Focus area:

Rail System Optimization

Prepared by Dr.-Ing- Armando Carrillo Zanuy and Yawei Hu from EURNEX, European Rail Research Network of Excellence for:
Working Group 7 for ERRAC RRIA

Contributors and reviewers, Working Group 7 ERRAC RRIA:

A. Carolin, TV
A. Berto, FSI
H. Samson, Strukton
B. Ludwig, ÖBB
M. Robinson, NewRail
C. Ebner-Mürzl, VA
M. Haebel, Knorr B.
EURNEX assembly

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1 Executive summary

The European railway community needs to increase its research production in basic aspects such as infrastructure, electrification, control systems, rolling stock, freight, and passenger services, building up and massively enlarging the efforts done in Shift2Rail and Europe's Rail Joint undertaking.

A key point for the next rail research program should be to optimize the rail system as a whole emphasizing the need for a holistic thinking approach where the different railway (sub)systems are understood as cooperating and fully integrated entities. To that aim continued investment in research and development, along with adherence to regulatory compliance and standards will position railways as a vital and valid component of the transportation sector and increase the reliability of the operating components and systems. Additionally, it is essential to understand how various components of the rail system interact with each other whilst ensuring stable operational conditions.

To address these objectives effectively, high-level research needs have been identified for different parts of the railway system. In addition, leveraging emerging technologies, and incorporating sustainability principles into railway planning and operations, the railway industry can thrive and contribute to a more sustainable and efficient transportation system. More in concrete, the program should focus on the following:

- Systems thinking which identifies root causes, anticipates consequences and optimizes the rail system.
- How rail system components interact with each other and external factors (socio-economic, energy, climate, biodiversity, other modes).
- Assessing the impact of rail optimization on other systems, exploring trade-offs and synergies for multiple benefits.
- Optimization of railways encompasses a wide range of areas, including railways infrastructure, electrification and power supply, control, and signaling systems, rolling stock, maintenance and repair, freight and passenger services, and addressing the externalities of railways.
- Delivering railway optimization involves extensive research, collaboration, integrated systems thinking, evaluation, implementation of best practices, continuous improvement, and training. It enhances performance, efficiency, and sustainability through innovative technologies, comprehensive assessment, and partnerships. The industry achieves extensive improvements and benefits stakeholders by considering interdependencies, identifying root causes, and implementing best practices. Continuous monitoring and refinement ensure ongoing optimization and adaptation to evolving needs, supported by a skilled workforce through training and knowledge transfer. Optimization delivers enhanced railway systems and benefits to society.

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2 Background and scope

Optimizing the rail system as a whole involves looking at the rail network and its surrounding environment as interconnected rather than just focusing on individual parts of the system in isolation. The rail system includes the physical infrastructure, trains, and equipment used for operation as well as interactions between subsystems. It also extends to the economic and social context, including passenger demands, economic viability, and environmental impacts.

2.1 Contribution to European Policies

Optimizing the rail system as a whole aims at the following:

- Improving mobility and connectivity within the EU, reducing road congestion, and making travel more convenient and affordable for EU citizens.
- Contributing to the EU's economic development by improving the rail industry's competitiveness, creating jobs, and exporting rail technologies.
- Promoting sustainability and helping the EU achieve its climate targets by reducing greenhouse gas emissions and reliance on road transport.
- Building a more resilient and prosperous Europe by promoting sustainable transport and reducing the negative impacts of transportation on the environment and public health. Rethink existing processes for production and operation
- Anticipating consequences of climate changes (hot, flooding, storms…) and fossil energy costs increase due to decrease of availability in Europe by developing not only new technologies but also new policy, new practices (for example acceptability of lower speed and omnibus trains) and new exploitation rules on the railway network (coupling and decoupling on fly, lower speed, new systems, light trains…).

