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ANALYSIS OF IN FORMATION SYSTEMS AND DATA STRUCTURE IN RAILWAY TRANSPORT IN SLOVAKIA

Abstract. This paper presents an analysis of information system and data structures used by the railway infrastructure manager in the Slovak Republic, focusing on system architecture, functional integration and data flows. The study examines the transformation of the national information environment from a fragmented system landscape into an integrated platform built around the Complex Interoperable System (KIS), which integrates timetable construction through the MK module, real-time traffic management and interoperability interfaces. The research is based on qualitative analysis of technical documentation, professional literature and regulatory frameworks, including Technical Specifications for Interoperability (TSI). The results indicate that although functional consolidation has significantly improved system consistency and operational transparency, partial fragmentation of data structures and incomplete integration of legacy applications remain major limitations. The study highlights the importance of unified data models, systematic data governance and deeper system integration as necessary conditions for further modernisation. Emphasis is placed on the alignment of national information systems with European interoperability requirements, particularly TSI TAF and TSI TAP. The findings contribute to a better understanding of the role of digital platforms in infrastructure management and provide recommendations for improving reliability, efficiency and data consistency in railway information systems.
Keywords: Information systems, Railway infrastructure manager, Interoperability, Data structures

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Introduction

The continuous digitalisation of railway transport has fundamentally transformed the way infrastructure is managed, traffic is controlled and data are processed. Information systems have evolved form basic operational support tool into integrated platform that enable timetable planning, operational control, reporting and international data exchange. In modern railway systems, digital infrastructure has become as important as physical infrastructure. (Gašparík, Čamaj, 2010; Čamaj, 2020)
The role of the railway infrastructure manager is central within this transformation. While railway undertakings primarily focus on transport execution, the infrastructure manager is responsible for capacity planning, access allocation, traffic management and maintenance coordination. These activities require advanced information systems capable of processing large volumes of infrastructure, timetable and operational data in both planning and real-time operational environments. (Mestický, Krásenský, 2010; Pepevnik, Belšak, 2011)
In the Slovak Republic, the information system environment of the infrastructure manager has undergone significant development in recent years. The consolidation of multiple legacy systems into a unified platform reflects a broader European trend towards integrated platform, that combines operational control, timetable construction and external data exchange within a single environment. (Šulko, 2024)

The increasing relevance of European interoperability requirements further highlights the need for harmonised data structures and standardized interfaces. The implementation of Technical Specifications for Interoperability, in particular in the area of telematics applications, imposed new obligations on infrastructure managers regarding information systems and data governance. Consequently, national systems must not only support domestic operational processes but also ensure compatibility with European platforms. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

This paper focuses on the analysis of informational systems and data structures used by the railway infrastructure manager in Slovakia, with particular emphasis on system architecture, functional integration and data flows. The objective is to evaluate the current level of digital integration, identify key strengths and weaknesses of the existing environment, and assess the readiness of the system architecture for future development and European interoperability. (Mestický, Krásenský, 2010; Čamaj, 2018; Čamaj, 2020)

1. Literature Review

The role of information systems (IS) in railway transport has significantly evolved from basic operational recording tools to complex, integrated platforms that support infrastructure planning, traffic management, decision-making, and real-time operation. Modern railway systems increasingly rely on digital environments capable of managing large volumes of static and dynamic data related to infrastructure, rolling stock, and train movements, ensuring safe and effective operation across the network.

1.1. Information Systems in railway transport – conceptual background

Gašparík and Čamaj (2010) provide one of the most comprehensive early systematic descriptions of information and communication technologies applied in railway transport. Their work outlines the fundamental classification of railway information systems into operational, planning, operational control, and diagnostic systems. The authors emphasize that the efficiency of railway operation strongly depends on the quality and interoperability of these systems, especially in terms of real-time data acquisition and centralised data processing. Their conceptual framework forms a basis for understanding how infrastructure-related information systems support both strategic and operational decision-making.

A similar conceptual perspective is presented by Pepevnik and Belšak (2011), who focus on the role of information systems within railway traffic management. Their work highlights the importance of timely and reliable data flow between dispatching centres, signalling systems, and infrastructure databases. The authors underline the necessity of integrating multiple data sources into a unified interface, stressing that the infrastructure manager depends heavily on system interoperability and data integrity to ensure continuous traffic control under both normal and degraded operational conditions.

