab track is the reduction of maintenance costs and the increase of availability. It was assumed from studies that a 34 % reduction in variable maintenance costs for the track and 27% reduction for S&C wherever the consideration was that the track was upgraded to slab technology.

Investigations of the project have also determined significant impacts, in terms of understanding the behaviour of certain infrastructure components, as well as developing potential solutions to solve their current obstacles to allow very high-speed traffic (VHST) or mix of high-speed and freight train traffic. Several track components such as switches and crossings (S&Cs), where the investigation of failure modes has leaded to develop breakthrough innovative concepts to improve their reliability using optimised geometry, grades or stiffness, or rail pads and under sleeper pads (USPs) combined with sleepers, on the optimisation of their design, including in relation with operational demands in terms of speed load (VHST or heavier axle load) and volume of traffic, have received a special attention, which has been driven to obtain results not only in terms of overall performance, but also obtaining a reduced need for maintenance in these components, thus lowering the operational costs linked to their related corrective or preventive activities.

Regarding S&C, installation cost is estimated to be 1.5 times the current average value, 150,000 €/unit; as for the slab track innovation, monitoring systems will also be available for S&C, their installation cost already included in the switches and crossings installation value.

Earthworks and structures have also been the focus of specialised activities, where the analysis of the dynamic solicitations for bridges in the structural design and the innovation applied for the design and construction of transition zones (with demonstrators located on site in high speed lines in the UK (HS1) and Portugal), have obtained results applicable to the design in the field with impact of not only both VHST and upgraded freight traffic, but from their mutual combination. Such achievements required establishing a systematic and documented approach not only for new lines but for infrastructure upgrading to meet the new demands on freight operations, because upgrading scenarios tend to increase the track and infrastructure deterioration and fatigue phenomena, due to the increase of axle load, speed and total length of each individual train. These degradations need to be addressed and mitigated in advance, and now will be appropriately counteracted.

All the above-mentioned impacts, wouldn't have been made in many cases if the developments of components, wouldn't have undergone joint with new concepts for railway structural and operational monitoring, both in sensors and identification technologies, that combined can offer insight to their integration in operation and their behaviour and durability through simulations and automated maintenance forecasts, and allowing also a prediction of the structural lifetime. The work has been directed toward the use of innovative simple and cheap sensors and a migration to intelligent components with in-built monitoring for new tracks structures and for existing ones.

Numerous technologies were considered for their suitability for application as part of a condition monitoring system, either for current railway elements (i.e. retrofitting) or to be built-in to new elements during production or installation (as it has been proved in the new slab track concepts have been designed, developed and prototyped), going through a holistic analysis in which wireless communication transmission was the focus, finally choosing RFID passive tags as referential and low cost technology in terms of identification of both infrastructure and rolling stock components, suitable for the railway environment of work, and fully safety compatible with other features of communication and generating no electromagnetic disturbance, requiring low power to be fed, while maintaining high levels of robustness. It has been able to be combined with COTS-sensor deployment, so that the recovered data can be turned to useful information with minimal post-processing, regarding accelerometric sensors (e.g. MEMS), or other that can measure temperature, humidity or stress, requiring also low energy harvesting to be in operation.

The introduction of advanced monitoring system will contribute for a reduction in fixed maintenance costs, the overall performance of the new system, for example leading to a reduction of S&C maintenance costs to approximately a third of that of the baseline value and will reduce the delay minutes caused by S&C by 50%.

A 60% reduction of unplanned unavailability will be obtained when combining slab track, new S&C and monitoring.

These monitoring systems have obtained an impact in the already tested railway applications, but also in such consideration into other future possible applications in the condition monitoring of pantograph-catenary interaction, weighing in motion and wheel defect detection systems and bogie condition monitoring on freight trains. Extended applications can be considered as well outside the railway system field, for example, in air-borne transportation or other different types of ground transportation.

Upgrade of freight services and terminals operation

In the Transport White Paper 2011, the European Commission identified the need to overcome the burden that the current transportation system places on economy and society through, for example: lack of capacity; impacts on the environment (emissions, congestion etc.); and the inability to cope with climate change and extreme weather events. Capacity4Rail consortium is confident about the outcomes of research and developed work carried in different SPs our over the last four years that its impact will be felt in both freight and passenger traffic and that it will to grow across European rail networks. To cope with this growth, the Capacity4Rail consortium has explored, analysed and suggested new and innovative technologies to create greater network capacity in a resource-efficient, faster, and more efficient and more flexible manner. The innovative techniques will deliver adaptable, automated, and resilient and, above all, affordable solutions to existing and projected capacity issues to the rail industry.

The outcomes of the project will provide societal benefits in several categories: economic (suggested through quantitative and qualitative CBA and FA analysis), delivered both directly (to the infrastructure and rolling stock owners and operators, as well as tax payers and ticket holders) and indirectly (to the European economy as a whole); and environmental (by providing the means to significantly increase railway capacity and thereby facilitating modal shift to railways from other less environmentally friendly transport modes).

An important impact of the outcome of SP2 (WP21 to be specific) is that the outcome of the research is published in a peer reviewed paper titled 'How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011' an 'open access' journal of European Transport Research Review. The paper has attracted a huge readership and downloads (1800 as of August 2017).

Out study suggests that it is possible to reduce GHG emissions for all modes but rail will still be the most efficient mode by 2050. An estimation of the effects of a mode shift (as noted above) to rail transport applying the world's 'best practice' shows that such a mode shift to rail can reduce EU transport GHG emissions over land by about 20 %, compared with a baseline scenario. In combination with low-carbon electricity production a reduction of about 30% can be achieved. A developed rail system, as suggested in different deliverables, can thus substantially contribute to the EU target of reducing GHG emissions in the transport sector by 60% compared to 1990 levels. To enable such a mode shift and to manage the demand for capacity, there is a need for investment at national and European level.

Upgrading of existing lines to handle increased demands on freight operations can carry costs that are as low as 15–20% of costs for rebuilding to the same standard. At the same time, environmental impact and operational disruptions typically decrease. On the other hand, failures in upgrading procedures may carry dramatic consequences in lost revenues and increased costs. With the guideline introduced in D11.4 and enhanced in D11.5, the possibilities to carry out the upgrading in a structured manner have increased significantly. The potential savings in decreased cost savings are massive.

Introducing costs, a freight terminal upgrade cost of 100 M€/terminal may be assumed. The benefits were, however, difficult to estimate at this stage. Surely, the benefits from this innovation are related to the operating costs: one of the main effects of the upgrade for the terminal would be quicker loading and unloading operations. In the absence of detailed information, a reduction of the operating costs of freight rail transport in the order of 10% is assumed because of terminal upgrades. Quicker loading and unloading operation also mean a reduction of freight trains travel time, assumed to be in the order of 5%.

Monitoring and processing of monitoring data is a topic of increased interest throughout Europe. To this end, there are massive investments in both hardware and software. The aim is that these investments will pay off due to more efficient and reliable operations. However, this requires both collected data and interpretation of the data to be relevant with respect to the objectives. The Capacity4Rail deliverables D41.1, D41.2 and D41.3 identify relevant parameters for different parts of the railway system. The reports also show how data can be interpreted and how data that cannot be directly measured can be interpreted from measurable data. Further, the reports introduce a framework for evaluating costs and benefits (in a broad sense) of different monitoring solutions. Finally, the reports include examples of operational installations. In total, this enhances the possibilities to make well-founded and aware decisions on monitoring strategies. It also reduces the risk of failed investments substantially and enhances the usefulness of collected data. In summary, the impact on efficient future monitoring strategies in Europe should be significant.

Traffic management

Potential impacts produced by the uptake of SP3 results by railway Industry would be the following:

The introduction of the "Capability trade-offs" tool developed can effectively support industry strategic investment decisions by quickly and clearly indicating the scenario achieving future operational targets while providing the best capability trade-off. This definitely paves the way for potential automation of long-term planning processes leading to more cost-effective and "leaner" deployment of railway investments.

The industrial use of an automatic integrated planning tool such as the CAIN-LiU framework developed can effectively support tactical and real-time decisions by advising on scheduling strategies which maximize economic satisfaction of all the actors involved. The real-life application of this tool showed indeed that the provided solution returned the best trade-off among requests of FOCs, network capacity utilisation for IMs and punctuality for TOCs. Additionally, such a framework includes a web train schedule database which is shared among IMs, FOCs and TOCs, making the timetable amendment process more flexible and faster than current practice in providing contingency plans in case of disruption or emergency.

The SysML schematic disruption management process can be effectively used by infrastructure managers of member countries to identify criticalities and opportunities for improvements in their current disruption handling procedures. The roadmap produced for increasing levels of automation outlines step-changes which need to be implemented for each asset to enhance the grade of automation of the entire railway system. The roadmap also can support the European railway industry in identifying the most suitable Grade of Automation which is required to achieve future operational targets and meet the demand forecasted for 2030 and 2050. Industrial uptake of advanced tools for train delay prediction is expected to provide significant improvements to the quality of traffic management decisions and information to customers, consequently increasing business effectiveness of infrastructure managers as well as customer's satisfaction.

Real-life implementation of the web-based semantic data architecture developed allows increasing the level of automation of railways by dynamically integrating asset condition monitoring directly with operation management, facilitating the implementation of integrated maintenance and timetable planning. In addition, this would enable predicting disruption events due to asset faults in order to prevent the disruption itself or mitigate its impacts on both service and customers by means of more accurate information, which is expected to lead to improved traffic management and better customer experience. The extension of the semantic web based architecture to the entire transportation system will provide the communication framework necessary to deliver the European Intermodal Transportation platform set as one of the main objectives for 2020 by the "White Paper" on transport of the European Commission.

Dissemination material, methodologies, tools and results produced by SP3 have also been included as educative material in courses which are given to students at the Faculty of Engineering of the University of Birmingham (United Kingdom) and the Technical University of Dresden (Germany).

Overall system technical and economic impacts

The overall technical impacts of all innovations could be seen directly in the resulting generation of new designs POCs, demonstrators, and derived in the actions and guidelines recommended as seen in D56.2.

The economic part was focused in a Cost-Benefit Analysis (CBA) based on a tool developed in the frame of the project, and which was performed for two practical case studies in the EU.

The first case study has been built on the Swedish sections of the Scandinavian-Mediterranean TEN-T Corridor. Both rail and road corridor sections were modelled with input data about infrastructure, operation and traffic forecasts. The analysis is made through a set of Scenarios where different sets of C4R Innovations, operational or market conditions changes are modelled.