2.2 Rail system optimization as a booster to European living.

Optimizing the rail system can make it a more attractive and competitive mode of transport, encouraging more people to choose rail over road or air transport.
It can contribute to economic growth by facilitating a simplified daily connection for people and freight. By investing in rail infrastructure and technology, the EU can enhance the rail industry's capacity to innovate, supporting economic growth and creating new opportunities.

How the rail system optimization impacts the significant societal challenges of the EU?

- Rail transport produces fewer greenhouse gas emissions, contributing to reducing the EU's carbon footprint.
- Rail transport can improve connectivity, promoting tourism and job opportunities and reducing economic disparities.
- Rail transport provides safe and comfortable transportation, helping older people mobility facilities and social activities.
- Rail transport connects people across regions and countries, promoting cultural exchanges and a sense of belonging to a shared community.

2.3 Common scope of projects

There is a need to include rail system optimization in new rail collaborative projects and partnerships. The projects should have a shared focus on the following:

- Systems thinking which identifies root causes, anticipates consequences and optimizes the rail system.
- How rail system components interact with each other and external factors (socio-economic, energy, climate, biodiversity, other modes).
- Assessing the impact of rail optimization on other systems, exploring trade-offs and synergies for multiple benefits.
- Optimization of railways encompasses a wide range of areas, including railways infrastructure, electrification and power supply, control, and signaling systems, rolling stock, maintenance and repair, freight and passenger services, and addressing the externalities of railways.
- Delivering railway optimization involves extensive research, collaboration, integrated systems thinking, evaluation, implementation of best practices, continuous improvement, and training. It enhances performance, efficiency, and sustainability through innovative technologies, comprehensive assessment, and partnerships. The industry achieves extensive improvements and benefits stakeholders by considering interdependencies, identifying root causes, and implementing best practices. Continuous monitoring and refinement ensure ongoing optimization and adaptation to evolving needs, supported by a skilled workforce through training and knowledge transfer. Optimization delivers enhanced railway systems and benefits to society.

The following high-level rail research needs in the different railway system parts have been identified:

3 Railways Infrastructure

3.1 Rails

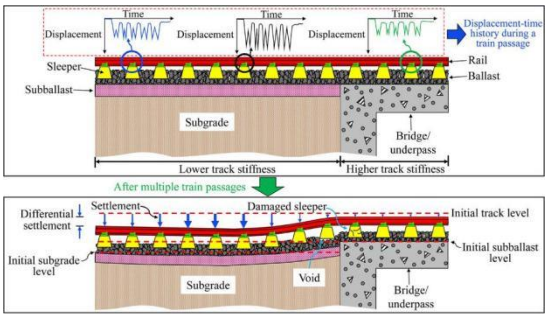
Developing new materials for improved durability and wear resistance, studying methods to reduce noise and vibration, and enhancing inspection techniques for detecting defects and cracks.

3.2 Sleepers or Ties

Exploring alternative materials for longevity and sustainability, optimizing designs for load distribution and reduced maintenance, and developing resistance against degradation factors.

3.3 Ballast

Optimizing gradation and shape for improved load distribution and stability, investigating alternative materials for better drainage and reduced fouling, and developing techniques for adequate compaction.

