CEF2 RailDataFactory

Deliverable 3.2 – Business case whether open data infrastructure would be attractive for European rail

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EXECUTIVE SUMMARY

This report analyses the potential for implementing Edge Computing and an Open Data Infrastructure in the European Railway industry. The railway industry faces several challenges, including efficient data transfer, network coverage, latency, and interference. To overcome these, various emerging trends and technologies have been considered.

Among the considered trends, Edge Computing and Open Data Infrastructure emerge as potential solutions. These solutions could help improve local data extraction for train wayside technologies. Both offline data retrieval and online data storage could potentially benefit from these new technologies. Edge computing allows for data processing closer to the source, thereby reducing latency, improving reliability, and enabling real-time decision-making in AI-driven autonomous systems. An Open Data Infrastructure fosters transparency, interoperability, and collaboration, potentially driving innovation within the industry.

We explored the concept of Internet of Things (IoT) Edge Computing, which involves the processing and analysis of data generated by IoT devices at the edge of the network. This approach reduces data volume transfer, addresses network coverage issues, and enhances communication within the railway network. In the context of railways, IoT Edge Computing can be implemented onboard trains and trackside facilities, processing data from sensors, cameras, and other equipment in real-time or near-real-time.

The proposed pan-European Railway Data Factory would leverage both Edge Computing and an Open Data Infrastructure to transform the European Railway Industry. This digital platform would provide a comprehensive overview of the railway network in real-time, offering benefits like improved train control and maintenance, enhanced passenger services, and efficient resource allocation. Participation and collaboration among users and contributors is one of the underlying elements that require further investigation to fully realise the potential of these solutions.

Implementing the proposed solutions will require concerted efforts by stakeholders in the railway industry. Key steps include the development of the pan-European Railway Data Factory, the application of Edge Computing, and the establishment of an Open Data Infrastructure. Despite certain challenges such as integration with existing systems, data protection, and potential resistance to change, the benefits of the proposed solutions outweigh the potential drawbacks.

ABBREVIATIONS AND ACRONYMS

Abbreviation	Definition
AI	Artificial Intelligence
GoA4	Grade of Automation 4
HPC	High Performance Computing
IAM	Identity and Access Management
IM	Infrastructure Manager
IoT	Internet of Things
ML	Machine Learning
OEM	Original Equipment Manufacturer
RU	Railway Undertaking

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INTRODUCTION

The European railway sector is on the verge to the strongest technology leap in its history, with many railway infrastructure managers (IMs) and railway undertakings (RUs) striving toward large degrees of automation in rail operation, and mechanisms to increase the capacity and quality of rail operation.

In particular, various railway companies – both IMs and RUs – and railway suppliers are currently working toward fully automated rail operation (so-called Grade of Automation 4, GoA4), for instance in the context of the Shift2Rail [1] and Europe's Rail [2] programs, in which sophisticated lidar and radar sensors as well as cameras are used to automatically detect and respond to hazards in rail operation, such as objects on the track or passengers in stations in dangerous proximity of the track. Another important use case is high-precision train localization by detecting static infrastructure elements and locating them on a digital map, as for instance covered in the Sensors4Rail project [3]. While the rail system has various properties that render fully automated driving principally easier than, e.g., in the automotive sector (for instance, railway motion is only one-dimensional, scenarios are typically much less complex than automotive scenarios. In addition, routing of train could be an accessible and important resource. The challenge is to locate a train based on the given route.), key challenges on the way to fully automated driving in the rail sector are that hazardous situations have to be detected much earlier due to long braking distances, and it is very challenging to collect and annotate sufficient amounts of sensor data with sufficient occurrences of relevant incidences to perform the required AI training and to be able to prove that the trained AI meets the safety needs.

For this, it is expected that single railway suppliers, IMs and RUs will not be able by themselves to collect and annotate sufficient amounts of sensor data for AI training purposes – but instead, an European data platform and ecosystem is required into which railway stakeholders (suppliers, Ims, Rus, railway undertakings, safety authorities, and others) can feed, process and extract sensor data, as well as simulate artificial sensor data, and through which the stakeholders can jointly develop and assess the AI models needed for fully automated driving.

Cross-border data exchange is crucial for railway undertakings, even if nationally different requirements exist. Through an improved use of technology, for example transfer learning or self-supervision learning with existing data, these national requirements can be partially resolved and a significant acceleration can be achieved. As an example, transfer learning is a machine learning (ML) technique in which knowledge learned from one task is reused to improve performance on a related task. Among other things, cross-border data exchange enables seamless coordination of the development of fully automated driving and interoperability between different national railway networks and, in particular, ensures efficient and smooth cross-border operations. The EU Directive (EU) 2016/797 [4] on the interoperability of the rail system provides guidelines and rules to promote such data exchange and ensures a standardised and effective approach across Europe.

1.1 Aim and Scope of the CEF2 RailDataFactory Study

The CEF2 RailDataFactory study focuses exactly on aforementioned vision of a pan-European RailDataFactory for the joint development of fully automated driving. The study, being co-funded through HADEA, aims to assess the feasibility of a pan-European RailDataFactory from technical, economical, legal, regulatory and operational perspectives, and determine key aspects that are required to make a pan-European RailDataFactory a success. For a better understanding of the studys aim and scope, please see Chapter 1.1 in Deliverable 1 [5].

