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Analysis of the Challenges Faced by the Rail Sector: Understanding the Rail Industry of the Future through the Incorporation of Technology and Digitisation

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Abstract

Technology and digitalisation will transform today's railway industry. The digitisation of rail will increase its capacity, safety and comfort, maintaining the EU's leadership in rail transport equipment and services. New technologies such as Artificial Intelligence, Big Data, Cloud Computing, etc. will have a major impact on the sector. Innovation will play a vital role as it will serve as a catalyst for the development of the necessary advances for the sector. This article aims to define the key drivers and milestones, as well as the technologies that enable the development of solutions to face these challenges. The article provides an understanding of the future of the sector through the incorporation of technological and digital transformations. Furthermore, the analysis aims to contribute to strengthen the capacity of companies to innovate and thus contribute to EU policies towards a greener and more digital economy, while supporting the resilience of the industry through innovation.

Keywords

Railway, Innovation, Technology, Competitiveness, Digitalisation, Rolling Stock, Infrastructure

1. Introduction

In 2021, the European Commission adopted the Communication "*The 2030 Digital Compass*: *The European way for the Digital Decade*", which mentions the importance of digital solutions that promote a more connected and automated mobility that reduces accidents, improves the quality of life and increases the efficiency of transport, as well as reducing its environmental impact. If the rail sector wants to remain competitive, it needs to adapt to this new revolution, where the development of digital technologies will be key to the sector's competitiveness. The digitisation of the sector will also contribute to achieve the ambitions of the European Green Deal and the Sustainable Development Goals.

There is an environmental concern about transport, as the transport sector as a whole account for a quarter of the EU's greenhouse gas emissions and this number is growing. To achieve climate neutrality, a 90% reduction of transport emissions is needed by 2050 (European Commission, 2021a). The drawbacks of the current mobility model, including air pollution, excessive energy consumption, health effects, etc., have led to a search for alternatives to mitigate these negative effects, among which electric traction modes of transport should be highlighted.

At European level, boosting the freight transport to rail mode is also one of the main challenges. Road transport currently accounts for almost 75% of inland freight transport (European Commission, 2021b), and this transport modal shift is a challenge that the Green Deal aims to address. By 2030, the overall volume of European transport is expected to increase by another 30% (Rail Freight Forward, 2020), which will have a significant impact on the whole rail sector, as growth cannot and should not be supported by road transport alone. The aim will be to shift some of the volume to rail and inland waterways. Rail is the transport with the lowest emissions, so its technological development is vital for the achievement of environmental objectives.

Another key aspect is sustainable transport and mobility. Transport needs must be met with the minimum environmental impact. Rail has the potential to become the backbone of European mobility. A strengthened European rail system would better connect people and businesses across Europe and reduce transport emissions by offering an alternative to road and air travel, giving a green boost to the European economy.

The article presents the methodology applied for the analysis of the key technological and digital challenges for the sector. Subsequently, both internal and external analyses of the sector are presented, in which the key trends and aspects of the future of the railway sector are identified, which serve as a basis for the identification of the key drivers and milestones set out in the article. The study has been carried out under the RIN-Rail Innovation Network project, funded by the Basque Government in the Elkartek 2022 programme (KK-2022/00027).

2. Background

The rail sector seeks to accelerate the development and deployment of innovative technologies, especially in the field of digitalisation and automation to achieve a radical transformation of the system and meet the sector's objectives in terms of sustainability and supply capacity. Research and innovation processes are needed to accelerate the transformation of rail.

At European level, one of the most important initiatives is the EU's Shift2Rail and its successor Europe's Rail Joint Undertaking, both of which aim to make rail transport more competitive. Several specific objectives have been achieved through the Shift2Rail innovation programmes:

- Rolling stock: standard wireless communication systems have been developed, both on-board and between the train and the trackside, which will facilitate the flow of data needed to implement advanced maintenance.
- Signalling: the evolution of Traffic Management Systems (TMS) takes into account the direct connection with the results of asset condition forecasting, in order to optimise possessions.
- Infrastructure: strategies, frameworks, processes and methodologies, tools, products and new and optimised systems for risk-based asset management, prescriptive analysis and holistic management.
- IT solutions: exploitation of existing IT services and/or provision of additional on-demand services, providing operators with tools and techniques to improve the perceived reliability of the entire ecosystem.
- Freight transport: study of asset management from a maintenance perspective, addressing in particular condition-based maintenance.

Furthermore, in the field of intelligent operation, Shift2Rail has driven research into many key areas that will serve as the basis for the development of a new generation of assets for automatic and autonomous operations.

In terms of connectivity, the Shift2Rail programme already initiated the development of wireless communication between trains. Work has been done on some subsystems, such as brakes and doors, significantly improving their performance (e.g., fully electronic braking or doors with smart sensors).