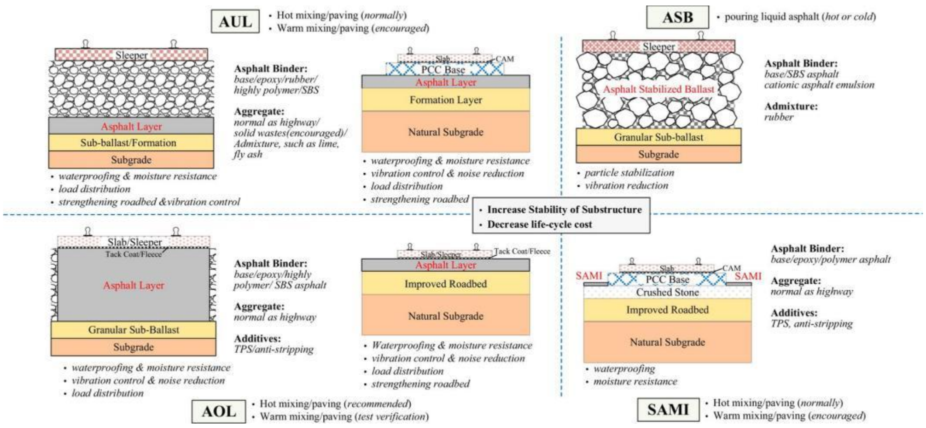


A-1 The relationship between roadbed force and sleepers

(Source:https://www.frontiersin.org/articles/10.3389/fbuil.2021.660292/full)

3.4 Trackbed

Studying soil behavior under railway loading, developing improved stability and reduced settlement designs, exploring reinforcement techniques, and optimizing drainage properties. Rail transport induced frequent changing loads needs explanation in order to understand durability, describe maintainablility and to optimize design.



B-2 The influence of different materials and layer arrangement on the force of the substructure

(Source:https://www.sciencedirect.com/science/article/abs/pii/S0950061820327604)

3.5 Fastening Systems

Developing robust and durable designs, exploring materials for fatigue and corrosion resistance, studying their impact on-track performance, and investigating maintenance reduction techniques. Prioritising 2 or 3 universal types of fasteners (including robotized tools).

3.6 Rail Joints

Improving joint designs for reduced track irregularities and extended service life, studying collective behavior under different loads and conditions, developing practical inspection and maintenance methods, and optimizing design.

3.7 Level Crossings

Developing advanced detection systems, improving visibility and safety measures, studying their impact on traffic flow, and exploring efficient maintenance and repair techniques will not only contribute to optimized rail system but also strengthen other transport modes.

3.8 Drainage Systems

Designing effective water management systems, exploring advanced collection and drainage technologies, studying their impact the stability of track and surrounding areas potentially invasive on the track by flood or landslides, and developing predictive maintenance methods will be a key in make rail system robust against with respect to climate changes and extreme weather.

3.9 Bridges, tunnels and civil engineering structures

Developing methods for determining more realistic and route-specific models of traffic-induced loads on bridges and noise barriers, with the aim to extend their time in service without compromising their performance. Utilize available information from different levels (object, route, network) and sources (management, inspection, measurement) through tailored data-fusion methods to improve predictive maintenance of structures. Foster methods that will improve availability of accurate structural condition data with high coverage of assets.

Harmonizing efforts on digital twins and development of digital product passport for structures will improve the sustainability of the rail system, save resources, and facilitate re-use of materials.

Coordinate new developments in rolling stock with corresponding safety and durability issues at bridges, fastenings, equipment of tunnels and noise barriers through development of unified compliance testing procedures that will consider resulting changes in aerodynamic effects and dynamic loading.

Improve sustainability of new constructions through innovative materials and integrated sensors with the ability of I2V & V2I communication.

3.10 Stations and terminals

Studying passenger movement patterns, peak travel times, and congestion points to optimize station layout, circulation, and platform capacity, improving no-barriers full accessibility for all, including the provision of elevators, ramps, and tactile guidance systems, contributes to a more optimized usage by people with reduced abilities. Development of innovative technologies and design features to enhance passenger safety and security, crowd management, and improve passenger comfort. Exploring strategies for efficient and cost-effective maintenance and cleaning of stations and terminals, including preventive maintenance schedules, cleaning methods, and repairs to infrastructure and facilities, contributes towards a more pleasant journey. Improve all intermodal connections to simplify transfers, increase comfort and minimize time.

3.11 Maintenance processes

Develop advanced methods and technologies for continuous monitoring of railway assets such as tracks, bridges, tunnels and signaling systems. This includes the use of remote sensor technologies, networkwide monitoring technologies (distributed sensing), onboard sensing, and methods of sensor integration in structures, as well as data analytics, to detect early signs of deterioration, defects, or failures.