1.2. Information Systems for Infrastructure Managers

While general ICT frameworks are widely discussed in literature, fewer studies directly address the perspective of the infrastructure manager as the system owner and operator of railway traffic control platforms. Mestický and Krásenský (2010) explicitly analyse information systems as an indispensable tool of infrastructure management, providing an infrastructure-oriented perspective on digital dispatching and train control systems. They describe the functional architecture of traffic management systems, including timetable processing, real-time monitoring, performance analysis and system integration. The authors conclude that a fragmented system environment without integrated data interfaces significantly increases operational risks and reduces system reliability.

Čamaj (2018) extends this view by focusing on the application of information systems to enhance the operational and organisational efficiency of railway transport. Although primarily oriented towards freight transport, the study emphasises the role of the infrastructure manager as a coordinator of complex data flows between multiple actors involved in railway operation. The research demonstrates how integrated information systems contribute to improved planning quality, reduced operational uncertainty, and enhanced transparency of transport processes, all of which are equally relevant within infrastructure management environments.

1.3. Information systems for timetable planning

One of the core responsibilities of the infrastructure manager is the development of the railway timetable. Gašparík, Čamaj and Zitrický (2011) provide a detailed description of traffic planning methodologies and related information systems applied in educational and operational contexts. Their work presents modelling procedures for the construction of the train schedules, including conflict detection and network optimisation, establishing the methodological foundation for timetable compilation aided by digital tools.

The specific software environment used in the Slovak Republic is described by Šulko (2010), who examines the software applications deployed by the Slovak infrastructure manager for timetable compilation. The study highlights the importance of the ZONA CP-VT system as the central platform for graphic timetable construction, data verification, and consistency control. Šulko emphasises that timetable quality directly depends on the accuracy of infrastructure data and the performance of timetable processing software.

A contemporary view is provided by Šulko (2024), who analyses practical process of timetable compilation and highlights the gap between system interfaces and underlying data complexity. The author discusses hidden analytical processes involved in path construction, conflict resolution, and infrastructure capacity consideration, pointing out that timetable outputs are the result of multi-layered data processing supported by various interconnected information systems.

1.4. System integration and data architecture

The integration of individual information systems into a coherent architecture is a dominant issue addressed across the literature. The complexity of railway data environments is further illustrated by Čamaj (2020), who investigate the optimisation of information system architectures within a railway enterprise. Although focused on railway undertakings, the underlying observation concerning data integration, system performance and digital transformation apply equally to infrastructure managers. The study demonstrates that optimization of IT systems is not limited to technological upgrades but requires strategic alignment of business processes with IT architectures.

The concept of multi-system integration and data harmonization is consistently present across all reviewed sources. They collectively indicate that the effectiveness of railway information systems is determined less by individual software solutions and more by their ability to operate as part of a unified data ecosystem.

1.5. Technical Specifications for Interoperability (TSI)

An important group of reference documents that significantly influence the architecture and operation of information systems of railway infrastructure managers in the European Union are the Technical Specifications for Interoperability (TSI). Their primary objective is to ensure technical, operational and data interoperability between national railway systems, contributing to the creation of the Single European Railway Area. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

From the perspective of information systems, the most relevant specifications are TSI TAF (Telematic Applications for Freight) and TSI TAP (Telematics Applications for Passengers). These specifications define standardized data formats, message structures and communication procedures for information exchange between railway undertakings, infrastructure managers and other actors involved in railway operations.

