Inter-railways data sharing for seamless travelling applications in Europe.*

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Abstract

Cross-border railway travel in Europe continues to face significant challenges due to fragmented digital ecosystems, incompatible data standards, and regulatory inconsistencies, despite progress in national railway markets. This study set out to investigate how data interoperability and emerging data-sharing ecosystems—particularly European Rail Data Spaces—can address these persistent barriers. Through stakeholder focus groups with national operators (ÖBB, SBB, DB), expert interviews, and a comparative analysis of existing data models such as Transmodel, GTFS, and NeTEx, the research identified key organizational and technical bottlenecks. The findings demonstrate that while standardized data formats have the potential to enhance interoperability, their fragmented adoption and lack of harmonized implementation across countries limit their effectiveness. To address these issues, the study proposes a theoretical framework for seamless cross-border rail integration, emphasizing the critical role of trusted, interoperable data environments in supporting a unified European railway network.

Keywords

Cross-Border Railway, European Railway Data Standards, Data Space, Digital Interoperability, Transmodel

Introduction and Objectives

The integration of cross-border railway services in Europe remains a challenge due to fragmented digital ecosystems, regulatory inconsistencies, and a lack of standardized data-sharing frameworks. While national railway markets have advanced through competition and digital innovation, international rail travel continues to face barriers such as incompatible ticketing systems, infrastructure discrepancies, and operational inefficiencies. This study explores the role of data interoperability and the role of Data Spaces in addressing these challenges. Using a multi-step methodology that includes stakeholder focus groups, iterative validation, and comparative data model analysis, the research evaluates current limitations and proposes a theoretical framework for seamless international rail travel.

The findings highlight that standardised data formats (Industry and European Union based), provide significant potential for enhancing interoperability. However, their adoption remains fragmented across different countries and stakeholders. The study emphasises the need for harmonized EU-wide implementation of data-sharing initiatives to foster a competitive and integrated European railway network. Future research will further explore data space solutions as a key enabler of efficient cross-border railway operations.

The liberalization of railway markets has progressed more substantially at the national level than on an international scale. Countries like Italy and Spain have successfully reduced high-speed train fares and reduced air travel on major routes [1, 2, 3]. Similarly, France and Germany have introduced private

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operators in regional train services offering benefits through market competition across tenders [4]. However, achieving similar advancements across borders remains a significant challenge.

To achieve its climate goals, the European Union aims to reduce transport emissions by shifting the modal share away from air and road transport [5]. This shift increases demands on national and private railway systems to offer valuable services, making rail travel an essential part of the EU's Green Deal strategy for sustainable and integrated mobility. While this transition aims to foster competition, reduce costs, and improve passenger services, it has created a complex digital ecosystem where multiple operators must collaborate to meet different passenger expectations.

Therefore, cross-country services operated by both private and public railway companies have become more frequent, but organisational and operational challenges are still present. For instance, in 2024 railway delay data from Austria reveals that cross-border passenger trains have significantly less punctuality compared to domestic services.

International rail travel also faces infrastructure and digital bottlenecks that reduce its appeal [6]. Passengers often struggle with unreliable or incomplete information, making it harder to trust rail as a viable transport option than compared to alternatives, resulting in complicated travel costs, time, and comfort decisions. Addressing these issues requires better interoperability between systems and improved communication. This challenge is analogous to the issue of data silos in the digital world. A data silo refers to a situation where data is isolated within a specific department, system, or organisation, making it inaccessible or difficult to share with other systems or teams [7, 8, 9].

These silos limit the ability of organizations to derive insights from integrated data, resulting in inefficiencies, redundancies, and missed opportunities (Patel, 2019). Similarly, in cross-border rail travel, fragmented digital systems and organizational silos create significant barriers to efficient operations, passenger experience, and service integration.

Digital twin technologies have emerged as a potential solution for addressing internal silos within railway organizations [10]. By integrating data across different sections, these technologies enable a holistic representation of operational information, improving decision-making and system-wide optimization. Digital twins facilitate the integration of various vertical aspects of railway organizations, such as infrastructure systems and traffic services.

Despite these advancements, cross-border rail travel remains fragmented due to the necessity of connecting multiple railway organizations. This fragmentation results in several challenges, including the absence of unified ticketing systems, differences in infrastructure standards, discrepancies in timetabling, and the use of incompatible digital platforms for scheduling and booking. As a consequence, other modes of transportation often appear more convenient and reliable to consumers, further reducing the competitiveness of rail transport for international journeys.