With the aim of facilitating integrated mobility, Shift2Rail is moving towards the necessary innovations from an end-user perspective. In order to achieve a smart integration with other transport modes while ensuring interoperability from the end-user point of view, work has been done on the Interoperability Framework. In addition, work has been carried out on platforms to manage traveler information, to define identification and preferences, travel information, to store tickets, etc. The aim is to provide a "one-stop shop", giving visibility to all available mobility offers, issuing a secure and electronic ticket, containing all necessary information and providing assistance to the traveler.

In the field of freight, Shift2Rail has set the basis for the transformation process towards a digitised and automated rail freight system, for which five areas of development have been identified:

- Digitalisation and automation of the fleet
- Digital transport management: Improved planning methods
- Intelligent freight vehicle concepts
- New freight propulsion concepts
- Business analysis and implementation strategies

The development of obstacle detection systems and the implementation of a freight train demonstrator is the first major step towards the automation of rail freight operations.

Furthermore, Shift2Rail offers a sector platform for the successful delivery of a European Digital Automatic Coupling (DAC) whereby all actors can support its implementation in the market and further support the automation of freight operations.

Another area of work is the digital twin. Recent European collaborative work carried out in the framework of the Shift2Rail programme has already paved the way towards this technology.

The LinX4Rail project, for example, provided the basis for a shared vision of rail system architecture, as well as for the development of a Conceptual Dara Model (CMD). The RailTopoModel and OntoRail projects, associated with the LinX4Rail activities, also contributed to a convergent sectoral approach to define the rail CMD and all the necessary elements developed by major initiatives such as IFC Rail and EULYNX. By combining all the knowledge developed, different simulation or operational subsystems will be made to work together, facilitating the way for building a shared and interoperable architecture. This approach should enable the development of a shared, global digital twin.

Innovation efforts are essential to contribute to a safe, efficient and environmentally sustainable European Rail Transport.

3. Analysis of Information Sources: Sectorial Contrast

In order to identify the challenges faced by the rail value chain, an external analysis and an internal analysis of the market were carried out. On the one hand, the external analysis focused on the search for information through bibliographic sources. During the analysis, different databases and relevant documents of the sector were consulted, as well as a technology monitoring platform owned by Mafex for the review of key documents of the sector. These documents, both in English and Spanish, included documents such as the World Rail Market Study by Rolad Berger—UNIFE, national and international mobility plans and the Science, Technology and Innovation Plan of the Basque Country, among others. Moreover, Mafex actively participates in different projects at international, national and regional level of innovative character that allow to know at first hand the advances in the sector.

On the other hand, the internal analysis was based on the consultation conducted with companies in the sector and served to contrast the external analysis. The analysis was carried out through different participatory workshops with companies of the railway sector guided by a specialised consultant, which encouraged business participation and discussion, looking for trends and challenges in the sector.

3.1. External Market Analysis

In a first phase, a market analysis—PESTEL (Political, Economic, Social, Technological, Environmental and Legal factors) has been carried out, which serves as a starting point to understand and identify the market trends to be considered and captured. The information collected includes reference documents at European, national and regional level. In addition, the information has also been completed with academic reports and scientific articles.

The PESTEL analysis carried out on the railway sector shows several important factors to consider. At the political level, the European Union has established the Sustainable and Smart Mobility Strategy and the Fourth Railway Package: measures to improve Europe's railways, both aimed at promoting the sustainability and competitiveness of rail transport in Europe.

In terms of economic factors, the international market offers opportunities for the rail industry by taking advantage of the recovery funds allocated to rail transport and to increase the competitiveness of freight transport.

In the technological field, the industry needs to increase its presence in the European Union's major R&D programmes such as Horizon Europe. In addition, it is necessary to work on a progressive modernisation of rail infrastructures, including the implementation of technologies such as ERTMS, intelligent network and digital Automatic Signal Announcement and Braking (ASFA). The industry also needs to increase its leadership in technological innovation and collaborate with other sectors that are more advanced in this aspect, such as the automotive and energy sectors, for greater technology transfer to the sector.

In the field of sustainability, given the need to reduce greenhouse gas emissions in transport by 90% by 2050 (European Commission, 2021a), it is necessary to promote rail transport as the most sustainable mode of transport. This will require investments to facilitate its deployment in urban environments and over medium and long distances, as well as increased use of renewable energy sources and storage systems.

3.2. Internal Market Analysis

During the months of May, June and July of 2022, 3 workshops were organised with the Mafex member companies. Mafex currently brings together more than 100 members representing the entire value chain and accounting for 83% of Spanish railway exports. The analysis covers the priorities of the entire railway value chain. The members invited to these meetings included technology centres and industrial companies from the entire railway value chain. The participants had knowledge of the sector and a high degree of technological component in their profile.

The workshops were based on a dynamic of presentation and discussion, and were open to comments and contributions of the rail industry participation. The objective was to align the sector's offer with the challenges and opportunities of the market from a technological point of view, considering both the deployment of current technologies and the development and adoption of emerging technologies, all with a medium and long-term perspective.

The specific objectives of each workshop are shown below:

WORKSHOP 1: Future market vision: Key issues for competitiveness: In this workshop, the key issues for competitiveness in the railway sector were identified and classified into levels, from general issues, to key drivers, to concrete milestones.