The first scenario (scenario 1) included the implementation of all C4R innovations throughout the Swedish rail network, as well as increases in train length up to 1500 m. The CBA resulted in a negative NPV, with the large investment not being offset by the producer surplus generated by the modal transfer. When the scenario was altered to include a very significant reduction in delays, this is enough to turn the NPV positive.

Two scenarios (2 and 3) were built with a more limited implementation of infrastructure innovations, mainly slab track. The results showed an improvement relative to scenario 1, showing the advantages of a more selective approach.

A Rail Positive Scenario (4) assumed a full migration to innovative freight wagons, including automatic couplers and EP brakes, leading to further operating costs reductions and a small speed increase. This scenario had the most positive results of all that were tested.

In order to test how some of the expected innovations in road transportation would affect the profitability of the investment in the rail sector being tested, road positive scenarios (5 and 6) were also tested. These assumed an increase in road truck gross weight and reductions in operating costs. The results showed the benefits that were present in Scenario 1 from modal transfer may be virtually obliterated. It was tested how the introduction of taxes on road transportation can partially offset these effects, boosting the rail sector.

A second case study was based on a more detailed analysis of a smaller corridor section in southern France (Montpellier-Perpignan) that was performed in the context of the demonstrations for D55.6. This corridor section has the further feature of being a bottleneck in the wider corridor it is inserted in.

A comparable set of scenarios was analysed for this corridor section showing overall positive results in terms of NPV, even for the ones with heavier investment. However, the relative changes between the different scenarios are not qualitatively different from the ones obtained in the first case study.

The results of the Montpellier-Perpignan case study in comparison with the Swedish one show how the kind of deep investment in infrastructure is more easily profitable in capacity constrained sections, even if this profitability hangs on an assumed increase in availability.

Both case studies show how improvements in operation leading to longer, higher capacity trains can have very positive impacts with relatively modest investments.

In the end, we can extract two main points on the economic impacts of the innovations that have been considered in the context of the Capacity4Rail project.

The first point to be taken is that deep infrastructure investments may or may not be profitable, depending on the conditions of the corridor. What becomes apparent from the results presented here is that there is a much higher chance of large investments, such as upgrade to slab track, being profitable in capacity constrained sections. However, local boundary conditions, which have big impact on investment cost, complexity of upgrade and operational risks must be necessarily considered in decision making. It should, however, be noted that the biggest share of the benefit is generated by gains in availability leading to increased capacity.

The second point concerns the very high profitability that the introduction of innovative operational concepts may have. We are talking about rolling stock innovations, such as automatic couplers, EP brakes, often combined with modest infrastructure investment in siding extensions to allow for longer and heavier trains.

In both the preceding issues, the main benefits generating mechanism is the modal transfer from road to rail that is allowed by the increased carrying capacity. Benefits in other categories are usually small in comparison. Still, some of the analysed scenarios show that improvements in delays or reductions in travel times can have significant positive impacts trough savings in value of time.

Further considerations on impacts deriving from the results of these case studies are made in Deliverable D56.1, specifically, concerning the European policy Targets and Roadmap as well as market share perspectives.

2.4 STAKEHOLDER STRATEGY

With the objective to define the C4R individual partner strategies, a questionnaire has been sent out to the C4R partners requiring them to answer the following questions:

1. INCREASED CAPACITY: FROM YOUR OPINION WHAT ARE THE NEEDS IN TERMS OF INCREASED CAPACITY, MAINTENABILITY, OPERATIONS AND RELIABILITY?
2. EXPECTED RESULTS: WHICH SPECIFIC AREA/S IN TERMS OF C4R PROJECT'S EXPECTED RESULTS WILL BE USEFUL/RELEVANT FOR YOUR INSTITUTION/COMPANY/ORGANISATION?
3. STANDARDS AND INTEROPERABILITY: WHAT RECOMMENDATIONS, GUIDELINES, STANDARDS AND TSI MODIFICATIONS BASED ON THE RESULTS WOULD BE USEFUL TO YOUR RESEARCH AREAS/ACTIVITIES/BUSINESS AND SHOULD BE DEVELOPED?
4. MARKET ANALYSIS: WHAT ARE THE STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT) THAT YOU IDENTIFIED IN THE MARKET DURING THE COURSE OF THIS PROJECT?
5. IMPLEMENTATION OF RESULTS: HOW DO YOU PLAN TO IMPLEMENT THE RESULTS
   a) In short-term (< 2 years after completion)?
   b) In long-term (> 2 years but < 10 years after completion)?

The answers and analysis of the answers have been separated according to the type of organisation of the partner (railway undertaker, infrastructure managers, rail supply industry, academia or sector association). The model of the questionnaire can be found in **Annex 1.**

2.4.1 RAILWAY UNDERTAKINGS AND INFRASTRUCTURE MANAGERS

2.4.1.1 C4R RESULTS RELATED TO NEEDS

From the point of view of Infrastructure Managers (IMs) and Railway Undertakings (RUs), the main need is the improvement of reliability and availability of railway assets with low maintenance effort and costs to ensure trains to run safely in their schedule.

Any innovation that can assist in giving a highly reliable, high capacity operational railway is of interest. IMs thus have challenges in the areas Infrastructure, Monitoring, Trains and Operations & Scheduling. The C4R-results in these 4 areas are highlighted in this order on the following parts.

Infrastructure

Infrastructure must be upgraded to increase availability and reliability considering structures, track, S&Cs and signalling from the point of view of IMs as follows:

- optimized ballasted tracks with combined, rail pads, under sleeper pads and extended life of rails with different grades and heavier profiles if necessary, for increased lifetime and reduced maintenance
- Slab tracks on sections with high-speed traffic or very high loads and limited space for additional tracks, or with mixed freight traffic and very reduced windows of time for track possessions
- improved S&Cs including systems for monitoring of condition
- Upgrade lines to E5 category of load on specific sections
- Upgrade lines for longer trains (even longer than minimum interoperable)
- Predictive maintenance to optimize maintenance efficiency and to reduce costs

C4R project has developed innovations whose results which correspond to these needs via new concepts of track, mainly based on modular slab track for mixed and VHS traffic and the two most promising concepts have been prototyped in real scale models and tested in the CEDEX Track Box placed in Madrid, under conditions like operational ones to test durability and fatigue. Besides, new concepts for switches and crossings (S&Cs) have been designed based on failure modes analysis, revisiting curving physics and wheel-rail profile interaction. Finally, the innovations have been incorporating sensors for condition monitoring. The result shows an optimized design for switches to achieve higher resilience.

A new RAMS and cost driven track design method has been developed and lead to general track design guidelines (also able to be applied for very high-speed trains or more demanding freight traffic) and to an identification of limiting factors especially in terms of admissible track irregularities and transition zones.

The developed knowledge has improved modelling of track and subgrade behaviour, to severe thermic and humidity condition, and has been included into the design guidelines, to dimension and prepare it in relation to flood and heavy rain events. Regarding structures, an improved knowledge on the dynamical behaviour of very high-speed trains on bridges plus new train categories including upgraded freight service, has been obtained from where appropriate design principles have been achieved.

The need for predictive maintenance is answered by the achievements in advanced monitoring, which will be reflected on the following paragraphs on monitoring. Also, prototypes of the most promising concepts both for plain track and switches were demonstrated on high-speed lines (sometimes with mixed traffic), on locations in operational tracks in the United Kingdom and Portugal.

Monitoring

IMs seem to need a reliable and online condition monitoring to help optimising the maintenance processes, developing condition-based and stable planned preventive maintenance. The reduction of necessary maintenance time and track-possession will increase the availability of tracks and lead to a more stable or even decreased specific charge of track fee based on the subject for most of the cases. This includes:

- Monitoring of S&Cs to identify the change of status and predict critical states
- Data models for prognosis of failure and for predictive maintenance
- Optimised planning and coordination of maintenance works for reduced non-operational times of the track

Predictive maintenance seems to be an essential need for IMs in order to maintain the track with optimised planning of the works, and thus reduced track-possession and lower operational costs. Continuous data about the condition of the components in combination with prognostic tools to predict the progression of deterioration are needed to come to an optimal coordination of track works with operations scheduled.

The already developed monitoring systems for new tracks and for retro-fitting have obtained a very promising result to fit the needs of IMs in this area. An important task was the technology assessment specifically within SP4 which led to the development of a new system with much better LCC than the on the shelf systems that were previously available on the commercial market.

Also in SP1 demonstrations were made, such as software developments to define the location of point machine, crossing and long sleepers, where it is possible to compare all the data collected, taken by measurement trains and see the growing rate of the defects found. Some are very eager to adopt the software to see the development of the defects and based on that, predict the practical maintenance time for S&Cs.

C4R gives an overview of up-to-date monitoring technologies from other industries, developed recommendations for approved, sustainable state-of-the-art sensors and energy harvesting technologies in railway applications and presents new concepts for using advanced monitoring in embankments, bridges, different tracks types and switches. The developed systems are designed for whole life-time prediction, condition based maintenance and fast health reporting even after natural events of force majeure (e.g. extreme weather).

Prototypes of the developed equipment are being tested on several mixed traffic lines under real traffic and weather conditions to prove the reliability and validity of the concepts.

Rolling stock and trains

In the area of wagons, locomotives and complete trains the IMs see the need for:

- Longer trains with "distributed" locomotives to split the train in parts with different destinations
- Automatic couplers implementation and use
- Preparation of the infrastructure for higher axle loads
- Enhanced interconnected braking systems (with low noise generation)
- Preference for “track-friendly” vehicles on operation, or appliance of higher (variable) fees

Corresponding to the need for higher loading capacity in the trains, several design alternatives have been studied to increase the usable length of a standard train, mainly with new wagon designs having better overall loading capacity per unit and per train, a lower LCC and extended capabilities for automated operations. The corresponding cost benefit analysis shows interesting progress for the car carrier wagon and the container wagon. An analysis has been also been performed on the behaviour of diverse breaking systems with a special view on the benefit of applying simultaneous braking. Equipping the train with an electric line and with an End of Train (EoT) device enables to perform a brake test from the driver’s cabin which can be a first step of progress before installing in freight trains an EP braking system.

Summed up, the C4R results in this area increase the overall capacity of the rail freight system substantially with adapted and efficient terminals, both time and cost saving, with multiple innovations on the wagons, simultaneously introduction of new modernized wagons components, with novel sensors and monitoring while using the enhanced traffic operation tools.

Solutions for lateral loading and unloading in marshalling yards, improvement of shunting, as well automation of processes in these type of facilities, and the last mile services to connect with main lines, raising the level of convenience and reducing the time of operations have been also addressed during the project, but will need further Proof of Concept (PoC) and implementation development.