1.2 DELINEATION FROM AND RELATION TO OTHER WORKS

The Shift2Rail project **TAURO** [6] also looks into the development of fully automated rail operation, for instance focusing on developing

- a common database for AI training;
- a certification concept for the artificial sense when applied to safety related functions;
- track digital maps with the integration of visual landmarks and radar signatures to support enhanced positioning and autonomous operation;
- environment perception technologies (e.g., artificial vision).

The difference of the CEF2 RailDataFactory project is that this puts special emphasis on the **pan-European Railway Data Factory backbone network and data platform** (located on the infrastructure side, but used for sensor data collected through both onboard and infrastructure side sensors) required for the Data Factory, and also investigates **commercial, legal and operational aspects** that have to be addressed to ensure that the vision of the pan-European RailDataFactory can be realized.

DB Netz AG and the German Centre for Rail Traffic Research (DZSF) have released OSDaR23, the first publicly available multi-sensor data set for the rail sector [7][8]. The data set is aimed at training AI models for fully automated driving and route monitoring in the railway industry. It includes sensor data from various cameras, infrared cameras, LiDARs, radars, and other sensors, recorded in different environments and operating situations, and annotated with labels for different objects and situations. The data set will be utilized in the Data Factory of Digitale Schiene Deutschland to train AI software for environment perception, and more annotated multi-sensor data sets will be created in the future.

The Europe's Rail Innovation Pillar **FP2 R2DATO project** [9], overall focusing on the further development of automated rail operations, also has a work package dedicated to the pan-European RailDataFactory. Here, however, the main focus is on creating first implementations of individual data centers and toolchains as required for specific other activities and demonstrators in the FP2 R2DATO project, and on developing an **Open Data Set**. A strong alignment between the CEF2 RailDataFactory study and the FP2 R2DATO pan-European RailDataFactory activities is ensured through an alignment on use cases and operational scenarios, though the actual focus of the projects is then different.

EU-wide research programs are being carried out on Flagship Project 2: "Digital & Automated up to Autonomous Train Operations" and in this context the European perspective is discussed. In addition, each country and each railway infrastructure provider has its own programs, where there is usually also an exchange within the Innovation and System Pillar in the R2DATO. The participants in this study also work in these bodies and try to reflect the European picture. Within the sector initiative "Digitale Schiene Deutschland", Deutsche Bahn already started to set up some components of the data center in Germany [10].

1.3 Aim and Structure of this Deliverable

This current document is the deliverable D3.2 of the CEF 2 RailDataFactory project, exploring the technological possibilities of Edge Computing and an Open Data Infrastructure as prospective solutions to address prevalent challenges in the rail industry, including efficient data transfer, network coverage, latency, and interference. The document presents a business case for these technologies, considering their potential to revolutionise the sector and the complexities involved in their implementation.

Edge Computing and Open Data Infrastructure potentially play a pivotal role in the Rail Data Factory. This report serves as a comprehensive guide to understand these trends, their application in the railway context, the potential benefits, and the challenges to be addressed for successful implementation. The information presented herein is drawn from research and analysis, providing a resource for stakeholders in the pursuit of technological advancement and subsequent phases of the project.

The remainder of this document is structured as follows:

- In Chapter 2, the current situation, challenges and opportunities are described;
- In Chapter 3, a proposal is made how Edge Computing and an Open Data Infrastruture can help solving these challenges;
- In Chapter 4, a market analysis for Edge Computing in the rail system is outlined;
- In Chapter 5, financial & commercial aspects of the Rail Data Factory are discussed;
- In Chapter 6, conclusions are accompanied with multiple considerations for next steps toward the envisioned pan-European Rail Data Factory.