WORKSHOP 2: Identification of relevant technologies: In this second workshop, the technologies associated with the key issues of competitiveness were identified. Participants discussed about the functions and applications of relevant technologies in the railway market and also about their own contribution to the key issues of competitiveness. In this sense, the technologies were structured by areas and by their impact on the previously identified market keys.

WORKSHOP 3: Analysis and prioritisation of technologies: In this last workshop, the technologies and solutions highlighted were characterised and parameters were established to select the critical milestones and associated technologies.

4. Methodology: Synthesis of Information

Through the workshops explained above, 4 major key areas have been identified for the competitiveness of all the agents and companies that are part of the railway sector. Below are the 4 main areas: 1) efficiency, 2) sustainability, 3) passenger experience and 4) freight.

4.1. Key Blocks for the Competitiveness of the Sector

4.1.1. Efficiency

The rail value chain is made up of 4 major stages involving multiple actors such as rolling stock and infrastructure manufacturers, operators, infrastructure managers and service providers.

The biggest challenge for companies in the short term is bringing supply in line with demand, as it seems that demand reduction is a shared experience. In most cases, this will lead to a reduction in costs and investments and will require supply chains to be more planful and efficient. This challenge can be met through digitalisation. Investing in sensorised and digitised production models will make companies more flexible, more able to plan and to receive market information more quickly.

4.1.2. Sustainability

Sustainability is a key factor for the competitiveness of the railway sector. Trains, in their different modalities (long-distance, underground, etc.), are currently the means of transport with the lowest CO_2 emissions per unit transported, between three and five times less than road journeys, and between seven and ten times less than air travel. It is also more efficient in terms of electricity consumption, thanks to the advances made by the industry. These include the use of regenerative braking, which leads to energy savings of 10% - 30% in commercial operations.

The modal shift to rail transport from other modes allows for a fundamental reduction of emissions into the atmosphere. It not only contributes to the reduction of greenhouse gases but also to the reduction of other pollutant gases (NOx and particulate matter) and other environmental pollutants such as noise, luminescence, etc. Work is also being done on battery-electric and/or hydrogen hybrid traction systems, as well as on the development of traction equipment with additional functions such as safety, braking and communications.

In fact, the concept of circular economy has started to become more and more relevant in the sector. Aware of the limited resources and the need to obtain the greatest value for the longest possible time, many companies have begun to design their products/services in such a way that at the end of their life cycle, materials and components can be recovered and recycled.

4.1.3. Passenger Experience

The aim is to seek innovative solutions that improve services and passenger experience through the use of technologies. Some of the solutions developed focus on improving comfort in the passenger environment (lighting and presence sensors), as well as customisation and flexibility inside trains. Another area of work is integrated mobility, offering solutions that enable door-to-door mobility and the integration of all modes of transport in the city on a single platform.

Digitalisation provides travellers a more attractive and integrated mobility, improving the passenger experience. It also enables rail operators to make their infrastructures smart, ensuring availability and increasing sustainability throughout the entire product lifecycle.

4.1.4. Freight

Considering that for the same quantity transported, rail emits 70% less CO_2 than lorries (EAFO, 2021), the current research is based on improving the conditions of supply by rail so that companies decide to opt for this means of transport. In the field of freight, work is being done on standardising and automating the loading and unloading of freight, as well as on the autonomous/virtual coupling of the fleet to optimise the operation. Work is also being done on the integration of the different types of transport-freight-passengers in search of the optimum transport, taking into account the criteria of energy efficiency, cost and time.

4.2. Key Drivers and Milestones

Based on the market context, a structured and time-ordered vision of the future key elements of the railway sector has been developed. In other words, after identifying the 4 key areas of the railway sector that apply to the project, a study has been carried out to identify the key drivers and the specific milestones the industry will face in the coming years.

The methodology and results are shown below:

Firstly, the key drivers applied to each key area were identified. The key drivers are aspects at market/business level that can significantly shape the future evolution (time frame 2030) of competitiveness within the sector, and therefore serve for the orientation of efforts and actions for the development of processes, products and services.

Secondly, milestones are identified. Milestones are events or situations through which the effect of the drivers is manifested and triggered. A key driver is divided into a number of milestones located over time (see Figure 1). They can take the form of objectives, requirements, or specifications that apply to the products/processes of the activities in the rail value chain. They are the "what for" of the technologies.

4.3. Technological Areas

Once the context of the railway sector has been studied identifying the main challenges that the sector will face in the coming years through the key drivers and milestones, the key technological areas have been identified. The methodology results in 6 technological areas: 1) Models (Industry 4.0), 2) Data, 3) Electronics and Connectivity, 4) Energy and Energy Management, 5) Materials and 6) Applications and Services. These technological areas cover a series of key technologies when it comes to meeting the different challenges raised (see Figure 2).