Improve predictive maintenance models by incorporating real-time data, historical information, and machine learning algorithms to accurately forecast asset performance, optimize maintenance schedules, and minimize downtime.

Develop efficient asset management strategies that consider the entire lifecycle of railway infrastructure, including design, construction, operation, maintenance, dismantling. This involves assessing the cost-effectiveness of different maintenance approaches and prioritizing investments based on risk assessment and criticality analysis.

Define objective and measurable indicators of sustainability, which consider all relevant aspects (materials, resource consumption, construction method, life-cycle, system boundaries), building on the EN 15643-5. Prepare methodology for “sustainability limit state" for the design of new structures. Foster “digital product passport” technologies to allow re-use of structural components.

Explore innovative inspection techniques, such as robotics, drones, embedded sensors, distributed fiber sensing and advanced imaging technologies, to enhance their efficiency and effectiveness. This includes automating inspection processes, improving data collection accuracy, reducing the need for manual intervention, storing big data for feeding preventive maintenance forecasting models.

Conduct research on materials used in railway infrastructure, including tracks, sleepers, ballasts, and bridge and tunnel components, to enhance their durability, performance, and resistance to wear, corrosion, and fatigue and explore the use of new materials less related to fossil energy for their fabrication. This involves testing new materials, evaluating their behavior under different loading conditions, and developing standards for their use.

Study and anticipate the impact of climate change on railway infrastructure and develop strategies to enhance its resilience. This includes understanding the effects of extreme weather events, flooding, and temperature variations on tracks, bridges, and other components, and identifying adaptation measures to mitigate these risks.

Design and implement decision support systems that integrate various data sources, models, and expert knowledge to assist maintenance personnel in making informed decisions. This includes tools for condition assessment, risk analysis, maintenance planning, and resource allocation.

Investigate human factors in railway maintenance operations, including factors that influence safety, efficiency, and well-being of workers. This involves studying the ergonomics of maintenance tasks, training programs, fatigue management, and the use of automation to improve safety and productivity.

Explore ways to minimize the environmental impact of railway maintenance activities. This includes researching eco-friendly materials, energy-efficient technologies, waste management practices, and strategies for reducing noise, vibration, and emissions during maintenance operations.

Promote collaboration and knowledge sharing among railway organizations to develop common standards, guidelines, and best practices for maintenance. This includes benchmarking performance, sharing lessons learned, and fostering international cooperation to improve maintenance efficiency and effectiveness.

3.12 Noise and Vibration abatement

Reduce noise and vibration annoyance levels in urban areas through improved noise barriers, low-noise tracks and bridges or urban planning (vegetation and quiet zones, access and traffic control). Increase accuracy of noise and vibration assessment methods in the process of mitigation measures design, to make the process more effective. Develop standardized measurement procedures to test the actual performance of noise and vibration reduction measures.

4 Electrification and power supply of railways

4.1 Overhead Catenary System

Developing more efficient and cost-effective designs, exploring innovative materials for overhead wires and support structures, optimizing contact wire tensioning methods, and improving maintenance and inspection techniques, have potential of reduce unplanned service interruptions and allow for significant cost savings of rail system.

4.2 Substation

Develop advanced substation designs for efficient power conversion and distribution, explore alternative energy sources, study grid integration and power quality issues, and investigate intelligent grid technologies for enhanced substation operation.

4.3 Feeder Cables

Developing high-capacity and low-loss cables, exploring materials and designs for increased efficiency and reduced electrical losses, studying cable aging and degradation mechanisms, and developing cable diagnostics and condition monitoring techniques.

4.4 Sectioning Insulators

Developing insulators with improved properties and mechanical strength, studying their behavior under different environmental conditions, exploring materials and designs for enhanced reliability and safety, and investigating failure modes and mitigation techniques.

4.5 Switching Equipment

Developing advanced switching technologies for efficient and reliable operation, exploring alternative materials for improved switching performance, studying fault detection and protection methods, and investigating switching equipment optimization for energy savings and reduced maintenance.