2 CURRENT SITUATION, CHALLENGES AND OPPORTUNITY STATEMENT

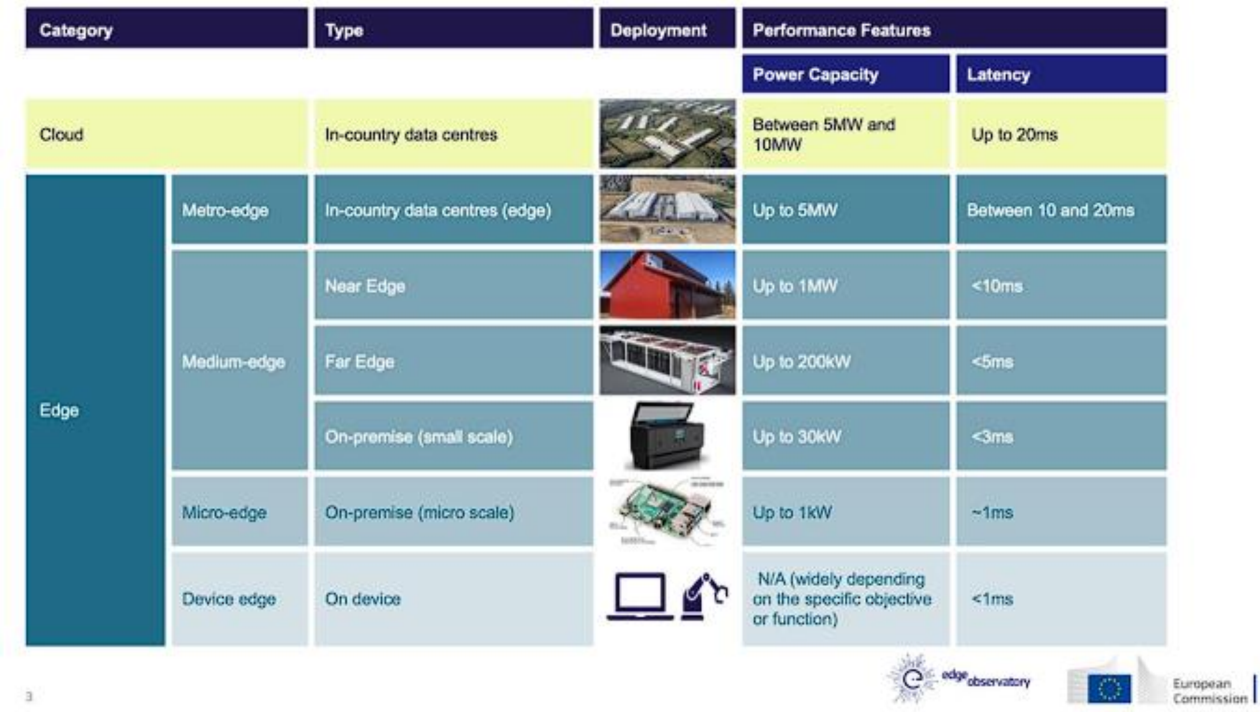
In Deliverable D3.1 [11], current challenges of transferring & mutating data in networks of rolling stock (data acquisition of the railway environment) have been described. Within the consortium, bottlenecks have been identified and these findings will be related to existing rolling stock requirements and standards in Europe. These insights will be used as basis in designing a possible train-track interaction.

The railway industry relies heavily on efficient and reliable wayside communication systems to ensure the safe and timely movement of trains across the network. However, this is challenged by several factors, including network coverage, latency, and interference [11]. To address these challenges, various trends and technologies were explored as potential solutions [12][13][14]. The next chapter will continue to deepen the exploration of (IoT) Edge Computing as a solution to most railway challenges.

The pan-European Rail Data Factory is a central component for future rail operations infrastructure and serves as an effective platform for data processing in the context of fully automated driving. In the following section, the classification of the systems, how the data is collected, pre-processed and selected within this system, and the data factory itself is placed in the context of the Edge Cloud.

The basis for the classification of Edge Cloud and Edge Computing for this study is from the project "Edge Observatory for Digital Decade, Edge Computing Nodes: Characterization, Deployment Monitoring and Trajectories - STUDY 2022/012" of the European Commission from the year 2023 [15]. Within this project, which was conducted under the DG CONNECT SMART 2019/0024 framework, an attempt was made to define a more precise classification for Edge Cloud. Figure 1 shows the resulting classification from a performance and latency point of view to create a distinction between IoT devices, Edge and Cloud. According to ISO/IEC TR 23188:2020 "Information technology - Cloud computing - Edge computing landscape" [16], the term Edge Computing is defined as follows:

“Edge computing is distributed computing in which processing, and storage takes place at or near the edge. Here, all nearness is defined by the system’s requirements.” [16]



Category		Type	Deployment	Performance Features: Power Capacity	Performance Features: Latency
Cloud		In-country data centres		Between 5MW and 10MW	Up to 20ms
Edge	Metro-edge	In-country data centres (edge)		Up to 5MW	Between 10 and 20ms
	Medium-edge	Near Edge		Up to 1MW	<10ms
		Far Edge		Up to 200kW	<5ms
		On-premise (small scale)		Up to 30kW	<3ms
	Micro-edge	On-premise (micro scale)		Up to 1kW	~1ms
	Device edge	On device		N/A (widely depending on the specific objective or function)	<1ms

Source: Consortium, 2023.

Figure 1. Classification of Edge Nodes [15].

In terms of the pan-European Rail Data Factory, the Data Touch Points are seen as crucial points for the collection, pre-processing and selection of data. These Touch Points are essential to ensure that relevant data can be collected in real time and processed efficiently.

The Edge Cloud terms used in this study are based on the above classification and an attempt has been made to fit this into the infrastructure element landscape of railway companies. Figure 2 provides a comprehensive overview of all elements needed in railway operations. However, the current data center landscape within railway infrastructure companies makes it difficult to make a clear allocation between on-premise, Edge Cloud and Cloud. This is mainly due to the fact that railway infrastructure companies, as part of the critical infrastructure, have to control all relevant environments internally. While the vehicles are under the responsibility of the railway undertakings (RUs), they represent a separate edge from the perspective of the infrastructure managers (IMs). The structure of the IMs is characterised by their hierarchical structure.