5. Results of the Study: Challenges of the Railway Sector and the Contribution of Technology and Digitalization to the Future of the Sector

5.1. Efficiency

Within the efficiency competitiveness area, 4 key drivers have been identified, 1) new materials, 2) increased capacity, 3) smart operation and 4) advanced manufacturing and industry 4.0 and 16 milestones have been defined (See Figures 3-6).

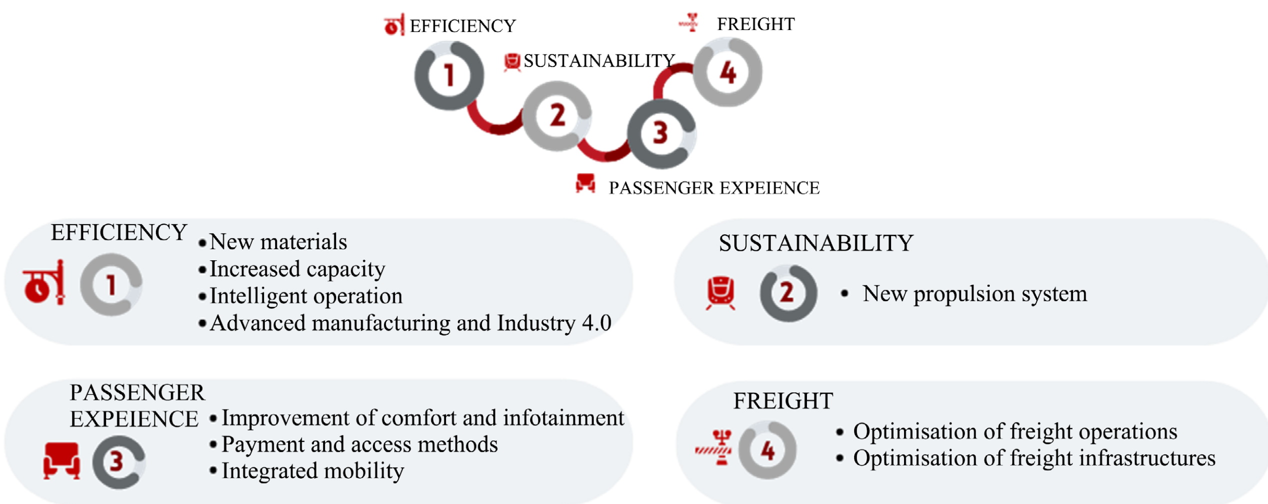

Figure 1. Key drivers and their milestones. Source: Own elaboration.

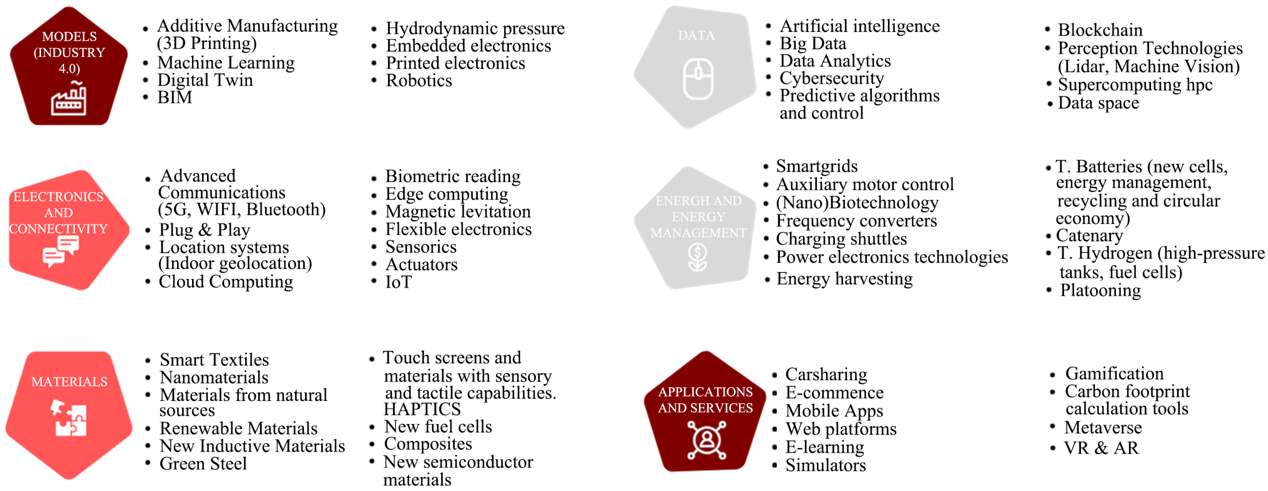

Figure 2. Technological areas and associated technologies. Source: Own elaboration.

	Models	Electronics and connectivity	Energy and energy management	Materials
Development of lightweight materials for railway construction			●	●
Development of smart and sustainable materials	●	●		●
Development of recyclable materials	●			●

Figure 3. New materials key driver and related milestones. Source: Own elaboration.

	Data	Electronics and connectivity	Energy and energy management
Increase in transportable freight	●	●	●
Reduction of traffic congestion	●	●	●

Figure 4. Increased capacity key driver and related milestones. Source: Own elaboration.