C-3 New electrification and power supply technologies

1-3 Title: New electrification and power supply technologies

(Source:https://www.voestalpine.com/railway-systems/en/company/news/making-switch-machines-intelligent/)

4.6 Power Filtering and Compensation

Developing effective filtering and compensation methods to mitigate power quality issues, exploring advanced power electronic devices for harmonic suppression and reactive power compensation, studying their impact on network stability, and investigating control strategies for optimal performance.

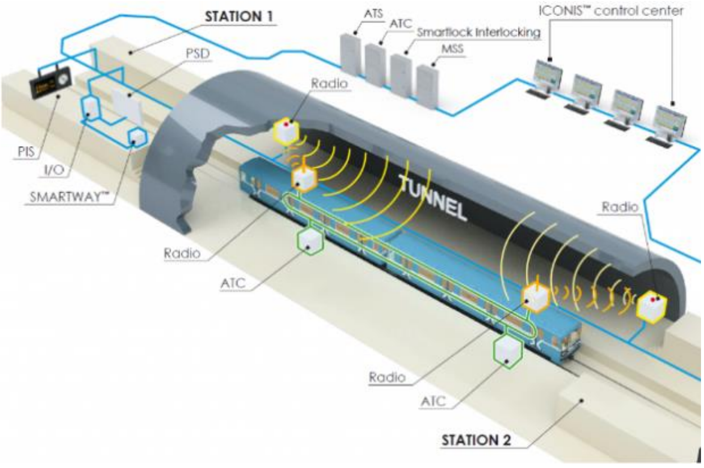
4.7 Protection Systems

Developing advanced protection schemes for fault detection, localization, and clearance, studying fault behavior and propagation mechanisms, exploring innovative protection devices and technologies, and investigating cyber-security measures for protection systems.

4.8 Control and Monitoring Systems

Developing intelligent control and monitoring systems for efficient operation and maintenance, exploring real-time data acquisition and analysis techniques, studying network-wide monitoring and control strategies, and investigating predictive and proactive maintenance approaches for enhanced system reliability.

5 Control and Signaling systems



D-4 Signal control system

(Source: http://www.railway-technical.com/signalling/)

5.1 Signals

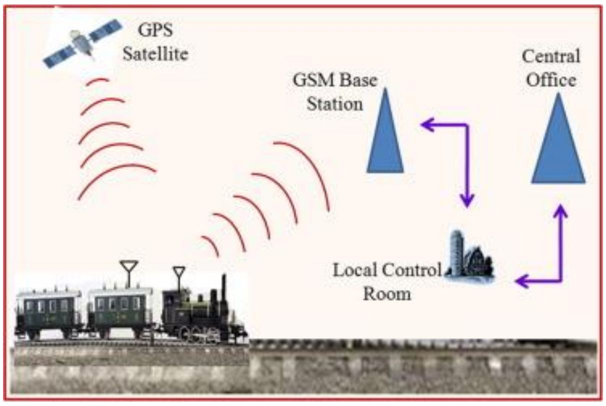
Developing advanced signal technologies for improved visibility and recognition, studying the effectiveness of different signal designs and placement strategies, and exploring ways to enhance signal communication and coordination with train operators.

5.2 Interlocking System

Developing advanced interlocking algorithms for efficient and safe train movements, exploring interoperability and standardization of interlocking systems, studying fault detection and recovery methods, and enhancing cybersecurity measures to protect them.

5.3 Train Detection Systems

Developing reliable and accurate train detection methods, exploring advanced sensor technologies such as axle counters or track circuits, studying the integration of train detection systems with signaling systems, and investigating fault detection and maintenance techniques for train detection equipment.



E-5 Detection and report system

(Source: http://www.railway-technical.com/signalling/)

5.4 Control Center

Developing advanced control center technologies for real-time monitoring and management of train operations, exploring decision support systems and automation for efficient control, studying operator interfaces and human factors, and enhancing communication networks for seamless control center operations.