Operation and scheduling

In the field of operation and scheduling a need of the IMs has been detected for increased automation level to create a more robust decision-making process. Timetable planning must be improved to take optimal operational decisions for traffic regulation. Fast and flexible planning of paths will lead to fast recovery after local, regional or national disturbances due to any circumstance.

To achieve the progress in this area the knowledge on state-of-art in timetable planning must be necessarily increased. Exchange about best practice, roles of timetable planning and user cases between IMs/RUs, the system suppliers and academia is essential to come to improved methods and automated tools. These two last aspects are one of the main levers to increase capacity, improve punctuality and increase cost efficiency and customer satisfaction.

Also, in this context the increase of average load factor of freight trains is to be mentioned. A high percentage of wagons are transported empty, which gives a high potential of that increment to be considered.

Processes for estimation of capacity and timetable planning, as well as timetable and traffic simulation systems were under development. The amount of available data is increasing at a high pace. The processes for tactical and operational planning are merging. Timetable processes have generated working documents that are improved successively for optimal partitioning of capacity with more flexible train paths.

Following results of C4R correspond to the needs of IMs related to timetable planning and operational process and therefore are of interest:

- Approaches and methods to optimize train operation
- A framework for simulation – linking strategic, tactical and operational level
- Data model to predict punctuality when parameters in the timetable is changed
- Integrated tools and modules for timetable planning and predictions of punctuality
- Interaction between IMs timetable systems and optimisation/data analysis models handling static and dynamic data
- Combined framework for simulation for operational, tactical and strategic planning
- Capacity trade-off framework - this will improve business planning
- Data architecture and models

2.4.1.2 Short-term actions after project end

After the project ends, the developed retrofit monitoring systems will be exposed to an advanced testing by the IMs. A comparison, analysis and interpretation of the results will be processed. Further on, a definition of target prices for these systems will be necessary.

By using the software and method, IMs will be following the evolution process of growth of the defects on S&Cs in order to intervene on time and thus to ensure the availability and reliability of track.

Actions of development and implementation on site for the slab track prototypes and the S&Cs will continue within the frame of the Shift2Rail initiative.

IMs have gained much knowledge in all relevant areas during the C4R-project and have already developed concepts for further research on this basis. Examples in the area of train operations, are the data models to predict punctuality in relation to changes of parameters in the timetable or the development of optimal timetables for tactical and operational scenarios.

The Framework for simulation strategic, tactical and operational traffic is taken forward and input to Shift2Rail projects IP5, TD2, ARCC, FR8Hub and CCA Plasa.

2.4.1.3 Long-term Actions

On the long-term integrated tools and modules for timetable planning and predictions of punctuality will be implemented. The developed capacity trade-off tool will also be tested and implemented.

Some IMs plan to implement Way Trackside Monitoring Systems (WTMS) into their own internal guidelines as an alternative inspection method for special cases.

Measurement devices will successively be installed or included in railway components. Continuous monitoring systems will be broadly established to get permanent information of the status and condition of train- and track-components.

By processing more measurement data on the lines, it will be possible to propose new precise thresholds for maintenance in Alert Levels (AL)/ Intervention Levels (IL)/ Immediate Action Levels (IAL) and decrease the cost of maintenance of plain track and especially S&Cs.

2.4.2 Rail industry

2.4.2.1 C4R results related to needs

The railway industry representatives participating in C4R are not only covering the design and building of railway infrastructure but also the maintenance of the system. Thus, they have a view that goes beyond the focus on particular railway services and components and their improvement. They also see the entire system of infrastructure and reflect on improvements in the long-term during the whole lifecycle of new railway systems and also about the benefits that measuring devices will contribute to in this context.

Rail industry see the need for current railway lines in operation to get an extra effort optimising the reliability and maintainability to reduce the amount of failure cases caused by common use of assets.

Also, they anticipate the bidding of future renewal or upgrade works on currently obsolete rolling stock or sections in order to increase capacity.

Infrastructure

As contractors of infrastructure construction and maintenance, they expect enhanced track systems that are easy to design, fast to deploy and require minimum maintenance. Especially a lower track possession time for maintenance works will lead to enhance satisfaction of the customers, all of it while minimizing cost and providing real-time data on health status.

The environmental requirements of reducing noise and carbon emissions throughout the whole life cycle of the infrastructure are also considered and respected by the suppliers. Innovation developed in C4R has to provide advantage and progress to the execution of maintenance works. In case of planning new railway lines, it must be taken into account to use resilient components, increase the durability of the track condition and develop an efficient maintenance program that includes preventive actions as those explored in this project. New high-speed lines require fast construction methods as well as sustainable and low-maintenance solutions.

The modular slab track systems developed by C4R in SP1 in combination with the health monitoring systems of SP4 have been designed respecting a comprehensive set of requirements. Along with technical requirements - regarding for example mechanical criteria, geometry and environmental aspects of the slab track – the relevant needs of the project stakeholders have been taken into account. Among others a low number of construction steps, modularity for a high degree of precast and extensive assembly works & assembly quality, easy replacement of track components and friendly repair procedures on unforeseeable events.

Another point regards the relatively low reliability of S&Cs which is directly affecting the railway capacity.

To answer to this requirement the C4R-project investigated short-term solutions for minimizing loads and rail profile degradation in the switch panel and medium-term solutions which have focused on improving the performance of the crossing panel. Long-term solutions are based on a whole-system approach including enhanced design, materials and components and incorporation of modern mechatronics for improved system kinematics and control.

Monitoring

The developed measurement equipment is providing additional benefit by its basic features, comprising low power consumption, energy harvesting, low cost, wireless transfer and ease of installation. It is suitable for new track and also as retrofitting kits for existing track. It is able to provide valuable information for the track and structure maintenance teams about temperatures, deflections, displacements, accelerations and stresses to carry out preventive maintenance and to optimise the planning of continuous regular maintenance.

The innovations are being studied on the new modular slab track prototypes and the concept has been further optimised. On site there have been installed retrofitted monitoring equipment dedicated to follow behaviour of transition zones and structures.

Operation & Scheduling

Like already mentioned in the section representing Infrastructure-Managers and Railway Undertakers, also from the point of view of railway industry the operation of trains needs to be enhanced.

The enhanced traffic operation tools allow an efficient timetable planning and by that a much quicker return to regular train operations after disruptions.

An enhanced planning of maintenance works and a more efficient use of the scarce working time out of operation is an expected positive side effect of this stabilization of operation, which should also be producing a bigger window of working time for track possessions and a higher output and so, a good influence on maintenance cost.

2.4.2.2 Short-term actions after project end

Rail industry will carry out more pilot tests in different countries and an exhaustive monitoring campaign and dissemination of results. One of the biggest issues to bring the developments of R&D projects to the market is a reluctance of decision makers to be open for testing. European Union seems rather slow in addressing market needs compared with other economies like China.

Thus, to be able to realize the in-situ trial of the new concepts Infrastructure Managers and other Administrations are strongly required to allow for some tests in their networks to prove the material.

A comprehensive overview of the deliverables and developed solutions has been put into a summary of dedicated industrial guidelines that should be followed both in the maintenance activities and in new rail infrastructure projects.

With the increased knowledge regarding rail high-speed technology and new concepts of track technology along with the access, not only to the innovations developed within the project but also to the roadmap that European railways will follow in the coming years, rail suppliers have the opportunity to stay in the lead of rail engineering and technology.

Regarding the offer for new and innovative services for consultancy and technical assistance to administrations and PPP related to railways maintenance and track design and construction, these achievements have left the industry in an optimal position to implement the new technologies earlier than expected and adapt them to fulfil future requirements better than other construction companies. All of which will reinforce their leadership position in the international railway market.

2.4.2.3 LONG-TERM ACTIONS

Industry members in the C4R project have high interest in participating in the potential market introduction and use of the developed modular slab track concepts, to be the primary provider of new and innovative systems.

In general, all the successful concepts developed in C4R which are relevant for suppliers can be integrated into the technical procedures, under the condition of a commitment of IMs to introduce the best-result innovations into their networks, at least in several lines and punctual zones.

2.4.3 ACADEMIA

2.4.3.1 C4R RESULTS RELATED TO NEEDS

Universities and Research Institutes have no direct needs in terms of increased capacity, maintainability, operations and reliability. They are mainly interested in methodological aspects and results, both for infrastructure (lines and terminals), equipment and vehicles. However, as a part of their continued research, it is important to build upon the current state of the art. Due to the ambitions of the rail industry, most of research resources should in some way contribute to the objectives of increased capacity, maintainability, operations and reliability.

To achieve this, from the point of view of academia a whole system approach for R&D is necessary, analysing the interacting levers to increase capacity, maintainability, operations and reliability.

Further needs are:

- Prioritization of the order in which research and implementation are undertaken
- Benchmarking of the quantity of improvements that are expected from R&D at which timescales
- Improved automation to deliver demand responsive timetables; improve the ability to respond more quickly to changes in demand (mainly applicable to capacity and operations)
- Closer focus on customer experience (passenger and freight services) as an overall target (general operations)
- Interoperability

- Better understanding of trade-offs between performance (e.g. punctuality) versus capacity (trains per hour & passengers/tons per hour) including appropriate KPIs
- Technologically enabling trains to run closer safely (improved signalling, predictable braking, more homogeneous performance of passenger and freight rolling stock)
- Models and processes to evaluate alternative solutions to deliver capacity improvements taking account of system impacts
- Whole life costs (future impacts, including sustainability and potential climate change effects)
- Adaptability of solutions to future changes (technological, demographical etc.)

Infrastructure

Academia underline the importance of upgrading the existing infrastructure. In order to increase capacity and facilitate new traffic opportunities like longer trains, increased train weight, increased axle-loads, higher speeds for freight and increased loading gauge actions have to be taken to the infrastructure. The needs are for low cost innovations which can be implemented up to 2030 without a major investment required by infrastructure managers, like for example EOT or longer freight services.

New railway lines are built for high-speed operations and the use of the existing lines is changed to freight. Since these lines originally had been designed and constructed for the former traffic demands, some actions have to be taken in order to meet current and future demands for increased capacity. Therefore, upgrading of existing lines is a necessity to meet new demands from freight operators, which too often can’t be satisfied by the infrastructure managers. Recent research clearly shows the existing restrictions, but also several possibilities to improve the situation.

Monitoring

As mentioned by all stakeholders, the development of new concepts for monitoring in embankments, structures, different types of track and components (i.e. S&Cs) will improve the knowledge of the track and subgrade behaviour.

If remote condition monitoring works, an automated routine combined with better data analytics will obtain automated maintenance forecasts and predictions of the structural lifetime.