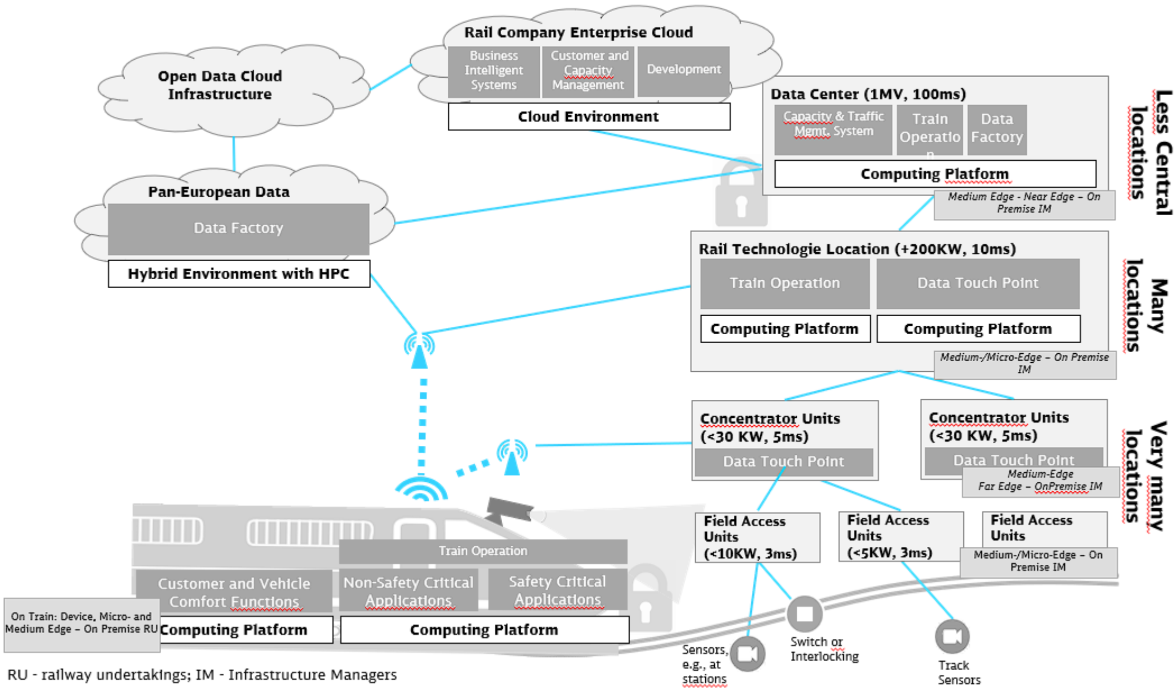


Figure 2. Mapping Edge Cloud requirements to railway infrastructure.

In summary, the pan-European Rail Data Factory offers a robust basis for data processing in the context of fully automated driving, whereby the integration with Edge Cloud technology plays a central role in order to fulfil the requirements out of Deliverable D1 [5] with the high number of vehicles and field elements. However, it remains a challenge to embed the complexity of the data infrastructure within the rail infrastructure in an efficient and thus climate-friendly way and requires basic framework conditions such as higher-level regulations and significant incentive systems.

Opportunities: Overview of considered trends and technologies to overcome challenges and limitations

Implementing advanced computational solutions in the railway industry involves processing data closer to the source of data collection, onboard trains or at trackside facilities, which reduces the need for data to be transmitted over long distances to centralised data centers capable of high performance computing (HPC). By processing large amounts of data generated in real-time, edge computing minimises latency, improves reliability, and allows decision-making in AI-driven autonomous systems. This approach can be particularly beneficial for applications that require real-time decision-making, such as autonomous train control systems, as it enhances the efficiency of data processing and overall communication within the railway network. The combination of edge computing and HPC leads to the following benefits:

- Minimises latency and improves the efficiency of data processing, enabling real-time decision-making for AI-driven autonomous train control systems;
- Reduces the need for data to be transmitted over long distances, conserving network resources;
- Requires additional processing hardware and infrastructure on trains and trackside facilities;
- May not directly address issues of network coverage and interference;
- Advanced Analytics and Machine Learning: Implementing advanced analytics and machine learning algorithms can help optimise train control, safety, and efficiency in AI-driven autonomous systems [17].

Several emerging trends and technologies were investigated in their potential to improve train automation and wayside communication. Currently, the following advancements appear promising:

- **Edge Computing:** By processing data closer to the source, edge computing can reduce latency, improve reliability, and enhance data security. It can also enable advanced analytics and machine learning, leading to insights that can improve train performance and maintenance.
- **High Performance Computing:** By using supercomputers and high-performance clusters to perform complex and computationally intensive tasks, it is achievable to perform near real-time simulations, data modeling, and other tasks that require massive computational power.
- **Open Data Infrastructure:** An Open Data Infrastructure can promote interoperability, collaboration, and innovation within the industry. It can make it easier for stakeholders to access and share data, leading to the development of new applications and solutions. Ensuring secure and managed access to this data is paramount. The Identity and Access Management (IAM) system, detailed in Deliverable D2.2 [18], serves as a foundation, verifying user identities and managing access, underpinning the trustworthiness of the entire infrastructure.

The next section of the business case will explore these solutions in more detail.

3 EDGE COMPUTING AND AN OPEN DATA INFRASTRUCTURE FOR THE RAIL DATA FACTORY

3.1 About Edge Computing and High Performance Computing

Edge computing is a term that refers to the concept of processing and analysing data closer to its source, supporting centralised data centers or Cloud resources. This routing approach helps reduce latency, improve efficiency, and minimise the need for data transmission over long distances. IoT edge computing is a specific application of edge computing in the context of IoT devices and networks. IoT edge computing focuses on processing and analyzing data generated by IoT devices, such as sensors, cameras, and other connected gadgets, close to their location.