	Models	Data	Electronics and connectivity	Energy and energy management	Applications
Monitoring of rolling stock and infrastructure	●	●	●		●
Improved infrastructure maintenance based on traffic characteristics		●	●	●	
Optimisation of maintenance cycles based on the status of critical systems	●	●	●	●	
Evolution towards Automated Train Operation (mainline network over ERTMS)	●	●	●	●	
Evolution towards Autonomous Train Operation (passenger and freight)	●	●	●	●	
Monitoring of railway safety	●	●	●	●	
Adjusting traffic to demand, smart optimisation of planning	●	●	●		●

Figure 5. Smart operation key driver and related milestones. Source: Own elaboration.

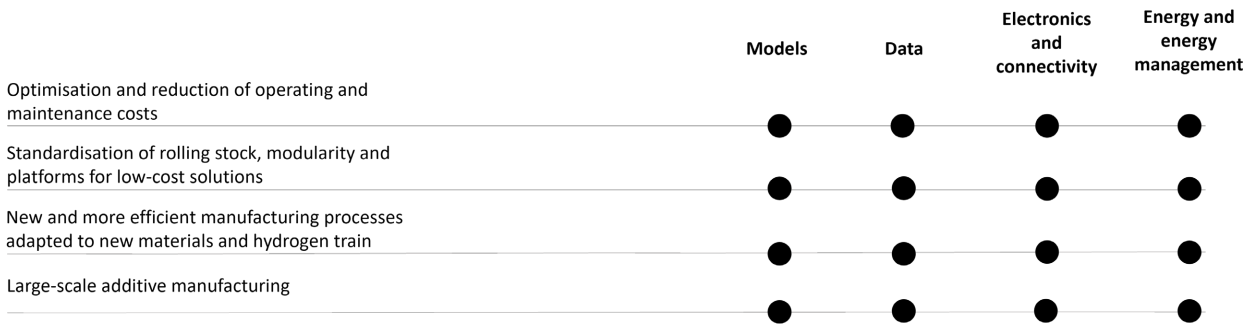

Figure 6. Advanced manufacturing and industry 4.0 key driver and related milestones. Source: Own elaboration.

5.1.1. New Materials

In the field of new materials, the analysis defines that the main needs of the sector related to the new generation of lighter and more reliable bogies, improving safety and comfort, reducing wheel/infrastructure wear, facilitating maintenance and reducing noise and vibrations.

One of the milestones is the development of new traction systems based on the technology of new silicon carbide converters. This solution reduces energy consumption, improves efficiency and increases reliability. Silicon carbide is a material that offers higher performance than conventional devices. These properties make possible a reduction in the volume and weight of various current traction systems, which are vital parameters for improving the efficiency of rail transport.

The use of this material in traction equipment has made it possible to reduce the volume and weight of the power core by 30%, and of the magnetic elements by 80%. In addition, the losses of the conversion system are reduced by 50%, thus increasing its efficiency.

The analysis also highlights the opportunity offered by the use of sustainable and recyclable materials in the systems of the stations or inside the trains.

5.1.2. Increased Capacity

The increase of capacity is related to network management planning and control. The main milestones for increasing capacity are related to the increase of freight rail transport and the reduction of traffic congestion. Meeting these challenges will mean optimising the capacity of rail operations, which will also increase punctuality, cost reduction and improvement of energy efficiency.

In this sense, on the one hand, it is necessary to define the network management process for railway operators and to carry out the necessary demonstrations. Designing the rail system of the future will offer greater capacity, punctuality and improve efficiency. This improved planning will also support decision-making, re-planning and punctuality prediction through data analysis, artificial intelligence, simulation and other technologies. Efficient information exchange and integrated decision-making for tracks, stations and resource management systems are also needed.

On the other hand, in order to achieve an increase of freight transport to rail mode, it will be necessary to have a constant flow of information that makes the travel easier, offering smoother connections.

To provide a solution to the milestones shown, it will be necessary to make use of artificial intelligence and machine learning techniques. Data extraction and management will also be necessary, based on standardised communication levels that facilitate the integration of various technical systems. To meet the challenge of increased capacity, the industry must apply new standards for remote control and driving functions, which are closely related to energy management technologies, as well as electronics and connectivity.

Technologies that help to manage demand are also of special relevance, in particular the control of on-board passenger flow or the real-time management of point variations in demand.

By means of real-time analysis of passenger information using systems such as intelligent video analysis, the capture of mobile phone codes with privacy protection, detention systems with Bluetooth or Wi-Fi technology, it would be possible to obtain verified data to optimise the planning of the transport offer and to detect and manage special situations of service demand.

5.1.3. Smart Operation

Today, the automatic operation of metro systems and passengers transport vehicles has become a reality. Most modern metro lines implement it or are prepared for high degrees of automation (GoA 4). Experience has shown the significant benefits that this brings; increased system capacity, punctuality, resilience and flexibility, and reduction of operation costs and energy consumption, among others. These benefits could also be provided by more automated and/or autonomous operations in other rail transport segments, such as regional and suburban trains, high-speed trains, freight trains or light rail and trams.