5.5 Trainborne Signaling Equipment

Developing robust and reliable frugal onboard signaling equipment, exploring secure and safe wireless communication technologies for train-to-wayside data exchanges (some prototypes existe in X2RAIL4), studying interoperability with trackside signaling systems, and investigating the integration of train-borne signaling equipment with other onboard systems. Studying the cutting edge concept of signaling in the cloud to avoid trackside equipements and reduce infrastructure cost for example to revitalize secondary lines.

5.6 Advanced Data Analytics and AI

Leverage data collected from communication systems, train sensors, and other sources to develop advanced data analytics and AI techniques. This research should focus on extracting valuable insights to enhance train scheduling, predict maintenance needs, optimize energy consumption, and improve overall operational efficiency.

Make Infrastructure Managers and Rail Undertaking aware that sharing data will bring advantage to the entire system, including them. From the data collected, the research should focus on extracting valuable insights to enhance train scheduling, predict maintenance needs, optimize energy consumption, and improve overall operational efficiency.

5.7 Power Supply

Developing efficient and reliable power supply solutions for signaling and communication equipment, exploring alternative energy sources such as renewable energy, studying electromagnetic energy harvesting, studying power quality and stability issues, and investigating backup power systems for uninterrupted power supply during outages or emergencies.

5.8 Wireless Communication Technologies

Develop advanced adaptable and reconfigurable wireless communication technologies for railway systems that can cope with railways constraints and technology evolutions). This includes investigating and optimizing wireless communication protocols considering wireless standards evolutions 5G, 6G towards higher frequency bands (millimetric waves, Li-Fi) and hybridization with satellite communications taking into account the launching of Governmental constellations such as IRIS2to provide reliable and high-speed connectivity as “network as a service” on moving trains whatever will be the segment market. Investigate the deployment of Software Defined Network (SDN), Slicing, Network Function Virtualization (NFV)and Edge Computing to permit flexibility, reconfigurability and energy saving at network level to decrease costs.

5.9 Train-to-X Communication

Explore robust, reconfigurable, adaptable and frugal T2X communication systems resilient to technology evolution that enable direct communication between trains (T2T), facilitating coordination and information sharing. This can enhance train operations, improve traffic management, and support features like platooning and virtual coupling on fly, where trains can travel closely together or when convoys composition can be changed dynamically to improve efficiency. The integration of long-range and short-range wireless communication systems is also important. The use of anti-collision radar systems as communicating systems should be investigating as this a trend in the automotive domain, avoiding the installation of another system.

Improve communication between trains and the railway infrastructure (T2I), including signaling systems, trackside equipment, and control centers. This research could involve developing adaptable and reconfigurable standardized communication interfaces able to cope with technology evolution, investigating the use of satellites in order to complement terrestrial communications systems, developing solution to minimize communication disruptions and maintain uninterrupted connectivity, particularly in areas with limited coverage or during high-speed train operations. The research should include investigating the use of sensor networks and new techniques for data collection and forwarding, and exploring ways to integrate communication systems with existing railway infrastructure.

5.10 Cybersecurity

Address the unique cybersecurity challenges posed by railway communication systems. Investigate methods to secure wireless networks on trains, protect communication channels from unauthorized access, and ensure the integrity and authenticity of transmitted data. This research should also focus on developing intrusion detection and prevention mechanisms to safeguard critical railway infrastructure. Cutting edge solutions based on Block Chains and Edge computing concepts should be investigating to increase efficiency and energy saving of cybersecurity processes.

5.11 Seamless Handover and Roaming

Design communication systems that enable seamless handover and roaming for trains moving across different cellular networks or Wi-Fi hotspots. This research should aim to minimize communication disruptions and maintain uninterrupted connectivity, particularly in areas with limited coverage or during high-speed train operations.