This fragmentation can be analysed through an analogous system model, such as the "Four-Layers Rail International Travelling" framework [11, 6]. This model outlines four core components of international rail travel:

- Infrastructure Layer
- Traffic Services Layer
- Transport Services Layer
- Mobility Platforms Layer

A key limitation of this model is that each country's four-layer system must not only function independently but also interconnect with the equivalent layers in other countries. This horizontal complexity significantly increases the difficulty of system-wide communication, requiring seamless data exchange and interoperability across borders. Likewise, in computer networking, the TCP/IP protocol model [12] demonstrates how different layers—application, transport, internet, and network access—work together to facilitate data exchange. Both models underscore the critical role of standardization and seamless integration in enabling efficient communication across systems.

The European Union has actively promoted the adoption of standardised data specifications and models, such as Transmodel, to harmonize data exchange in passenger public transport services [13].

While these efforts have led to improvements, the landscape remains fragmented due to the presence of industry-specific schemas, proprietary data-sharing mechanisms, and a lack of universal adoption of standards.

A proposed solution is the development of a European Rail Data Space. This initiative envisions an interoperable and secure data ecosystem for the rail industry, similar to Mobility Data Spaces. It enables trusted data exchanges among key stakeholders, such as system suppliers, train manufacturers, operators, and service providers [14]. The realization of such a system presents significant technological, organizational, and policy challenges, but many aspects of this vision remain unexplored.

This highlights the need to identify the specific challenges facing the railway sector and to evaluate how digital and data-driven solutions can address these barriers. This research aims to investigate why cross-border railway travel remains limited and to identify the role of European and industry standards for public transport data exchange in addressing these challenges. The study proposes a theoretical framework for enabling seamless cross-border passenger travel. It highlights key barriers to interoperability, including technological fragmentation, organisational silos, and policy inconsistencies, while exploring the role of standards and data-sharing ecosystems in passenger cross-border railway services.

Methods

This research incorporates views of three national railway operators representing the DACH area and from European transport data model experts. We investigate the organisational and operational barriers in the data domain of European international railway travel, focusing on data integration and interoperability issues. The methodology employs a multi-step approach:

- **Stakeholder Focus Group:** A focus group was conducted to gather diverse perspectives on the challenges and opportunities in cross-border rail data integration. Participants included:
  - Digital railway experts from DACH (ÖBB – Austria, SBB – Switzerland and DB – Germany).
  - External company that utilizes railway data for innovative solutions (XSatellite).
  - European specialists in Transmodel integration TT&J and 5t.
- **Iterative Validation Process:** The railway sector is highly complex, with expertise distributed across multiple specialized areas. To address gaps or unclear aspects during the focus group, a preliminary analysis was conducted using an "educated guess" approach to formulate initial insights. These insights were then validated through a second round of interviews with experts, ensuring the reliability and accuracy of the collected data.
- **Comparative Analysis:** A detailed comparative analysis was conducted to evaluate existing industry-based data models alongside Transmodel standards.
- **Literature Review on Data Spaces:** This step categorizes key findings and explores potential solutions to the challenges identified in the first two steps. This analysis aims to assess whether these barriers to cross-border rail travel can be effectively addressed through the adoption of Data Space technologies.

Main Findings

The preliminary findings highlight key challenges and opportunities in cross-border railway integration, emphasizing the need for collaboration on operational barriers, organizational complexities, and regulatory fragmentation. Specific issues include inefficient border infrastructure, staffing shortages, complex regulatory frameworks across European states. These challenges lead to delays, tariff inconsistencies, ticketing issues, and disruptions in international rail travel.

Data formats and interoperability standards such as GTFS and NeTEx serve distinct functions, yet varying levels of adoption create further fragmentation. Additionally, the growing role of APIs has

become increasingly valuable. However, a lack of harmonized implementation limits their full potential in enabling seamless railway data exchange.

A key outcome of the comparative analysis is the limited implementation of Transmodel, a widely recognized transport data-sharing framework. While Transmodel reflects a national-level vision for data standardization, many operators opt for proprietary models tailored to their internal operations. This preference can limit cross-border data exchange due to incompatibility in crucial travel phases, including trip preparation, booking and ticketing, access to the station, boarding, ticket validation, and live travel updates.

Current EU directives for railway data integration are implemented inconsistently across countries, with some regulations being misinterpreted or applied to only one mode of transport (e.g., National Access Points prioritizing road networks data sharing over rail). While many technical challenges in cross-border rail are solvable, institutional barriers are present. The success of seamless international rail travel will depend not only on technological solutions but also on stronger organisational commitments and regulatory alignment among countries.

The final stage of this research will present a comprehensive table that compares different technical solutions (including data spaces) based on their capability to integrate examples of data space solutions addressing the challenges identified in this study. This table will form the theoretical framework for cross-border rail travel in Europe, offering a structured approach to data harmonization and interoperability.

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Declaration on Generative AI

During the preparation of this work, the author(s) used also GPT-4 in order to: Grammar and spelling check, and bug corrections. After using these tool(s)/service(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication’s content.

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