In the future, the entire rail system will require a higher number of trains operating simultaneously on the same network as well as a higher degree of automation and connectivity for integration the rail systems to meet specific needs and operational requirements. This also implicitly means that legacy systems (i.e. the comprehensive network until 2050) and segregated railways (e.g. urban, suburban and local networks) will have to support automation to contribute to a pan-European deployment of interoperable, plug & play, modular, scalable and upgradeable Automatic Train Operations (ATOs) and seamless automated/autonomous operation across Europe towards zero infrastructure signalling and interconnection of other autonomous transport modes where necessary.

Regarding the incorporation of technologies, the main objective is to provide high degrees of automation on segregated or partially segregated networks, as well as to provide self-regulating management functions for rolling stock to enable its automation.

In this sense, the challenge today is the migration towards driverless train operation, i.e. to support the migration of existing legacy systems to ATO GoA4 on ETS. For this purpose, modular and evolutionary solutions are being developed considering ATO over ETCS, or in non-ETCS area using lateral signalling information.

To this end, current technologies allow the development of algorithms integrated in the on-board electronics to obtain the vehicle's location in real time and in a secure way. Within this vision, the existence of a standardised automation platform, covering all phases from architectural design to testing, certification and commissioning of a given deployment, will be an essential asset complementing digital twins and advanced traffic management.

Automation requires new functions based on rapidly evolving technologies, such as artificial intelligence (AI), whose certification is uncertain when applied to safety-related functions, and where existing procedures and regulations may not be applicable. Such functions will in many cases rely on new generation sensors providing artificial perception of the environment, and whose reliability and accuracy are highly dependent on training and machine learning, leading to increased costs. Due to the quick evolution of these technologies and of computing power, these solutions will also need to be modular and capable of evolving.

High degrees of automation require connectivity, between trains, between trains and infrastructure, and between trains and users, through appropriate communication and information management links. Such connectivity is also the basis for the virtual docking mechanism, which should be exploited in passenger services, going beyond the current low Technology Readiness Levels (TRL) prototypes, and paving the way for a new type of light Automatic Train Protection (ATP). Harmonised and equitable allocation of dedicated frequency bands, together with cybersecurity and security applied to automation and connectivity, are important challenges to be addressed.

5.1.4. Advanced Manufacturing and Industry 4.0

Advanced manufacturing and industry 4.0 is a key driver in the transformation of the rail sector, addressing several critical challenges, including the optimisation and reduction of operation and maintenance costs. With the application of advanced technologies, such as robotics, artificial intelligence and internet of things, significant improvements in the efficiency of production and maintenance processes can be achieved.

Standardisation of rolling stock is essential to increase interoperability and safety, as well as to reduce manufacturing and maintenance costs. In addition, the creation of low-cost solution platforms enables mass production of components and parts, reducing unit costs and increasing production efficiency.

Another important milestone in advanced manufacturing and industry 4.0 is the development of new manufacturing processes adapted to new materials and technologies, such as the hydrogen train.

Large-scale additive manufacturing has also become an essential milestone for the railway industry as it allows the production of more complex and customised parts, reducing production time and the number of parts required. It also enables faster and more efficient prototyping, reducing production costs and improving efficiency.

5.2. Sustainability

Within the sustainability block, one key factor, propulsion systems, has been identified and 7 milestones have been defined (See Figure 7).

Propulsion Systems

Sustainability is one of the main challenges of the sector. In railway systems, most of the consumption comes from the traction part. In this sense, the analysis identifies three lines of action: defining self-consumption plans, defining technological developments for the use of energy and the use of resources.

The challenges for optimising energy efficiency focus on the recovery of electrical energy from braking and the development of new components and connection schemes to improve the efficiency of the system by reducing electrical losses and consumption for use in direct current lines.

To address this challenge, the main enabling technologies are related to materials and energy and energy management. This may include applications for traffic operation in different driving environments, signalling or protection systems with energy saving criteria, optimal gear design, economical driving, schedule design, regenerative braking exploitation.

5.3. Passenger Experience

Within the user experience area, three key drivers have been identified, 1) improved comfort and infotainment, 2) payment and access methods, and 3) integrated mobility, and 16 milestones have been defined (See Figures 8-10).

	Models	Data	Electronics and connectivity	Energy and energy management	Materials
Optimisation of energy management (train and network)	●	●	●	●	●
Development of electric charging networks		●		●	●
Manufacturing solutions tailored to the hydrogen train, including cost reduction	●	●		●	●
Electric traction equipment with additional functions (safety, braking, communications)		●		●	●
Extended capacity battery propulsion	●	●		●	●
Deployment of the hydrogen economy in the energy sector				●	●
Battery-electric and/or hydrogen hybrid (bimode) traction systems				●	●

Figure 7. Propulsion systems key driver and related milestones. Source: Own elaboration.