However, maintenance methods and strategies based on this type of monitoring needs also further development, to improve the output performance and reduce time of track possessions.

The work on new strategies has been based on the research and development of innovative sensors, low-current technologies, energy harvesting for power supply and wireless networks for data transmission. Thereby promising measurement equipment for new lines and as retrofitting kit for existing lines has been developed and is about to be tested in situ in Portugal & Great Britain.

Operation and scheduling

To sum it up, the project-results are fitting to the expectations and requirements:

- Data architecture for operations and related applications: data notations and models
- Capacity trade-offs tool - underlying model and systems approach to capacity increase will be useful in supporting the rail industry stakeholders (funders, infrastructure managers, train operating companies) in making investment decisions to deliver improved capacity and performance
- Robustness increase in critical points - optimisation techniques and KPI analysis
- Capacity analysis methods for freight and whole system capacity
- Roadmaps and migration scenarios within research planning
- Results of future requirements analysis
- Predictive infrastructure health monitoring and data storage/manipulation techniques
- Methods for identifying and evaluating new monitoring technologies
- Low cost, self-powered sensor network technology
- Data collected from trial and demonstration sites
- Real-scale tests on CEDEX Track Box will be useful to show the path for the future generation of slab tracks and will show if ballasted tracks can be designed for trains travelling at very high speeds without huge maintenance costs
- Cost-benefit-analysis: Decisions based on longer term and whole life costs including external impacts

Besides these results the project has given further benefits to the participating academia. The main benefits were achieved from the development of the assessment methodologies. For example, methods and models for the assessment of rail freight terminals have been processed in collaboration between industry and academia comprising the results of relevant case studies. This co-work has led to fruitful comments and feedback on the designs for the rail freight terminal of the future and the methods and models to assess freight services.

Another point - already mentioned by the other stakeholders - is the need of increasing the reliability of heavily used lines and stations as a fundamental requirement for increasing the capacity of goods and passenger railway transport with all its social, environmental and economic improvements.

Modern, outstanding algorithms that run on high-performance machines created by research centres and universities, allow forecasts of network states across different companies and countries and may significantly support current operational decisions for best efforts in increased capacity of the network.

Another academia task, as incorporating smart interfaces between the different actors in the railway business is one efficient jigsaw piece to reach the high aim. The development of integrated interfaces, that allow easy access to current network states of different IMs while being ensured by cyber-security and honouring the jurisdictional demands is an important basis for traffic management decisions and customer services.

With the increased knowledge academia have gained a better understanding of industrial needs and "white spots" where further research is needed. Understanding of the progress necessary towards achieving the 2050 goals will clarify and delimitate future research needs.

2.4.3.2 Short-term actions after project end

This increased knowledge is a common aspect of academia and a base for the following actions. Also, the established collaborations with IMs and suppliers will be kept on and used for further evaluation and testing of concepts. Most of the academia members plan to introduce the new findings into their current training and education activities. In this context, they consider providing the information to convince political institutions as a very important part of their contribution for successful exploitation.

On the other hand, the respective focus of the participating academia has a high variety. Each of them has its own specific orientation and a different interest on how to deal with the outcomes of the project, which shows in the following bullet-points:

- Consider some of the innovations proposed in C4R in the development of new optimization techniques to effectively exploit infrastructure capacity (while other innovations are to be regarded in long-term)
- Implement the Capability Trade-offs tools through discussions with the national departments for Transport and the Rail Delivery Group
- Publish work on capability trade-offs tool
- Use knowledge on data architectures knowledge in national projects
- Develop integrated algorithms supporting traffic management across fixed ranges of railway network, served by two different infrastructure managers, especially for transnational relationships
- Analyse processes in order to adjust developed models
- Further pilot applications and exploitations of developed methods and models in terms of incremental change by pilot demonstrations, and use them in educational and training activities, as well as in focused research investigations.

2.4.3.3 Long-term Actions

In general, in the long-term all academia will carry on their research activities in the areas of infrastructure, monitoring, operations and rolling stock, while on the other side will be continuing to point out the areas where further enhancement and future research are needed. Some of the innovations proposed in C4R will be considered in long-term in the development of new optimization techniques to effectively exploit infrastructure capacity.

The variety of different approaches already mentioned also shows regarding the long-term actions:

- Improving the guidelines and propose areas that can be enhanced
- Exploit condition monitoring and predictive maintenance algorithms in future industry projects
- Extend capability trade-offs goals and knowledge into a framework for optimising railway capability in line with goals identified in C4R
- Introduce capacity simulation and automatic calculation facility into railway operations simulators
- Development of integrated algorithms for transport management across flexibly selected ranges of railway network, even if they are served by different infrastructure managers
- Adjusting processes in order to implement and use developed models for robust traffic management decisions
- Experiment the developed methods and models, in terms of a step change, by taking up a pilot demonstration project
- Generalised application of developed methods and models, with pre-industrialization and high-level consultancy purposes.

2.4.4 Sector associations

2.4.4.1 C4R results related to needs

The sector associations in C4R responding to the questionnaire had a special focus on rolling stock, trains and train components and related monitoring equipment, nevertheless keeping a look on the overall system. In the overall project, UIC, UNIFE and other participants represent most of the railway membership in the European Union.

Setting apart its role of work package leader in the Dissemination of the project, UIC and their different working groups and specialized forums and platforms (Infrastructure, Rolling Stock) were regularly informed on the project results and will help in their future implementation. This had major importance owing to the very wide membership of international railways in this platform.

UNIFE is a European association that represents the interests of the railway supply industry in Europe at the level of both European and international institutions. Its membership comprises manufacturers and integrators of railway rolling stock, subsystems, components, signalling equipment and infrastructure. UNIFE has participated actively in dissemination, exploitation and training activities. Its particular focus will be dissemination and exploitation, from here on. Through its committees, technical forums, and events it will provide inputs and access to results to the rail industry members, including maintenance contractors and suppliers. Further, it will distribute material at its annual and joint research events throughout the years. UNIFE is in close association with the national industry associations and constitutes as such also a point of dissemination to the industries outside of the project.

Even though through UIC and UNIFE excellent output for dissemination is available, the project foresees in addition that external stakeholders will also have some access to the project results provided they become involved in the Rail Reference Group.

In general, sector associations see the need for a supply chain which must achieve competitiveness and reliability, together with a capacity to respond flexible to varying high volumes. This implies for example, flexibility in the length of the train to increase competitiveness and flexibility, connectivity with all sensors necessary to organize a predictive maintenance resulting in a higher reliability, new EP braking system on wagons for a better manoeuvrability favourable to an increase of reliability.

C4R with its proposals and its cost benefit analysis shows the overall gain for the supply chain. It helps to detect the obstacles to be overcome with specific support policies as the introduction of certain new technologies implies a significant transition period during which benefits are reduced and cost remain high. Research on these policies, training of teams to adopt the innovation proposed, precise case analysis like those done for vehicle transport logistics distribution (such as STVA) show how to help market uptake.

The developed solutions are improving the competitiveness and reliability of train services, enabling an easier insertion in the theoretical timetable graph and getting better paths due to a better driving capacity thus increasing network capacity.

2.4.4.2 Short-term actions after project end

As the theoretical designs for demonstrations come to positive results, the next step is to continue accompanying the already developed real-life demonstrations, to resolve appearing new obstacles, detect the first segments in which the innovations may bring the best results and capitalize on them for further developments.

Support the introduction of low cost investments with high return, such as EOT for lengthening the trains, connected sensors for automated brake tests, camera controls at departure to check safety status, and increase the existing assets utilization.

Generally, sector associations will help filling the gaps by innovations in wagon technology and train operation taking globally into account rail as a system. Also by dissemination of the results in the logistics community through workshops and international conferences in which they participate.

2.4.4.3 Long-term Actions

In the long-term associations will help to support the introduction of such investments which represent a step change in railways. ElectroPneumatic braking, automated couplers and full connectivity, may for example, require a higher investment and a certain transition time for successive introduction of the systems, but on the other hand promise a higher return. An important role of sector associations lies in the publishing and marketing of the results and expected benefits to convince IMs and RUs of the realistic returns of these long-term investments.

2.4.5 ERA and TSIs

The relevant points over which the European Railways Agency (ERA), could be affected as a stakeholder could be inputs for the review of the current in-force TSI's. The main aspects to be covered are open points mostly related to the infrastructure and rolling stock subsystems:

- For TSI Infrastructure (INF TSI), it'd be necessary to solve open points related to
  - VHST and ballastless track systems:
  - VHST and mixed traffic load design and categories
- For both TSI Locomotives and passenger rolling stock (LOC&PAS TSI) and TSI Freight wagons (WAG TSI), it'd be intended to solve open points and introduce innovation in TSIs related to rolling stock in general and braking in rolling stock for railway freight systems
- For TSI Operation and Traffic Management (TSI OPE), it'd be necessary to solve open points and introduce innovation:
  - related to operation and traffic management in terms of operational planning, traffic capacity and timetables, especially in chapters 4.2.3.4 and 4.2.3.6.

- also, the related to braking in rolling stock for railway freight systems

3. Dissemination of results

3.1 Dissemination objectives

All consortium partners have contributed and will continue contributing to some extent to the dissemination and communication activities.

Dissemination and exploitation of results have been crucial to the acceptance and implementation by railway undertakings, suppliers and end-users of the technologies developed in the project.

During the first stage of the project, communication was mainly aiming at raising awareness about C4R by presenting the objectives, processes and expected results of the project, as well as building the necessary networks to increase the efficiency of the project and its connections to its environment.

At the final stage, dissemination activities have been focused on promoting the results achieved and making the appropriate target audience aware and sensitive to their potential benefits, in order to facilitate implementation of the project results.

All along the project duration, ongoing communication activities have been necessary to keep dissemination active to continuously present, discuss and get feedback on the progress of the project.

With a global system view, C4R have covered a wide range of technical areas, and a large variety of dissemination targets.

The C4R dissemination strategy tried to reach the following objectives:

- To raise awareness for the project approach and results;
- To generate active involvement of railway stakeholders in the evaluation and usage of C4R results;
- To stimulate active involvement of researchers into C4R related research activities;
- To dissemination the scientific and technical new knowledge;
- To encourage the implementation of outcomes by end-users.

Because of its fairly broad representativeness, both in terms of railway stakeholders and in terms of geographical scope, the market penetration of the C4R results has been guaranteed by the participation of:

- Railway operators (undertakings and infrastructure managers), guaranteeing that project solutions satisfy user needs and fulfil railway requirements;

- Research groups and universities;
- Railway suppliers, large industrial groups as well as SMEs;
- International professional associations, Railway organizations at EU and international level

Thanks to the worldwide membership of UIC, the international outreach of universities and the wide presence of major industrial partners and European associations, the consortium in itself is the primary base for dissemination.