5.12 Spectrum Allocation and Interference Mitigation

Investigate efficient spectrum allocation methods for railway communication systems, taking into account the increasing demand for wireless services. In collaboration with spectrum regulation bodies, explore robust and safe cognitive radio concepts and dynamic frequency allocation over Europe in order to allow trains to be able to access dynamically to larger frequency bandwidth when necessary for train operations.

Additionally, explore techniques to mitigate interference from other wireless systems, both within and outside the railway environment, to ensure reliable and interference-free communication.

5.13 Human-Machine Interfaces

Study human factors and user experience aspects of communication systems for railway personnel and passengers. Investigate intuitive and user-friendly interfaces, wearable technologies, and voice-based interaction methods to enhance communication, information dissemination, and emergency response capabilities.

6 Rolling stock

6.1 Locomotives

Developing more energy-efficient and environmentally friendly locomotive designs, exploring alternative propulsion systems.

6.2 Running Gear

Improving the performance and efficiency of running gear components, developing new materials, studying the sources of noise and vibration in running gear, assessing the impact of environmental factors, exploring the aerodynamic characteristics of running gear and the slipstream effects, developing measures to enhance stability, mitigate derailment risks, and improve the overall safety of train operations.

6.3 Passenger/Freight Car's body

Developing lightweight, durable car body designs, exploring materials for improved energy efficiency and crashworthiness, studying interior comfort and accessibility features, and investigating aerodynamic optimizations for reduced energy consumption.

6.4 Couplers and Buffers

Developing advanced coupler and buffer designs for safe and efficient train coupling, studying compatibility and interoperability between different coupling systems, exploring energy absorption technologies for enhanced safety, and investigating wear and maintenance issues.

6.5 Braking Systems

Developing advanced braking technologies for reliable and efficient train stopping, exploring regenerative braking for energy recovery and re-use optimization, studying braking performance under different operating conditions, and investigating maintenance and fault detection techniques for braking systems.

6.6 Electrical Systems

Developing efficient and reliable electrical systems for train operation, exploring advanced power distribution and management techniques, studying onboard energy storage systems, and investigating ways to enhance electrical system integration with other onboard systems.

6.7 On board Communication and Safety Systems

Developing advanced communication systems for seamless train-to-train and train-to-wayside communication, exploring enhanced train control and signaling technologies, studying safety

systems such as automatic train protection and collision avoidance, and investigating cybersecurity measures for safeguarding communication systems.
To enhance rolling stock, allow easy maintenance and to cope with technology evolution, it is urgent to replace wired on-board communication network (TCMS) by a wireless reconfigurable solution (Wireless TCMS) allowing inter-consists and inter-carriage wireless communications, easy reconfiguration of train structure and network capacity adaptation thanks to the use of AI coupled with SDN and slicing techniques.

7 Freight and passenger services

7.1 Operations

Optimizing train scheduling and timetabling algorithms, studying operational efficiency and capacity management, exploring simulation and modeling techniques for operational planning, investigating ways to improve performance and reliability of services, and enhancing operational decision-making processes for planning and rescheduling to minimize the effect of disruptions. Search for transport services capable to maximize the decarbonization effect of rail mobility, both in passengers (e.g., high speed night train) and freight traffic (e.g., automation of marshalling and composition to compete in wagonload).

7.2 Ticketing and Fare Systems

Developing intelligent ticketing solutions, studying fare pricing and revenue management strategies, exploring mobile ticketing and contactless payment technologies, investigating interoperability and integration of ticketing systems, and enhancing ticketing system security and fraud prevention.

7.3 Customer Service

Studying passenger behavior and preferences, exploring personalized travel experiences and passenger information services, investigating customer satisfaction and feedback mechanisms, developing service quality assessment tools, and enhancing accessibility and inclusivity for all passengers.

7.4 Safety and Security

Developing advanced safety and security technologies, studying risk assessment and mitigation strategies, exploring surveillance and monitoring systems, investigating emergency response and crisis management protocols, and enhancing cybersecurity measures to protect critical railway infrastructure.