	Models	Data	Electronics and connectivity	Materials
Implementation of interactive screens for the passenger's entertainment during their journey.	●	●	●	●
Temperature control adaptable to the number of passengers		●	●	●
Smart windows	●	●	●	●
Inclusive mobility and infrastructure	●	●	●	●
Real-time travel information to the passenger	●	●	●	●
Customisation and flexibility of train interiors (adaptation to the needs based on the time of the year)	●	●	●	●
Improved comfort in the passenger environment (lighting, presence sensors, etc.)		●	●	●

Figure 8. Improved comfort and infotainment key driver and related milestones. Source: Own elaboration.

	Data	Electronics and connectivity	Materials	Applications
Adequacy of current payment methods in the rail sector	●	●	●	
Adequacy of access methods	●	●	●	
Development of mobile applications to facilitate the purchase of tickets, travel tracking, station guidance, etc.	●	●		
Incident tracking system to assist with incident management and other user requests.		●		●
Safe environment against cyber-attacks (personal data, train, infrastructure)	●			

Figure 9. Payment and access methods key driver and related milestones. Source: Own elaboration.

	Models	Data	Electronics and connectivity	Materials	Applications
Single ticket, also between different modes of transport		●	●		●
Integration of all transport in a city on a single platform		●			●
Door-to-door passenger mobility (Last Mile)		●			●
Smart stations (UNE 178109)	●	●	●	●	●

Figure 10. Integrated mobility key driver and related milestones. Source: Own elaboration.

5.3.1. Improved Comfort and Infotainment

In the area of improving comfort and infotainment, the analysis confirms the sector must work on the adaptability of train interiors to the new needs of the different types of customers: families, people with reduced mobility, etc. This involves, among other things, the development and application of lighter anti-noise and anti-vibration materials in the structure and interior design of railway vehicles, the incorporation of telematic technologies to eliminate access barriers and the improvement of on-board services such as electronic ticketing, services adapted to passengers on smartphones or tablets.

Another challenge identified in the analysis is the development of ecological and intelligent air conditioning systems. These systems would vary according to factors such as the number of passengers, temperature or other aspects.

To facilitate accessibility, the sector should focus its efforts on the development of guidance systems with innovative technologies, such as magnetic positioning, radio frequency or Bluetooth guidance, which will significantly improve accessibility and mobility for disabled people.

The configuration of user passageways can also be modified to provide greater passenger comfort by modifying the layout of environmental elements (lighting, colour, etc.) or auxiliary elements.

5.3.2. Payment and Access Methods

Payment and access methods focus primarily on ticketing and the train stations of the future. All elements of Station 4.0 are based on the Internet of Things (IoT), Artificial Intelligence (AI) and predictive maintenance to improve the customer's travel experience, the quality of service offered and to offer new functionalities.

5.3.3. Integrated Mobility

In order to integrate rail into the mobility ecosystem, firstly, the rail industry must offer solutions to match supply with demand, by tracking flows of people and freight, and develop service offerings to better match multimodal supply with actual demand.

Furthermore, the analysis confirms that efforts should focus on improving the integration of rail within the European mobility ecosystem by developing more interfaces with other modes of transport.

In this line, it is necessary to design railway stations and logistics centres that connect other modes of transport, and that have smart, efficient and flexible interchanges. To this end, digital integration requires a distributed IT model across shared transport modes implemented as a platform that monitors and provides a digital abstraction of all mobility resources and enables the development of new coordination capabilities, making use of developed tools such as the digital twin, simulators, etc.

The analysis shows the importance of offering solutions for multimodal traffic disruption management, providing the ability to forecast, adjust and respond to actual traffic conditions in real time. These solutions are aligned with matching mobility demand with available supply.

If data is available, the challenge will be to dynamically adapt the different mobility offers taking into account the specificities of each mode to achieve the best match between supply and demand.

It is therefore necessary to define a framework specifying rights and obligations on data exchange and service interactions between personal and freight mobility operators.

5.4. Freight

Within the freight section, two main key drivers have been identified, 1) optimisation of the freight operation and 2) optimisation of freight infrastructures, and 10 milestones have been defined (See Figure 11 and Figure 12).

5.4.1. Optimisation of the Operation

The objective is to transform rail freight transport into the backbone of the European multimodal logistics industry, with high performance, efficiency and sustainability values.

One of the milestones identified for the operation optimisation driver is the use of the night train for freight, an increasingly used solution that allows night time freight to be used without disrupting passenger traffic during the day, but which still needs to increase its use in order to help optimise the use of rail infrastructure and reduce delivery times.

Also, real-time monitoring and tracking of freight is essential to improve the efficiency of the rail operation. By knowing the exact location of the freight at all times, it is possible to take better decisions in order to optimise transport routes and schedules.

	Models	Data	Electronics and connectivity	Energy and energy management	Applications
Night freight train (including noise abatement)	●	●		●	
Real-time monitoring and location of goods		●	●	●	●
First and last mile	●	●			
Autonomous/virtual fleet coupling (Platooning)	●	●			
Standardisation and automation of loading and unloading of goods (0 human error)	●	●	●	●	●

Figure 11. Optimisation of the operation key driver and related milestones. Source: Own elaboration.