In the railway sector, much of the data collection is done through sensors, cameras, track-side infrastructure and other onboard equipment, making IoT edge computing an attractive alternative for train-wayside communication. It reduces the volume of data transfer and its associated limitations by processing and analysing the data generated by IoT devices, such as sensors and cameras, closer to the source. Together with HPC this enables real-time or near-real-time processing, which is crucial for many IoT applications, by performing computation and data analysis at the edge of the network. As a result, only relevant or processed information is transmitted to central data centers or Cloud resources, instead of sending all the raw data. By processing the data locally, edge computing can help overcome challenges related to network coverage, latency, and interference, leading to more efficient and reliable communication within the railway network.

3.2 Edge Computing Devices

This paragraph lists the most common types of edge computing devices. It’s important to note the choice of edge computing device depends on the specific application, the amount and type of data being generated, and the computing and storage requirements. Please consider the building blocks as described in Deliverable D2.1 [18].

1. **Edge gateways**: These Touch Points are typically used to collect and preprocess data from sensors and IoT devices at the edge of the network. They can perform data aggregation, filtering, and analysis, and communicate with other devices and systems.
2. **Micro data centers**: These devices are small-scale data centers that can be deployed at the edge of the network to provide computing power and storage capabilities. They can perform data processing, analytics, and storage, and communicate with other devices and systems.
3. **Edge servers**: These devices are similar to traditional servers but are optimised for edge computing applications. They can perform data processing, analytics, and storage, and communicate with other devices and systems.
4. **Edge routers**: These devices are used to route network traffic at the edge of the network, providing connectivity between devices and systems.
5. **Edge devices with AI / ML capabilities**: These devices are equipped with AI / ML capabilities that enable them to process and analyse data in real-time. They can be used for predictive maintenance, anomaly detection, and other advanced applications.
6. **Edge accelerators**: These devices are used to accelerate specific types of data processing, such as machine learning or image recognition, at the edge of the network.

These edge computing devices are pivotal to the efficient functioning of the system. They perform real-time data processing and analysis which not only allows for immediate decision-making but also significantly reduces latency, making the system more agile and responsive. The types of edge computing devices deployed depend on the specific application and its requirements, the volume and type of data being generated, and the computing and storage demands.

Some of the most commonly used edge computing devices include edge gateways that collect and preprocess data, micro data centers that provide local computing power and storage capabilities, and edge servers that function similar to traditional servers but are optimised for edge computing applications. Additionally, edge routers ensure smooth network transmission at the edge of the network, facilitating connectivity between different devices and systems. Advanced edge devices with AI/ML capabilities are also used for complex tasks such as predictive maintenance and anomaly detection. Edge accelerators, designed to fast-track specific types of data processing, are particularly useful for applications like machine learning or image recognition.

Beyond the immediate edge computing devices, HPC centers play a crucial role, especially for data-intensive tasks and AI-enabled use cases. While edge devices can efficiently handle on-the-spot data processing, HPC centers, with their vast computational capabilities, are essential for in-depth data analysis, model training, and other tasks that demand high computational power. These centers work in tandem with edge devices, ensuring that both real-time and deep analyses are catered to optimally.

These edge computing devices are securely connected to the central Cloud-based system through a robust network connection. This allows for the generated data to be transferred for more comprehensive analysis and storage. The central database shoulders the responsibility of storing and analysing the massive volumes of data produced by the railway system. It further provides invaluable insights and recommendations based on this data, enhancing the efficiency and effectiveness of the operations. Considering the sensitive nature of the data involved, robust security measures, including firewalls, intrusion detection systems, and encryption, should be implemented at every layer of the architecture to ensure the security and integrity of the edge computing system [13].

Given the technologies described above, the following conceptual design could be made as an example of how data from the train to back-end systems - the pan-European Data Factory Backbone Network - is transferred on a high frequency basis. In short:

- Trains pass edge Touch Points where data is transferred on a high capacity rate;
- Edge components distribute data further in the edge network to end-points;
- This data could be camera/lidar/radar images, localisation data or other sensor/meta-data;
- The end-point is the Rail Data Factory, all users in the pan European network can use the data sent to enrich their models, study operational scenarios etc.

The potential use cases that can be used are extensively documented in Deliverable D1 [5].

3.3 Open Data Infrastructure

An Open Data Infrastructure can revolutionise the way data is shared and used in the railway industry. The introduction of the Rail Data Factory could open the availability of a centralised, open source of reliable data from the railway industry would open up a wide range of use cases across various aspects of the industry.