The uptake and implementation of the research findings by the players themselves and their active participation in the dissemination process ensure a fairly large and effective spreading of the information among the different railway stakeholders.

3.2 Dissemination targets

C4R has delivered outcomes to the different audiences and targets:

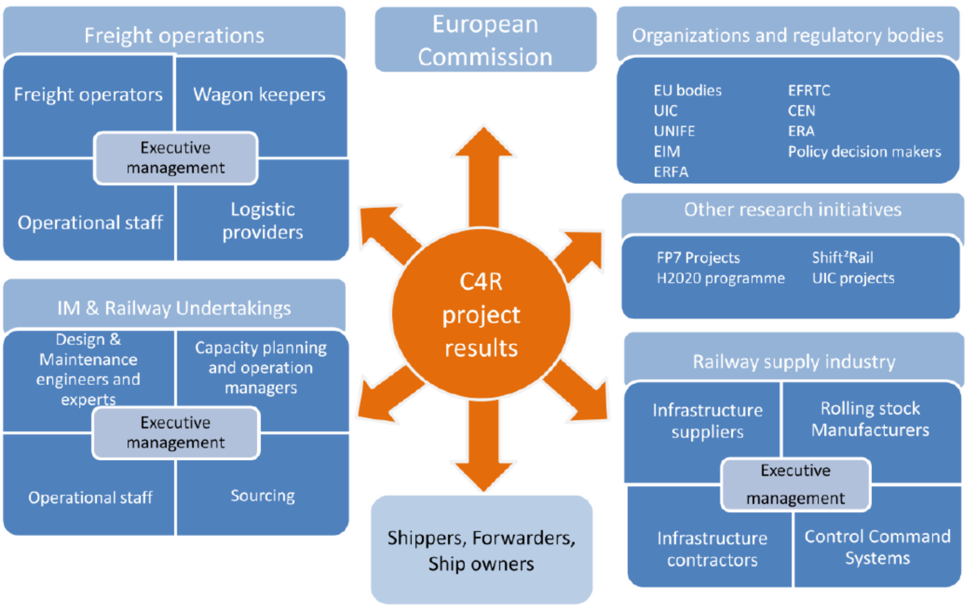

Figure 3-1 Targeted audience of C4R project results

3.2.1 European Commission

As it is co-funding the Project, the European Commission is the first recipient of all the deliverables.
At the end of the project, the final summary report gathers an overview of the project context, achievements and potential impact. Besides, the European Commission has been informed of any scientific publication related to the project.

3.2.2 Other Research Initiatives

Linking with other freight-related or similar projects allows cross-fertilization and mutual enrichment of projects.
Several opportunities for networking with other EU projects have been established during the dissemination events held along the project lifetime, in order to establish links, identify interactions, create synergies and avoid duplication of work.

Synergies have been created with other ongoing FP7 and H2020 projects and Shift²Rail since many members of the C4R project are directly involved within these other activities and as C4R was identified as a project which feeds the various Innovation Programmes of Shift2Rail.

The dissemination of the activities has been ensured via

- the natural circulation of information through shared experts;
- the identification of key actors of other projects like for example Shift2Rail, OnTime, NetiRail, D/LCC and Innotrack to be invited in C4R events.

3.2.3 Freight Operators

For Freight operations, the targets are mainly the decision makers which can be the shippers themselves or the wagon owners, leasers or operators, the railway undertakings, the combined operators and the wagon manufacturers. Besides, the infrastructure managers have to know the project results in term of freight operations as these must be compatible with infrastructure evolutions and constraints.

A large dissemination at various stage of the project progress has been ensured by the participation in seminars, conferences and exhibitions.

During the course of the projects dissemination events have been specifically dedicated to Freight. The first freight dissemination workshop was held in Paris on 10-11 September 2015. It aimed at promoting the project’s objectives and disseminating available results.

The second freight dissemination workshop was held in Brussels on 26 June. It focused on innovations in wagon design, in connectivity, in terminal design and operations to match the changing needs of the logistics market in order to allow rail freight transport to find its right place in the supply chains.

3.2.4 Infrastructure Managers and Railway Undertakings

Executive management

This audience is of primary importance, as it is the one who decides on the use of the project results and turn the proposed innovations and optimization into practice.

During the course of the project, presentations were given within UIC Freight Forum and Rail System Forum, held ad UIC, where the executive management is represented.

Design and maintenance engineers

Infrastructure design and maintenance engineers and experts are a key audience, easier to identify in the railways according to their respective technical skills. They are generally well informed of the technical context of the ongoing research, as they are or have been involved themselves in current or previous projects, reviewing actions, working groups or standardization committees.

Consequently, this audience is reached in many different ways:

- Directly with the deliverables of the project;
- Through the UIC working groups they are active in: Track Experts Group (TEG), Operation Focus Group, Works planning and capacity allocation Working Group and the Sector Expert Teams (SETs);
- Through their participation in workshops and dissemination seminars;
- Through general conferences, and exhibitions;
- Through their direct involvement into the reviewing process of the project.

Capacity planning and Operation Managers

Capacity Planning and Operations Managers in various countries have been contacted when gathering data for the road maps for the development of modelling and simulation tools. This has ensured that as future concepts are developed, the industry has the ability to evaluate them. This has supported strategic trade-off decisions as well as tactical real-time operational decisions.

A training platform Digital Operations was organized in Olomouc on April 25-26, 2017, *"Digital Operations for enhanced performance and capacity in European railways".* It has been an excellent opportunity to hear about the latest developments in advanced tools for railway planning, simulation of railway operations, railway traffic management and innovative data architectures to enable the digitalisation of railway systems.

There have been interesting discussions on how to uptake these innovations and future directions for European Railway research. The outcome was that we should get a shared European procedure to favour the development of innovations at a higher TRL, since the way railway technology is progressing is definitely not going to meet on time the EC strategy set up with the White paper on Transportation.

Railway staff at operational level

Railway staff at operational level may be indirectly interested in the C4R results and the influence that they may have on the different national codes, regulations and practice.

Translation of the key C4R reports and results to be disseminated as Guidelines will be of importance to reach this population with an often limited understanding of the English language.

Training platforms (infrastructure, operations, migration) will be set up using the training competences of the Academia involved in the dissemination tasks (Newcastle University, University of Birmingham, Technische Universität Dresden, Instituto Superior Técnico) with the support of the railway undertakings. The training platforms and programmes will be established when enough results are available.

See also 2.4.1 *Strategy for the use of expected project results/RUs and IMs.*

3.2.5 Railway Supply Industry

Executive management

This group can be contacted by the UNIFE high level committees (UNIRAILINFRA – UNIFE Infrastructure Committee, Strategy committee, Presiding Board, UNIFE Standards and Regulation Committee, UNIFE Technical Plenary), at UNIFE's office and at the events of the association throughout the year.

The infrastructure contractors are addressed through the EFRTC structures and other UNIFE and EFRTC contacts.

Infrastructure, Rolling Stock and Signalling Suppliers

Depending on the level (management or operational), supply industry has been reached

- via the UNIFE committees and forums and
- via dissemination workshops during the project,

Moreover, C4R has been present during:

- TRA 2014 in Paris and TRA 2016 in Warsaw;
- Innotrans 2014 and Innotrans 2016 in Berlin;
- WCRR 2016 in Milano;
- Several UIC international conferences, such as UIC World Congress on High-speed Rail 2015 in Tokyo, …
- and all UIC Track Expert Group Meetings and Train Track Interaction and Rails System Forum meetings, etc.

They have been the ideal forum to present the latest developments in the project. These events are attended by the supply industries and European (and International) railway Infrastructure Managers and Operators and therefore have been an ideal forum to link end users with the technologies and results of the project.

Infrastructure contractors

The contractors have been reached via EFRTC Committees and General Meetings, where relevant outcomes of the project can be disseminated.

Relevant information has been and will also be disseminated furthermore through the EFRTC website. In addition, contractors have been invited to attend training workshops when relevant.

See also 2.4.2 *Strategy for the use of expected project results/Industry* as well.

3.2.6 Organizations and Regulatory Bodies

UIC

Setting apart its role of project coordinator and work stream leader in the Dissemination of the project, UIC is a target of major importance owing to the very wide membership of international railways. The different working groups and specialized forums and platforms (infrastructure, rolling stock, and freight) have been regularly informed on the project results and will help in their future implementation.

UNIFE

UNIFE is a European association that represents the interests of the railway supply industry in Europe at the level of both European and international institutions. Its membership comprises manufacturers and integrators of railway rolling stock, subsystems, components, signalling equipment and infrastructure. UNIFE has participated in dissemination, exploitation and training activities. Through its committees, technical forums, and events UNIFE gives access to rail industries, including maintenance contractors and suppliers and on the other hand provides input from this audience.

UNIFE is in close association with the national industry associations also a point of dissemination to the industries outside of the project.

CEN

CEN produces European standards, and as such is directly involved in railway standardization with its Technical Committee 256 for Railway Applications. It is proposed to maintain a meeting with the representative of this body, to define, within the framework agreed, the way C4R results may contribute to future European Standards. The involvement of many members of the C4R project within CEN working-groups, helps to reach this goal.

CER AND EIM

Discussions between the C4R partners, CER and EIM representatives have been established during the Workshop Dissemination events and can be the basis for future standards or joint research activities.

The European Union Agency for Railways

In order to present useful information to the European Union Agency for Railways (formerly known as ERA) in charge of future regulation in the railway field, a joint action will be initiated by the Associations represented in the project, CEN, CER and EIM representatives, under the direct coordination of the Steering Committee of C4R.

The dissemination efforts are twofold:

- Make sure to delineate, as clearly as possible, the content of,
  - TSI revisions or other regulations for which ERA is the competent technical body;
  - European Harmonized Standards (to be used as sufficient means of compliance with EU regulations);
  - Other industry standards (best practice)
- Provide sufficient understanding of the findings, hypotheses and limits of impact assessments, and the corresponding tools.

EFRTC

Beside the dissemination of project results by EFRTC, some of its members will be involved in checking the feasibility of innovations proposed for the execution of track construction, renewal and maintenance.

See also 2.4.4 *Strategy for the use of expected project results/Associations*

Scientific and academic communities

Although the C4R project is mainly aiming at practical implementation into the railway activities, the high level of implication (40%) and skills of the academic partners has highly contributed to the production of scientific publications, thus sowing further research projects.