7.5 Freight and Passenger Information Systems

Developing real-time information systems for passengers and freight operators, studying data integration and interoperability, exploring predictive analytics for operational decision-making, investigating dynamic routing and tracking technologies, and enhancing stakeholder communication and information exchange.

7.6 Regulatory Compliance and Standards

Studying regulatory frameworks and compliance requirements, exploring international standards and interoperability, investigating safety regulations and certification processes, developing guidelines for sustainable and environmentally friendly practices, and enhancing industry collaboration and knowledge sharing in regulatory matters.

7.7 Cross-operated, Cross-Borders and Cross Modals Services

Developing frameworks and procedures for seamless operations and service integration across different railway operators, borders, and modes of transportation. Creating integrated systems for real-time tracking, monitoring, and coordination of services using IoT, data analytics, and digital platforms. Optimizing freight routing, cargo handling, customs procedures, and documentation to streamline operations and enhance efficiency. Addressing regulatory barriers and establishing frameworks for seamless operations and legal alignment. Fostering collaboration among governments, railway operators, freight forwarders, and shippers to develop joint strategies and share resources to mitigate risks due to voluntary physical- or cyber-attacks without penalizing the efficiency of freight traffic and the comfort of passengers.

8 Externalities of railways

Rail system optimization significantly impacts railway externalities, both positive and negative. Optimization improves performance, efficiency, and sustainability, reducing traffic congestion, air pollution, and energy consumption. Enhanced rail systems promote economic development, job creation, and social inclusion. To minimize negative externalities, optimization mitigates noise, vibration, negative impacts on biodiversity and land use. Optimization manages and mitigates negative externalities, maximizing positive implications for a sustainable and environmentally friendly transportation system at full lifecycle level, benefiting the industry and society.

9 Conclusive remarks and recommendations

To advance the railway industry and promote sustainable transportation, prioritizing rail system optimization is crucial. This approach should adopt systems thinking mindset to identify root causes, anticipate consequences, and optimize the rail system. Understanding the interactions between rail components, rolling stock and external factors are essential.

A key approach is to promote projects that address integrated systems thinking, understanding trade-offs and synergies among railways' components.

Specific research needs for different railway system parts have been identified, including rolling stock technology, track maintenance equipment, electrification, power supply systems, signaling and telecommunication, maintenance, and infrastructure facilities. Research efforts should focus on enhancing performance, safety, and efficiency through innovative solutions and technologies but also European policies analysis.

To enhance efficiency, sustainability, and service quality in the railway system, it is imperative to invest in research, foster collaboration, and adopt new technologies. Consistently addressing research requirements and interdependencies is crucial for ensuring reliability, efficiency, and environmental friendliness.

10 References:

1. Finite Element Modeling of the Dynamic Response of Critical Zones in a Ballasted Railway Track. [Piyush Punetha, Krijan Maharjan, and Sanjay Nimbalkar], Available at: http://www.railway-technical.com/infrastructure/[Accessed 31052023].
2. ScienceDirect. [Online], Available at: https://www.sciencedirect.com/science/article/abs/pii/S0950061820327604 / [Accessed 31052023].
3. Voestalpine. [Online], Available at: https://www.voestalpine.com/railway-systems/en/company/news/making-switch-machines-intelligent / [Accessed 31052023].
4. Railway-technical. [Online], Available at: http://www.railway-technical.com/signalling / [Accessed 31052023].
5. Leanbi. [Online], Available at: https://leanbi.ch/en/blog/leanbi-boosts-digitization-in-rolling-stock-maintenance-in-rail-traffic/ / [Accessed 31052023].
6. Intelligenttransport. [Online], Available at: https://www.intelligenttransport.com/transport-articles/136782/digitalising-rolling-stock-teldat/ / [Accessed 31052023.
7. Vossloh. [Online], Available at: https://www.vossloh.com/en/press/press-releases/detail/pressdetail_53568.html / [Accessed 31052023].