- **Improved Data Sharing and Integration:** An Open Data Infrastructure would enable various stakeholders within the European rail industry, such as railway operators, maintenance companies, regulators, and travelers, to share and integrate data more easily. This would lead to a comprehensive and holistic view of operations, performance, and trends across the entire rail network.
- **Enhanced Operational Efficiency:** By sharing real-time operational data, rail operators can optimize routes, schedules, and maintenance activities. This can lead to reduced downtime, improved on-time performance, and better utilisation of resources like trains and crews.
- **Innovative Services for Passengers:** Open data can fuel the development of innovative applications and services for rail passengers. Travelers could access real-time train information, including schedules, delays, and seat availability, through mobile apps or websites. This transparency could enhance the overall travel experience and encourage greater use of rail transportation.
- **Predictive Maintenance:** An Open Data Infrastructure could facilitate the collection and analysis of maintenance-related data from various sources. By leveraging predictive analytics, rail operators could identify potential equipment failures before they occur, reducing costly downtimes and improving safety. It could also be beneficial in planning regular maintenance activities on infrastructure such as vegetation management to ensure clearance width is free of obstructions.
- **Safety and Security Improvements:** Open data could enable the sharing of safety-related information, such as incident reports, near-miss data, and track conditions. This could help identify safety trends, improve risk assessments, and enhance overall rail network safety.
- **Interoperability and Interconnectivity:** Standardised open data formats and interfaces could promote interoperability among different rail systems and operators. This could facilitate seamless travel across borders and promote multimodal transportation integration.
- **Data-Driven Decision Making:** Access to comprehensive and accurate data would empower stakeholders to make informed decisions. Regulators could monitor industry performance and enforce standards more effectively, while rail operators could fine-tune their strategies based on data-driven insights.
- **Economic Growth and Innovation:** An Open Data Infrastructure could stimulate economic growth by encouraging the development of new services, startups, and technologies built on top of the available data. This innovation ecosystem could create jobs and foster a culture of technological advancement.
- **Transparency and Accountability:** Open data promotes transparency within the rail industry. Passengers, regulators, and other stakeholders can hold rail companies accountable for their performance, ensuring that services are delivered as promised.
- **Reduced Environmental Impact:** Optimised operations driven by data could lead to more efficient energy consumption and reduced greenhouse gas emissions. Open data could also support initiatives for modal shift, encouraging travelers to choose rail over less sustainable transportation options.
- **Promoting Interoperability:** An Open Data Infrastructure can make it easier for different systems and technologies to communicate with each other, thereby facilitating interoperability. This is crucial for the successful operation of automated trains, as they

need to interact seamlessly with other systems such as traffic management systems and digital twins.

- **Encouraging Collaboration and Innovation:** By making it easier for stakeholders to access and share data, an Open Data Infrastructure can foster collaboration and innovation within the industry. This can lead to the development of new applications and solutions that improve train performance, passenger experience, and operational efficiency.

In conclusion, the implementation of Edge Computing and an Open Data Infrastructure as proposed for the pan-European Rail Data Factory can help resolve challenges of current technology, enhance the performance and efficiency of automated train systems, and drive innovation in the sector. The next chapter will discuss the costs, potential risks, and mitigation strategies associated with this proposed solution.

4 MARKET ANALYSIS

The potential market for Edge Computing or IoT Edge Computing in the rail industry is increasing due to the growing importance of digitalisation and automation in modern transportation systems. The following is an overview of the demand, competitive landscape, risks, and opportunities associated with Edge Computing in the rail industry:

4.1 Demand for Edge Computing in the Railway Industry:

The demand for Edge Computing in the rail industry is driven by several factors, including:

- The need for real-time data processing and decision-making in various rail operations such as train control, signaling, and asset management.
- The increasing adoption of advanced technologies like IoT, AI, and Big Data analytics in the rail industry to enhance operational efficiency, safety, and asset availability.
- The push for sustainable and green transportation, which requires better monitoring and management of energy consumption and emissions.
- Interoperability, as addressed in [17], which focuses on enabling multiple consumers in the Rail Data Factory to access and retrieve data and/or models.

These factors contribute to a growing demand for Edge Computing solutions in the rail industry, which can provide lower latency, improved reliability, and increased data security.

4.2 Competitive Landscape

The competitive landscape for Edge Computing in the rail industry is characterised by the presence of both established players and few newer entrants. Key players in the market include technology giants, along with specialised rail technology providers. These companies offer various Edge Computing solutions, including hardware, software, and services, catering to the specific needs of the rail industry.

Start-ups and smaller companies are also entering the market, focusing on niche applications and innovations in Edge Computing technologies. This competitive landscape fosters innovation and drives the adoption of cutting-edge solutions in the rail industry.

- One provider offers Edge Computing solutions for the rail industry, including a platform that automates the deployment and management of AI, analytics, and IoT workloads on edge devices. They also offer a platform specifically designed for railway applications, enabling data analytics and real-time insights.

- Another company provides a fully managed service delivering Cloud intelligence locally on edge devices. Their solution is deployable in the rail industry for real-time analytics, AI, and other applications.
- A different provider offers a range of services to assist organisations in managing their IoT devices and edge data. Their offerings are applicable in the rail industry for various purposes such as predictive maintenance, real-time analytics, and AI-based decision-making.
- One specialised rail technology provider focuses on Edge Computing solutions for the rail industry, emphasising data analytics and real-time decision-making. Their suite of solutions includes a Cloud-based platform that leverages Edge Computing for applications like predictive maintenance and asset management.
- Another company offers a range of digital solutions for the rail industry, featuring a platform that utilises Edge Computing for real-time data processing and analytics. Their platform enables applications such as predictive maintenance and advanced diagnostics for rail infrastructure and rolling stock.
- A provider's Edge Computing capabilities support IoT applications across multiple industries, including the rail sector. These capabilities allow real-time data processing, AI-driven analytics, and other applications for railway operations.
- Additionally, there is a German start-up that specialises in AI-powered IoT sensors and analytics solutions for railway operations. Their Edge Computing platform enables real-time processing of data from sensors on trains, tracks, and other railway assets, providing insights into maintenance needs, energy efficiency, and other operational metrics.