See also 2.4.3 *Strategy for the use of expected project results/Academia.*

3.3 Dissemination Media

All dissemination material of the project is summarized in the deliverable D61.4 *Dissemination and training activities (Final).* Most notably the C4R website can be highlighted (http://www.capacity4rail.eu/) which is regularly updated during and after the project. It is a complete site where extensive information and documentation related to the C4R project is easy to access.

- ✓ Project objectives and consortium are presented
- ✓ All C4R events were announced in the "news" tab and all presentations made during these events are available.
- ✓ All dissemination materials, as newsletters and brochures are available under the "documents" tab;
- ✓ Once they have been accepted by the project officer, **ALL** deliverables **-63 public deliverables have been produced during the project -** are available under the "results" tab;

In C4R, all deliverables are public. These are:

D11.1	Design requirements and improved guidelines for design (track loading, resilience)
D11.2	Design requirements, concepts and prototype test results (Intermediate)
D11.3	Design requirements, concepts and prototype test results (Final)
D11.4	Upgrading of infrastructure in order to meet new operation and market demands (Intermediate)
D11.5	Upgrading of infrastructure in order to meet new operation and market demands (Final)
D12.1	Innovative designs and methods for VHST (Intermediate)
D12.2	Innovative designs and methods for VHST (Final)
D13.1	Operational failure modes of S&Cs
D13.2	Innovative concepts and designs for resilient S&Cs (intermediate)
D13.3	Innovative concepts and designs for resilient S&Cs (Final)
D21.1	Requirements toward the freight system of 2030/2050 (intermediate)
D21.2	Requirements toward the freight system of 2030/2050 (Final)
D22.1	Novel rail freight vehicles (Intermediate)
D22.2	Novel rail freight vehicles (Final)

D23.1	Co-modal transhipments and terminals (Intermediate)
D23.2	Co-modal transhipments and terminals (Final)
D24.1	Catalogue: Rail Freight Systems of the Future (Intermediate)
D24.2	Catalogue: Rail Freight Systems of the Future (Final)
D24.3	Standards
D24.4	Final Technical Report of SP2 Freight
D31.1	Review of existing practices to improve capacity on the European transport network
D31.2	Illustration of the application of capability trade-offs using data from selected routes
D32.1	Evaluation methods and selected scenarios
D32.2	Capacity impacts of innovations
D33.1	European standard for traffic management
D33.2	Requirements for incident management plans
D34.1	Data notation and modelling
D34.2	Verified data architecture
D41.1	Critical components and systems - current and future monitoring
D41.2	Monitoring-based deterioration prediction
D41.3	Strategies for data collection and analysis
D42.1	Requirements for next generation monitoring and inspection
D42.2	Recommendations and guidelines for next generation monitoring and inspection
D42.3	Report on demonstration of innovative monitoring concepts
D43.1	Guidelines for installation and maintenance of sensors in new infrastructure
D43.2	Demonstration of new monitoring techniques
D44.1	Recommendations for monitoring of critical components in the railway
D44.2	Marketable retro-fit kits for selected applications

D44.3	Recommendation for an Open-Source and Open-Interface for railway advanced monitoring applications
D51.1	Railway road map – paving the way to an affordable, resilient, automated and adaptable railway
D51.2	Interim milestones to achieve step-changes in Railway capacity and performance for passengers and freight
D51.3	Identified activities and technologies
D52.1	Compendium and evaluation of RAMS, LCC and migration tools, and methods and sources of data
D52.2	Templates and tools for analysis of scenarios
D52.3	Dataset of costs and RAMS data for analysis
D53.1	Sites for migration
D53.2	Migration scenarios and paths
D53.3	Report on migration scenarios/paths for selected real sites/corridors
D54.1	Integrated methodology for the analysis of scenarios and migration
D54.2&3	Assessment of technologies, scenarios and impacts
D55.1&2	Test Plan Demo and Risk Assessment
D55.3	Report from Laboratory demonstrations
D55.4	Report from on-track demonstrations
D55.5	Report from virtual demonstrations
D55.6	Final evaluation and assessment
D56.1	Refined Railway system 2030/2050
D56.2	Guidelines for further research and development activities
D61.4	Dissemination and training activities (Final)
D61.5	Exploitation of results from CAPACITY4RAIL

4. Conclusions

The 2011 White Paper on European Transport has pointed out the fundamental importance of transport for mobility in Europe, for the future requirements of society as for the growth and vitality of the European economy. With CAPACITY4RAIL solutions have been developed in the sections of Infrastructure, Monitoring, Trains and Operations & Scheduling and have been tested in situ in real conditions, in laboratories as also by virtual demonstrators.

The project has achieved significant advances to improve the railway system by regarding the investigation and demonstration of innovative concepts for increased capacity with a holistic system approach. The developed technical, processual and IT-solutions provide a huge set of possibilities for IMs and RUs for the enhancement of the rail capacity in each of the treated sectors.

This deliverable gives an overview to the main results and lists the guidelines and standards which have been worked out. The summary description of the content of the guidelines is brought together in D56.2.

The performed SWOT analysis & Business cases and perspectives are summed up in the chapter "Market Analysis". The Strengths, Weaknesses, Opportunities and Threats of the C4R project and the railway sector have been analysed and compared with the needs of the sector and with the opinions of the stakeholders of railway system.

Regarding strengths of the project, the chosen leading technology partners based on latest research and brought a lot of knowledge, for example about sensors & monitoring but also about upgrading of freight lines and operational capabilities. The multidisciplinary character, combining IM / RU / Academia / Industry partners has generated additional "know-how" and created the base to come to results which provide a high commercial and industrial benefit of the sector. Through UIC and UNIFE, among other associations, an excellent output for dissemination is available.

On the side of the weaknesses, besides known disadvantages of railways like limited flexibility and reliability, high fix costs and long innovation cycles, main challenges for the future lie on one hand in the necessary high investment for innovations together with the dependence of some Infrastructure managers on political decisions. And on the other hand, there is a general absence of standards for data related processes (collection, exchange, interpretation etc.). To cope with the quick development of IoT and Big Data, the standards already developed by C4R should be further evolved and a better exchange and sharing of data between the partners promoted.

As there are various opportunities it is difficult to condense the analysis to one or two main opportunities. Nevertheless, and not very surprisingly the fast evolution of digitalisation and the quick development of new technologies play a major role as they also provide chances for the railway sector to gain new markets and to develop new services for the customers. Further opportunities in this field are based on advancing technologies for extensive and continuous information about status and condition of assets with various possibilities of related technical (e.g. predictive maintenance) and economic benefits. In the sector of rolling stock operations and traffic management these technologies are necessary for better coordination of train operations and thus enhancing the stability and automatization of timetabling.

Changing society demands play into the opportunities on one hand as for example the increasing need for sustainability can easily be fulfilled by the railway system. On the other hand, the changing societal requirements confront the railway sector with a set of threats, which results from environmental, governmental and market demands.

The quick change of the conditions, which influence the railway sector, comprises society and market requirements like the wish for comfortable planning of multimodal logistic solutions but also the tight competition of other transport-modes.

That is especially relevant with pure road mass transportation, more adaptable, able to make door-to-door services, and in the verge to achieve higher levels of automation, loading capacity and clean energy fuelled services, which will make difficult a modal shift to railways.

The main threat related also to that weakness, is resulting from financial-budgetary issues. Strong political support and clear leadership based on well-analysed concepts is needed for a successful upgrading of the railway equipment, as high investments in the sectors infrastructure, rolling stock and train operation have to be carried out in a concerted and coordinated action.

As a logical consequence, Capacity4Rail defined possible scenarios and migration paths from the current railway system to the future one considering the innovations and technologies identified and assessed several cases through Cost-Benefit Analysis (CBA) and a Multi-Criteria Analysis (MCA).

To sum up the results of the CBAs in a very short and simplified manner, the profitability of deep infrastructure investments depends heavily on the conditions of the respective corridor. In capacity constrained sections large infrastructure investments like upgrading to the new slab track and the resilient S&C can be profitable. The highest potential is nevertheless to be gained by generating more availability of the existing network as for example by introduction of innovative operational concepts, mostly related to upgrading of freight train services. Automatic couplers and EP brakes in combination with modest infrastructure investments in siding extensions to enable longer and heavier trains permit a very high profitability, but are on the other hand realistic only in long term.

Reduction of train-preparation time before departure is seen to bring the positive effect in shorter time, as it is achievable with less investment, and will generate a significant increase of capacity and competitiveness. Equipping the train with an electric line and End of Train device to perform a brake test from the driver’s cabin should be the first measure to progress before installing an EP braking system.

In the section of the terminals and marshalling yards, linear terminals with horizontal transfer processes allow shorter transition times and lower cost by reducing the shunting equipment and automating the container-logistics. For marshalling yards, the CBA comes to a negative result due to the huge necessary investments like automatic couplers, automatic brakes on wagons, automatic wagon identification, duo- and driverless locomotives.

The general strategy on how to get implemented the described project results, is based on one hand on the extensive prototyping and testing of the developed solutions, which leads to high acceptance and confidence of the involved partners. On the other hand, the strategy can benefit from the preliminary selection of main key stakeholders for the project in association of other superior level organisations, including UIC and UNIFE.

Additionally, the introduction of the final results of C4R into the ongoing EU Joint Undertaking Shift2Rail and associated projects, promises further research, development and propagation.

This deliverable describes furthermore the strategic potential impacts, which are comprising, due to the holistic approach, all sectors from infrastructure and advanced monitoring, freight services, terminals processes to train operation, traffic management and finally to the overall system technical impacts with its related economic results.

The stakeholder strategy bases on a questionnaire which has been used for the SWOT analysis as for a check about the stakeholders' expected needs and results. It shows a rather good correlation between these two aspects in all sectors as the stakeholders have been given the opportunity to largely introduce their requirements during the project.

The dissemination of results again benefits from the broad representativeness of the project stakeholders, including IMs and RUs, R&D-Institutions as also Rail industry, European and international associations and regulatory bodies, which ensures a large and effective spreading of the information and implementation of the results in the different sectors.

Dissemination strategy makes use of different activities apart from the direct involvement in the active process of the project. The different target groups are reached through participation in dissemination workshops and seminars, general conferences and exhibitions and translation of the results into other languages.

Several dissemination workshops in infrastructure and freight have already taken place, where C4R has been present at diverse important exhibitions like Innotrans and for the future dissemination - specially to transmit the information about project results and new know-how - specific training platforms will be established.