	Models	Data	Electronics and connectivity	Energy and energy management	Applications
Integration of different types of transport in search of optimal transport (energy efficiency, cost and time).		●	●		●
Optimisation of mixed freight networks with logistics hubs	●	●	●	●	●
New European corridors, in search of a Single European Railway Area				●	
Development of the new Hyperloop transport mode for freight transport					
Increased use of high-speed (mixed) lines				●	

Figure 12. Optimisation of infrastructure key driver and related milestones. Source: Own elaboration.

Another important aspect is the first and last mile. The integration of rail with other modes of transport, such as road transport, allows the efficient connection of the origin and destination points of freight and the optimisation of the delivery process.

In this area, another milestone has been identified regarding virtual/autonomous coupling of the fleet, an emerging technology that can revolutionise rail operation by allowing trains to be coupled and uncoupled automatically, reducing waiting times and the costs associated with the operation.

Finally, standardisation and automation of the loading and unloading of freight is critical to optimising rail operations. This makes possible to reduce waiting times at loading and unloading stations and to increase the efficiency of the operation in general.

5.4.2. Optimisation of Infrastructures

The key driver for optimisation of rail infrastructure for freight transport is crucial to improve the efficiency and competitiveness of this mode of transport. To achieve this, different milestones have to be considered which have a significant impact, such as the integration of different modes of transport. This is essential to optimise freight transport. Combining the different modes of transport, such as rail, sea and land, will allow to take advantage of the benefits of each one and to reduce costs and delivery times.

Another aspect to take into account is the optimisation of mixed networks with logistics hubs. Logistics hubs are key points that allow the connection and distribution of goods to different destinations. Optimising these hubs by improving infrastructure and services will help to maximise efficiency and reduce waiting times.

The creation of a Single European Railway Area will enable more efficient freight transport. These corridors, connecting different European countries, aim to reduce transport times and improve coordination between the different rail systems. The increase in high-speed lines will also contribute to greater speed and efficiency of the rail system.

The development of new transport modes such as the hyperloop can have a major impact on rail infrastructure for freight transport. This technology promises high-speed transport through sealed tubes, which can significantly improve the efficiency of freight transport.

6. Conclusions and Future Research

The global rail industry market will continue to grow by 1.6% per annum in real terms until 2026 (Worldwide Market for Railway Industries, 2022). The market volume of the global rail industry is currently around €190 billion. Despite the fact that COVID-19 led to a disruption of supply chains and mobility restrictions, the global rail industry market is expected to grow by 4.3% (including inflation) annually until 2026, reaching EUR 236 billion (Worldwide Market for

Railway Industries, 2022).

Furthermore, industrial sectors are undergoing a paradigm shift and market uncertainty is particularly high today. After the emergence of COVID-19, war broke out in Ukraine. The world's third largest market for the railway industry, Russia, was severely punished by Western nations in the course of the invasion of Ukraine. Europe is facing high energy prices and the railway industry is particularly affected by energy dependence on steel and aluminium.

High inflation rates have an impact on infrastructure budgets, construction work has to be suspended or readjusted, and the digitisation of networks is becoming increasingly important. Indeed, digitisation serves to create additional capacities and thus contribute to the necessary modal shift.

By digitising operations, systems and infrastructure, railway operators are pursuing several important objectives, including: 1) optimising operational excellence, 2) increasing network capacity, 3) reducing costs, 4) improving passenger experience, 5) improving safety measures.

To achieve these objectives, the rail sector must accelerate the deployment of innovative technologies to achieve the transformation of the sector. The challenge is to reinforce the integration of rail into the digitised and decarbonised mobility offer in order to become a major player in the passenger and freight mobility market.

Technologies to support asset identification and tracking, as well as innovative materials, will lay the necessary foundations for smart management and maintenance. Dedicated sensor systems, tools for human interfaces, robots for automated inspection and maintenance, and legal aspects are examples of the challenges to be addressed.

When the railway system is fully digital and connected, the availability of real-time and historical data from the whole system will unlock a whole range of new possibilities. This will allow an opportunity to develop a new class of "digital twins" of assets. Digital twins will enable more effective prediction and monitoring of asset performance, and can therefore be applied to transform many different aspects of the industry. In particular, a digital representation of the real railway system will allow visualisation, simulation and prediction of the current and future state of the system.

To accelerate this change, innovation activities in the rail sector should:

- Be designed to provide a framework that enables the correct execution, in terms of R&D programmes and their subsequent implementation, of the vision, derived from the business ambitions of the railway sector.
- Be flexible enough to adapt the vision to business, scientific and technological developments.
- Ensure accessibility and transparency to all stakeholders by creating open and inclusive standards for all actors in the sector, managing stakeholders' intellectual property where necessary and ensuring security with regard to cyber security and its evolutions.

- Being adaptable to deal with interfaces with other modes of transport.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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