These companies represent a mix of technology giants and specialised rail technology providers, offering a variety of Edge Computing solutions to possibly cater to the specific needs of the rail industry. As the market grows, it is expected that more startups and innovative businesses will enter the space, making the competition more diverse.

4.3 Risks associated with Edge Computing

The (IoT) Edge Computing market presents certain risks, such as:

- **Regulatory and standardisation challenges:** The rail industry is highly regulated, and implementing Edge Computing solutions may require compliance with various regional and international standards.
  This can be addressed by assessing and staying up-to-date with relevant regulations and compliance requirements, and implementing solutions that comply with these regulations.
- **Interoperability challenges:** The Edge Computing market is characterised by a variety of hardware and software solutions, making interoperability between different devices and systems a possible challenge. This requires standardisation efforts and increased collaboration among industry players.
  By investing in standardisation efforts, such as the adoption of common communication protocols and data formats, the rail industry can address interoperability challenges. This requires collaboration and participation among industry players.

- **Security and privacy risks:** As Edge Computing involves processing sensitive data at the edge of the network, there is a risk of data breaches, cyber attacks, and other security threats. Ensuring data security and privacy is crucial and may require significant investments in security infrastructure and protocols.
  These security and privacy risks can be mitigated by investing in robust security infrastructure and protocols, such as encryption, access controls, and monitoring tools. This requires collaboration with security experts and vendors to ensure best practices are implemented.
- **Initial investment:** Implementing Edge Computing solutions may require substantial upfront investments in hardware, software, and network infrastructure. The cost of Edge Computing varies wildly depending on scale, data, location, expertise and the evolving nature of edge technology. Hence, it is difficult to make a realistic cost estimate.

The (IoT) Edge Computing market presents certain risks. These risks may require significant investments in security infrastructure, standardisation efforts, and compliance efforts to mitigate. However, the potential benefits of Edge Computing, such as enhanced efficiency, new revenue streams, and sustainability goals, make it a promising solution to current railway challenges.

5 FINANCIAL & COMMERCIAL ANALYSIS OF THE RAIL DATA FACTORY

This chapter evaluates the financial and commercial implications of the proposed pan-European Rail Data Factory and the application of Edge Computing infrastructure to feed the open European infrastructure. The long-term benefits are explored, taking into consideration the diverse technological and infrastructural landscapes across European railway systems.

5.1 (Long-term) Benefits

The pan-European Rail Data Factory should enable stakeholders to jointly share and contribute data, but also develop, train, and evaluate AI functionalities, which can lead to cost savings, increased operational efficiency, and improved safety. By pooling resources and expertise, stakeholders can create more value together than they could individually. These values could include, but are not limited to:

- **Data monetisation:** The pan-European Data Factory creates opportunities for data sharing and monetisation. Stakeholders can potentially generate revenue by providing access to their data, tools, and services, or by participating in the development and sale of AI models and related applications.
- **Market expansion:** The pan-European Data Factory can facilitate market expansion by promoting collaboration and interoperability among stakeholders. The unified platform can create new market opportunities by lowering barriers to entry and fostering innovation in rail automation technologies.
- **Investment and funding:** Implementing the pan-European Data Factory will require significant investments in infrastructure, technology, and resources. Identifying funding sources, such as public-private partnerships or European funding programs, and demonstrating the commercial viability of the project, will be essential to attract investment.
- **Partnerships and collaborations:** The success of the pan-European Data Factory depends on the collaboration of multiple contributors, which could include IMs, RUs, suppliers, and regulatory authorities. Establishing strong partnerships and fostering cooperation among stakeholders and contributors will be crucial to its commercial success.
- **Competition and differentiation:** As the European railway sector becomes more automated, competition among technology providers and service operators may intensify. The pan-European Data Factory can help stakeholders differentiate themselves by enabling them to jointly develop and deploy innovative AI solutions for rail automation.
- **Legal and regulatory compliance:** The commercial success of the pan-European Data Factory depends on navigating legal and regulatory requirements such as data privacy, cybersecurity, and cross-border data transfers. Ensuring compliance will help build trust among stakeholders and mitigate potential risks. A particular challenge is obviously that the Data Factory as an international infrastructure and ecosystem has to fulfill the superset of different laws and regulations as required in the involved countries. Legal and regulatory considerations will be evaluated at a later stage in this study.
- **Opening up the market:** The vendor market for the railway industry is relatively small, with a limited number of players and a limited number of products being sold. For example, only a few major original equipment manufacturers (OEMs) dominate the market, selling a limited number of rolling stock units with a lifecycle of up to 30 years. This creates a challenge for the industry when it comes to developing cutting-edge technologies, such as

autonomous driving systems, due to the high development costs and the relatively small market size.