A fundamental aspect in the dissemination strategy is the inclusion of the standardization and regulatory bodies like UNIFE, CEN, CER, EIM and the European Railway Agency. A joint action under the coordination of the Steering Committee of C4R will be initiated to provide extensive understanding on C4R outcomes and to consider TSI revisions, European Harmonized Standards and other industry standards.

During the project 63 deliverables have been created which are publicly available on the C4R website (http://www.capacity4rail.eu/).

In conclusion, during C4R project many innovative solutions have been developed according to the requirements of the railway sector, practical use has been proven, potential impacts assessed, and Scenarios & Business Cases created to show possible application. Through the dissemination strategy and the public availability an implementation for the enhancement of railway capacity can be seen positive in short-term as in long-term vision.

5. References

1	C4R Capacity4Rail 2015, deliverable	D11.1	Design requirements and improved guidelines for design (track loading, resilience)
2	C4R Capacity4Rail 2017, deliverable	D11.2	Design requirements, concepts and prototype test results (Intermediate)
3	C4R Capacity4Rail 2017, deliverable	D11.3	Design requirements, concepts and prototype test results (Final)
4	C4R Capacity4Rail 2016, deliverable	D11.4	Upgrading of infrastructure in order to meet new operation and market demands (Intermediate)
5	C4R Capacity4Rail 2017, deliverable	D11.5	Upgrading of infrastructure in order to meet new operation and market demands (Final)
6	C4R Capacity4Rail 2017, deliverable	D12.1	Innovative designs and methods for VHST (Intermediate)
7	C4R Capacity4Rail 2017, deliverable	D12.2	Innovative designs and methods for VHST (Final)
8	C4R Capacity4Rail 2015, deliverable	D13.1	Operational failure modes of S&Cs
9	C4R Capacity4Rail 2016, deliverable	D13.2	Innovative concepts and designs for resilient S&Cs (intermediate)
10	C4R Capacity4Rail 2017, deliverable	D13.3	Innovative concepts and designs for resilient S&Cs (Final)
11	C4R Capacity4Rail 2014, deliverable	D21.1	Requirements toward the freight system of 2030/2050 (intermediate)
12	C4R Capacity4Rail 2017, deliverable	D21.2	Requirements toward the freight system of 2030/2050 (Final)
13	C4R Capacity4Rail 2016, deliverable	D22.1	Novel rail freight vehicles (Intermediate)
14	C4R Capacity4Rail 2017, deliverable	D22.2	Novel rail freight vehicles (Final)
15	C4R Capacity4Rail 2016, deliverable	D23.1	Co-modal transhipments and terminals (Intermediate)
16	C4R Capacity4Rail 2016, deliverable	D23.2	Co-modal transhipments and terminals (Final)
17	C4R Capacity4Rail 2016, deliverable	D24.1	Catalogue: Rail Freight Systems of the Future (Intermediate)
18	C4R Capacity4Rail 2017, deliverable	D24.2	Catalogue: Rail Freight Systems of the Future (Final)
19	C4R Capacity4Rail 2017, deliverable	D24.3	Standards
20	C4R Capacity4Rail 2017, deliverable	D24.4	Final Technical Report of SP2 Freight
21	C4R Capacity4Rail 2014, deliverable	D31.1	Review of existing practices to improve capacity on the European transport network
22	C4R Capacity4Rail 2017, deliverable	D31.2	Illustration of the application of capability trade-offs using data from selected routes

23	C4R Capacity4Rail 2015, deliverable	D32.1	Evaluation methods and selected scenarios
24	C4R Capacity4Rail 2017, deliverable	D32.2	Capacity impacts of innovations
25	C4R Capacity4Rail 2016, deliverable	D33.1	European standard for traffic management
26	C4R Capacity4Rail 2017, deliverable	D33.2	Requirements for incident management plans
27	C4R Capacity4Rail 2015, deliverable	D34.1	Data notation and modelling
28	C4R Capacity4Rail 2016, deliverable	D34.2	Verified data architecture
29	C4R Capacity4Rail 2016, deliverable	D41.1	Critical components and systems - current and future monitoring
30	C4R Capacity4Rail 2016, deliverable	D41.2	Monitoring-based deterioration prediction
31	C4R Capacity4Rail 2017, deliverable	D41.3	Strategies for data collection and analysis
32	C4R Capacity4Rail 2014, deliverable	D42.1	Requirements for next generation monitoring and inspection
33	C4R Capacity4Rail 2016, deliverable	D42.2	Recommendations and guidelines for next generation monitoring and inspection
34	C4R Capacity4Rail 2017, deliverable	D42.3	Report on demonstration of innovative monitoring concepts
35	C4R Capacity4Rail 2016, deliverable	D43.1	Guidelines for installation and maintenance of sensors in new infrastructure
36	C4R Capacity4Rail 2017, deliverable	D43.2	Demonstration of new monitoring techniques
37	C4R Capacity4Rail 2014, deliverable	D44.1	Recommendations for monitoring of critical components in the railway
38	C4R Capacity4Rail 2016, deliverable	D44.2	Marketable retro-fit kits for selected applications
39	C4R Capacity4Rail 2017, deliverable	D44.3	Recommendation for an Open-Source and Open-Interface for railway advanced monitoring applications
40	C4R Capacity4Rail 2014, deliverable	D51.1	Railway road map – paving the way to an affordable, resilient, automated and adaptable railway
41	C4R Capacity4Rail 2017, deliverable	D51.2	Interim milestones to achieve step-changes in Railway capacity and performance for passengers and freight
42	C4R Capacity4Rail 2014, deliverable	D51.3	Identified activities and technologies
43	C4R Capacity4Rail 2014, deliverable	D52.1	Compendium and evaluation of RAMS, LCC and migration tools, and methods and sources of data
44	C4R Capacity4Rail 2015, deliverable	D52.2	Templates and tools for analysis of scenarios
45	C4R Capacity4Rail 2017, deliverable	D52.3	Dataset of costs and RAMS data for analysis
46	C4R Capacity4Rail 2014, deliverable	D53.1	Sites for migration

47	C4R Capacity4Rail 2017, deliverable	D53.2	Migration scenarios and paths
48	C4R Capacity4Rail 2017, deliverable	D53.3	Report on migration scenarios/paths for selected real sites/corridors
49	C4R Capacity4Rail 2016, deliverable	D54.1	Integrated methodology for the analysis of scenarios and migration
50	C4R Capacity4Rail 2017, deliverable	D54.2&3	Assessment of technologies, scenarios and impacts
51	C4R Capacity4Rail 2016, deliverable	D55.1&2	Test Plan Demo and Risk Assessment
52	C4R Capacity4Rail 2017, deliverable	D55.3	Report from Laboratory demonstrations
53	C4R Capacity4Rail 2017, deliverable	D55.4	Report from on-track demonstrations
54	C4R Capacity4Rail 2017, deliverable	D55.5	Report from virtual demonstrations
55	C4R Capacity4Rail 2017, deliverable	D55.6	Final evaluation and assessment
56	C4R Capacity4Rail 2017, deliverable	D56.1	Refined Railway system 2030/2050
57	C4R Capacity4Rail 2017, deliverable	D56.2	Guidelines for further research and development activities
58	C4R Capacity4Rail 2017, deliverable	D61.4	Dissemination and training activities (Final)
59	C4R Capacity4Rail 2017, deliverable	D61.5	Exploitation of results from CAPACITY4RAIL

6. Appendices

Annex 1: Questionnaire for SWAT-Analysis

Collaborative project SCP3-GA-2013-60560

Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations

FP7-SST-2013-RTD-1

QUESTIONNAIRE

about the

Exploitation and Implementation

of the

C4R-Results by the project members

INTRODUCTION

This questionnaire aims to ascertain how each C4R partner intends to exploit and implement the C4R results. The following questions will have to be answered by the partners involved with the C4R project. To collect the information, a separate Excel-Document is enclosed.

INCREASED CAPACITY

What C4R will provide to the overall system in the railway transportation

Capacity4Rail will bring a step improvement in European rail network capacity, for both passengers and freight, using innovative techniques to deliver adaptable, automated, resilient and affordable solutions.

To make rail an attractive option to freight and passengers, a coherent approach has been adopted. The research and development on operations and infrastructure needs to be done with a rational systems approach, looking at increasing the capacity and resilience of rail networks, whilst reducing the cost of maintenance and ultimately the costs to the end users. This can only be done if an overall framework for research is adopted and implemented in a systematic and system wide manner, with a buy in from all the stakeholders in the process.

Overall, C4R will provide societal benefits in the complete system of the railway transportation, throughout the European community. According to the assigned challenges of 2011 White Paper on European Transportation, in order to increase the current capacities and working towards the design and development of modern fully integrated railway systems for freight and passengers. The aim is to meet the requirements for 2030/2050 through several features, some of them listed below:

- Improved network reliability and resilience
- Lower costs of design, construction, operation and maintenance
- More effective use of the infrastructure for freight and passenger traffic
- Reduced noise and carbon emissions
- Significantly increased capacity for passengers and freight.

- WHAT ARE YOUR NEEDS IN TERMS OF INCREASED CAPACITY, MAINTENABILITY, OPERATIONS AND RELIABILITY?

Please use the provided Excel-Document to enter your answers.

EXPECTED RESULTS

Outline of C4Rs results

C4R will provide advances and improvements in infrastructure, rolling stock and changes to operation management systems, but considering them together as part of an overall system. Both technical demonstrations and system-wide guidelines and recommendations, will be presented as the basis for future research and investment, increasing the capacities of the rail networks in the future. The following results are expected, along the progresses carried out in the different SPs:

SP1- Infrastructure

- New railway track and switch & crossing concepts developed. Key objectives are high RAMS performance and low cost of design, construction and maintenance.
- Modular construction allowing generic components to be manufactured in large numbers, also more simple, quicker and low-cost installation.
- Integrated health monitoring with ubiquitous data capture and autonomous data exchange and logic. Data interpretation allows to adopt effective preventative maintenance regimes. Through planned works efficient use of maintenance resources is enabled. Systems will thus help to minimize network downtime.
- The new designs benefit society by using recycled materials and delivering low noise and carbon emissions in construction and operation.

SP2- New Concepts for Efficient Freight Systems

- Improvements to the design of rail freight paving the way to allow blending of rail passenger and freight traffic and enabling improved overall system performance.
- Lighter weight rolling stock help to reduce energy usage, provide lower energy costs and reduce carbon emissions. Further they minimize track damage, lower maintenance costs and network downtime.
- Novel transshipment technologies helping to reduce constraints at transport hubs and nodes. Lower the cost of access to rail freight services to make them economically more attractive and hence encouraging modal shift to rail from more carbon-intensive transport modes.