The Rail Data Factory aims to address this challenge by opening up the vendor market and creating more competition. By collaboration and shared data and solutions and services, the Rail Data Factory can reduce the costs and barriers to entry for new players, including start-ups and smaller vendors. This can encourage more innovation and development in the industry and ultimately lead to more advanced and efficient technologies being adopted.

5.2 Economic/commercial Incentive Model & Value Creation for the Rail Data Factory

To encourage participation and collaboration among stakeholders (such as various RUs, IMs and suppliers) an economic incentive model can be used. To attract stakeholders, encourage collaboration and data-sharing, and ensure long-term sustainability of the pan-European data-factory, several components can be considered to incentivise participation:

- **Collaboration on research and development:** Encourage stakeholders to jointly participate in research and development projects, allowing them to pool resources, share costs, and benefit from the platform.
- **Tiered membership or subscription models:** Create different membership tiers or subscription levels, offering varying access to data, resources, and services. This provides options for stakeholders with different financial capabilities and needs while generating revenue to support the Data Factory.
- **Revenue-sharing agreements:** Establish agreements to share revenue generated from the Data Factory's services, tools, or AI models among stakeholders, proportionate to their contributions.
- **Performance-based incentives:** Offer financial incentives or discounts to stakeholders based on their contributions to the Data Factory, such as data sharing, innovation, or achieving specific performance metrics.
- **Cost-sharing agreements:** Develop agreements that allow stakeholders to share costs associated with infrastructure development, AI training, data storage, and other investments. This makes participation in the Data Factory more financially viable for all parties involved.
- **Public funding and grants:** Securing public funding or grants from government agencies or international organisations supports the development and operation of the Data Factory. This will reduce financial burdens on stakeholders and encourages participation.
- **Intellectual property rights:** Consider developing a clear intellectual property framework that defines ownership and licensing arrangements for shared data, AI models, and other innovations resulting from the Data Factory. This ensures that stakeholders feel secure in contributing their resources and know they will benefit from their investments.

Overall, the goal of the incentive model should be to create a collaborative environment where stakeholders can create more value together than they can individually. It is essential to keep in mind that the pan-European Data Factory should enable stakeholders to jointly share and contribute data, while also developing, training, and evaluating AI functionalities. This can lead to cost savings, increased operational efficiency, and improved safety. To promote the adoption of the incentive model, a phased approach can be implemented. In an initial phase, the focus should be on collaboration and research and development. As stakeholders become more comfortable with collaboration and data-sharing, other components of the incentive model, such as performance-based incentives, can be introduced.

Ultimately, the fair share of costs will depend on the goals and priorities of the various stakeholders involved, as well as the funding and resource constraints they face. Finding a fair and sustainable way to divide costs will be crucial to the success of the Rail Data Factory, as it will ensure that all stakeholders feel invested in and committed to its ongoing development and success.

6 CONCLUSIONS AND RECOMMENDATIONS

In conclusion, implementing a standard, collaborative and scalable pan-European Rail Data Factory, powered by Edge Computing and an Open Data Infrastructure, has the potential to revolutionise data processing and sharing across the European Railway Industry. It can enhance efficiency, safety, and performance, paving the way for a more integrated rail network. However, various factors need to be considered.

Standardisation: A crucial aspect of implementing a pan-European Railway-backbone network is establishing standard protocols for data messaging, Open Data Infrastructure, and device integration. Standardisation would enable seamless interoperability between different types of rolling stock, data links, and wayside communication systems, paving the way for a more efficient and integrated European rail network.

Collaboration: Collaboration between various stakeholders, such as rail operators, infrastructure managers, technology providers, and regulatory authorities, is essential for the successful implementation of a pan-European Railway-backbone network. By pooling resources, expertise, and insights, stakeholders can drive innovation, reduce costs, and accelerate the adoption of new technologies.

Scalability and Flexibility: The pan-European Railway Backbone Network must be designed with scalability and flexibility in mind to accommodate future growth and advancements in technology. This includes considering innovative solutions such as Edge Computing and machine-to-machine communication to support real-time data processing, machine learning, and analytics without latency issues.

Regulatory Compliance: Operators must ensure that their proposed solutions comply with relevant regulations and standards, such as Eurospec [20], while also anticipating potential future regulations related to data management, privacy, and security.

Funding and Financing: Securing adequate funding and financing for the implementation of a pan-European Railway Backbone Network is crucial. Operators can explore various funding options, such as public-private partnerships, government grants, and European Union funding programs.

Ultimately, the business case will weigh the benefits of implementing Edge Computing and an Open Data Infrastructure against the costs and risks involved. It is evident that there is a promising business case for Edge Computing and an Open Data Infrastructure in the European Railway Industry. Nonetheless, further research is needed to:

- determine if the advantages of using Edge Computing and an Open Data System are greater than the costs and potential risks involved,
- and to better understand the complete range of potentials and intricacies these technologies offer.

A significant component of this further research must focus on elucidating ways to stimulate participation and collaboration among users and contributors. Finding and encouraging these synergies is a crucial part of creating a collaborative pan-European Rail Data Factory. Therefore, a commitment to continuous exploration and cooperation among all stakeholders is essential for the successful advancement of this initiative.

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