SP3- Operations for enhanced capacity

- Development of a new adaptable, autonomous operational techniques contributing to the core objective of increasing available and useable capacity across the network. This will ensure that fixed infrastructure assets deliver incomes and meet the performance requirements.
- Ameliorating operations to significant improvement of the resilience and reliability of the rail network, at both a system- and service-level. Thus, encouraging passenger modal shift, reducing productivity loss from system failures and ensuring that rail travel is viewed as a reliable and cost-effective alternative to other transport modes.

- Novel traffic management techniques will also allow the optimization of train movements for smooth, energy-efficient operations, lowering energy cost and environmental impacts.

SP4- Advance monitoring

- New strategies based on innovative sensors, low-current technologies, energy harvesting for power supply and wireless networks for data transmission. These systems help to reduce efforts and costs in the monitoring activities enhancing the availability of the track.
- Development of new concepts for monitoring in embankments, structures, different types of track and components (i.e. S&Cs) will improve the knowledge of the track and subgrade behaviour. Automated maintenance forecasts and predictions of the structural lifetime is provided.

SP5- System assessment and migration

- Technical and economical assessment of technologies, roadmaps and migration scenarios, necessary to meet the target system supporting the cost-effective implementation of necessary technologies. The project builds the base for an economic driven decision of improvements.
- Linking operation, infrastructure and freight to ensure a goal-oriented improvement of the system to provide more capacity and thereby more turnover and benefit.
- The analysis of future requirements and the link to other transport modes ensures a target system, making them cost effective and meeting the future requirements of the customers.

The work of SP5 will be also be helping to drive the overall system approach, ensuring that CAPACITY4RAIL adopts a comprehensive system approach acting as a ‘container’ for all the work developed in the whole project. SP6 will be dealing with the works for management, dissemination and training & exploitation of the whole as well.

The research in CAPACITY4RAIL will bring a complete system approach aiming at contributing to an important change on how to obtain an affordable, adaptable, automated, resilient and high-capacity railway for 2020, 2030 and 2050. Efficiency will be mostly achieved by ensuring a high level of capacity and availability of the network at low cost. Secondly by higher speed freight vehicles, allowing optimized interleaving of freight trains into mixed traffic. Thirdly by improved planning models for operation, aiming at sustainability by introducing innovative concepts of infrastructure including use of low carbon and recycled materials and conceptual designs of environmental friendly vehicles. Intermodal integration within the global transport system will be improved through enhanced transshipment of passengers and freight.

- WHICH SPECIFIC AREA/S IN TERMS OF C4R PROJECT'S EXPECTED RESULTS WILL BE USEFUL/RELEVANT FOR YOUR ORGANISATION?

Please use the provided Excel-Document to enter your answers.

STANDARDS AND INTEROPERABILITY

C4Rs guidelines for the implementation of increased capacity

C4R will also look towards 2030/2050 by

proposing guidelines for future deployments in the short term

recommendations for technologies to de developed and deployed in the long term and investigating the key opportunities for funding these within national and EU funding schemes.

Conformity with developed solutions and implementation of recommendations and guidelines is assured through the incorporation of the results of work into UIC International Railway Solutions (IRS) and guidelines. IRS and guidelines thus offer the earliest opportunity to develop consensus towards standardization, based on their acceptance by Member railways as best state of- the-art knowledge on a particular subject.

The focus is towards presenting best practice to its Members so as to assist them to create the optimum conditions for inter-operability, maintenance, renewal and construction of the European railway network.

These IRS and guidelines - provided by UIC as a standardization body and formerly known as Leaflets - already form the basis for Technical Standards for Interoperability (TSIs) and other European standards. The project results will be presented to UIC but also to other relevant standardization bodies like, ISO or CEN/CENELEC. Moreover, some projects results should help to close specific open points of the Infrastructure subsystem TSI, but also other TSIs related to operation and rolling stock.

Contacts will be established with European Railway Agency in order to regularly inform ERA about specific results of the project.

To support these changes the delivered guidelines, recommendations and standards will include proposals for:

- Development of new concepts for railway track of the future, in view of potential application for mixed traffic. But also for very high speed (over 350 kph) that encompass cost savings, rapid construction, resilience and enhanced maintainability. Providing general track design guidelines for very high-speed track (VHST) and modifications or closure of open points in INF TSI
- Laboratory and in situ procedures for VHST components and appropriate modifications to the standards currently used

- Guidelines for assessment of different alternatives for sensors power supply such as direct connection to railway facilities or autonomous systems and rail dedicated energy harvesting technologies
- Best practice techniques, technical parameters for today and proposed future performance in Europe covering
  - global freight transport chain improvement and
  - new operation processes of the infrastructure,

  suggesting future common standards for rolling stock and monitoring systems, coordinated permanently assuring a system technically integrated between vehicles and infrastructure.
- Standards and technical specs for fully integrated rail freight systems and review existing standards of rail freight systems, specifically TSIs applied to them, such as WAG TSI or TAF TSI
- Changes needed to accommodate the characteristics of the newly designed fully integrated rail freight systems to meet the expectations of 2030/2050.

Specifically, standards that should aim at:

  - increase of the interoperability and the efficiency to reduce costs and to ensure reliability, flexibility, optimal use of the infrastructure
  - while meeting the sustainability targets set up by the European Union in terms of noise, pollution, energy saving and more generally in terms of acceptability by the citizens

This should require modifications on numerous TSIs, such as TSI LOC&PAS, TSI OPE and TSI NOI

- Derive joint requirements, European standards and testing for incident management plans

- WHAT RECOMMENDATIONS, GUIDELINES, STANDARDS AND TSI MODIFICATIONS BASED ON THE RESULTS WOULD BE USEFUL TO YOUR BUSINESS AND SHOULD BE DEVELOPED?

Please use the provided Excel-Document to enter your answers.

MARKET ANALYSIS

Results of the market study

C4R tries to analyse and open the railway market for advanced technologies. C4R is learning from other industries by benchmarking highly automated branches like oil-, gas- and wind-offshore platforms and infrastructures, mining- & coal-industries, facility-management and automotive. The market analysis includes:

- The upgrading of infrastructure, which is necessary in order to meet new operation and market demands. Only way to define it is to identify market requirements, technical barriers and future ways of operating the VHST, freight operation and even mixed traffic in the same infrastructure.

  Elements developed will need generating business cases for the concepts above-mentioned. This will lead to the selection of the two most promising ones, according to their estimated LCC and RAMS.

- Assessment methods will also include a technique to evaluate capacity improvements, the market for potential growth of capacity on key TEN routes and measures for implementation. Traffic and operational development will also need accordingly increased capabilities for longer and heavier trains.

  Description of intelligent systems for planning and dispatching trains as well as development of traffic systems for train load, single wagon load, intermodal and high-speed freight rail are necessary to be provided with innovative operational models. These systems shall cover a larger market than today. Also, they will try to answer the needs of networks on how to be organized to hub and speak between each other for TEN routes.

- The development in rail freight and market share for rail is especially essential to quantify the most important market segments in terms of the total market and the modal split in Europe, and to extend the experience in other world markets.

  Also, to define existing and future customer requirements for different goods/market segments. Based on this define the most promising innovations. Solutions with the highest and quickest positive impact will be introduced to finally propose an implementation plan.

  Industrial logistic concepts will be under consideration for a picture of future freight visions till 2030/2050 including an “Analysis of Market up-take”. The aim is to get a more sustainable system in which future rail transport can be more energy-saving, efficient and flexible. A rolling stock/vehicles design or a conceptual terminal design methodology can be conceived for different markets on the definition of performances to be achieved by them for the fulfilment of demanded target markets, even unusual cargos.

Definition of business cases to establish these innovations shall be provided, so the newly designed systems will be market-driven ensuring seamless low-cost operations for service providers and customers alike.

- Monitoring development and applications: In the case of monitoring today's railway applications are often developed only for railway, with the consequence of very high costs. For example, remote inspection and maintenance are a standard in manufacturing engineering – but not for railway applications like switches up-to-day.

  According to this line of development, standard commercial open source solutions provided to the market should be fit for new infrastructures but also it would be possible to introduce them as marketable retro-fit kits for selected applications

- WHAT ARE THE STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT) THAT YOU IDENTIFIED IN THE MARKET DURING THE COURSE OF THIS PROJECT?

Please use the provided Excel-Document to enter your answers.

IMPLEMENTATION OF RESULTS

Implementing C4Rs results

CAPACITY4RAIL will produce a step change in the capacity of rail networks in Europe by demonstrating innovative technologies in several domains and providing specifications for future technologies to be deployed in a system wise manner. The project will also identify those technologies which will help increase capacity over the next 30 years, as well as classifying the opportunities for future funding with both research and infrastructure programs on national and European levels. The results from the project address in detail the requirements of the EC call and will have an important impact on both research in rail and society in general by addressing key items of the EC white paper on transport. The following sections detail the impacts in these domains.

C4R addresses the future railway system with increased capacity and high competitiveness. The technical and economical assessment of technologies, roadmaps and migration scenarios, necessary to meet the target system will support the cost-effective implementation of necessary technologies. The project builds the base for an economic driven decision of improvements and separates “nice to have” from strictly necessary technologies and procedures.

The results will be used in the long-term for

i) the improvement of the existing infrastructure and the new HSL in project
ii) Implementation of the new products developed
iii) a better decision-making and reduction of the maintenance-cost.

Several areas will be covered in such extent that there will be immediate market uptake possibilities at the end of the project. Leading stakeholders are involved, declaring their will to use the result in actual operation. This guarantees an imminent implementation potential of the results.

Migration of new technologies in an existing system is the key factor for successful implementation and improvements. CAPACITY4RAIL shows ways for migration and procedures to assess technologies and migration paths. The identified mid- and long-term steps which are necessary to increase capacity and to meet the “railway system 2030/2050” connected with low TR levels point out the field for future research and development. The documents and procedures, developed in CAPACITY4RAIL support a traceable and goal-oriented development and the comparison between the target and actual performance.

CAPACITY4RAIL looks for the link between operation, infrastructure and freight. This ensures a goal-oriented improvement of infrastructure and freight vehicles to provide more capacity and thereby more turnover and benefit. The requirements of the customers will drive the improvement of the system. The analysis of future requirements and the link to other transport modes ensures a target system, that is cost effective and meets the future requirements of the customers.

- HOW DO YOU PLAN TO IMPLEMENT THE RESULTS?
    - In the short term (less than 2 years after completion)
    - In the long term (more than 2 years after completion but less than 10 years after completion)

Please use the provided Excel-Document to enter your answers.