According to TSI TAF, infrastructure managers are required to provide relevant operational and infrastructure related data through interoperable information systems. This includes information on infrastructure characteristics, train paths, planned and unplanned restrictions, operational train positions and network capacity. These requirements impose strong pressure on national information systems to be standardized and integrated with European-level data exchange platforms. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

Similarly, TSI TAP regulates the provision of timetable data and information necessary for passenger information services. From the perspective of the infrastructure manager, TSI TAP represents the interface through which timetable data and infrastructure constrains are shared with railway undertakings and third-party service providers. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

The importance of TSI in the domain of information systems lies not only in data standardization but also in the transformation of national information platforms into open, interoperable systems aligned with European regulations. Consequently, information systems of infrastructure managers evolve from isolated national databases into components of a European-wide railway information ecosystem. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

2. Methodology

The study is conducted as qualitative analytical research focused on describing and evaluating information systems used by the railway infrastructure manager in Slovakia. The research design is descriptive-analytical, aiming to analyse system architecture, functions and data structures rather than to perform quantitative performance assessment. The analysed systems include PIS/KIS, ZONA CP-VT, APMDK and VDS as the core components of the infrastructure manager's information environment. (Čamaj, 2020; Mestický, Krásenský, 2010)

2.1. Research methods

Document analysis – Internal and public documentation related to infrastructure information systems was analysed.
Content analysis – Scientific literature addressing IS architecture, railway data models and EU interoperability standards was reviewed.
System analysis – Systems were analysed as interconnected components in a information ecosystem.
Comparative analysis – The Slovak system environment was benchmarked against international research findings.

Data Sources

Data were obtained from professional literature, internal methodological materials, public documentation of the infrastructure manager and European interoperability regulations.

Research procedure and limitations

The research was conducted through a systematic process of literature review, system identification, functional and architectural analysis, benchmarking with international sources, and synthesis of results.

The study is limited by restricted access to internal system documentation and the absence of primary operational data.

3. Results

The information environment of the railway infrastructure manager in Slovakia consists of several interconnected systems that jointly cover timetable planning, operational traffic control, reporting and data exchange with railway undertakings. These systems form a hierarchical architecture in which individual applications serve specialised functions while sharing common data sources. (Šulko, 2024; Mestický, Krásenský, 2010)

At the core of this environment is a group of operational systems responsible for real-time traffic management and operational documentation. These are complemented by planning-oriented systems that focus on timetable construction and capacity planning, as well as by communication platforms that provide data exchange interfaces with external stakeholders. The interconnection of these systems enables continuous data flow timetable planning through operational execution to performance evaluation. (Šulko, 2024; Mestický, Krásenský, 2010)

3.1. Information Systems Used by the Infrastructure Manager in Slovakia

Timetable planning system – ZONA CP-VT

The ZONA CP-VT system represents the fundamental application used by the infrastructure manager for timetable construction and graphical timetable processing. The system enables timetable designers to create and modify train paths based on detailed infrastructure data and operational constraints. (Čamaj, 2018; Šulko, 2024)

ZONA CP-VT operates on a structured infrastructure database containing track parameters, station layouts and operating restrictions. It allows conflict detection between train paths and supports timetable stability analysis. Furthermore, timetable outputs generated in ZONA CP-VT are exported to other information systems used for operational control and passenger information services, making it a key supplier of structured timetable data. (Čamaj, 2018; Šulko, 2024)

The original ZONA CP-VT system had been replaced by the MK (Capacity management) integrated within the KIS platform. The MK module currently represents the central tool for timetable development and graphic timetable construction in the Slovak railway infrastructure environment. (Šulko, 2024)

The MK module operates on an integrated infrastructure database and enables creation, modification and validation of train paths directly within the KIS environment. In contrast to the former standalone architecture, timetable processing is now embedded in a unified platform that ensures consistency between planning data and operational systems. The transition eliminated data duplication between independent systems and improved synchronization between planning and execution layers. (Šulko, 2024)

Timetable outputs generated by the MK module are directly published within KIS and made available for operational management and data exchange with external stakeholders, ensuring continuity across the lifecycle from planning to execution. (Šulko, 2024)

Operational information systems – PIS and KIS

The operational Information System (PIS) is central platform for monitoring and recording operational train movement data in real time. PIS collects information from traffic control centres, dispatching systems and station reporting modules, and stores data related to train positions, delays, cancelations and infrastructure restrictions. (Mestický, Krásenský, 2010; Šulko, 2024)

The Complex Interoperable System (KIS) represents the current core operational system of the infrastructure manager, replacing the former PIS platform. KIS consolidates functionality previously distributed across multiple applications and provides a unified information environment for operational control, reporting and external communication. KIS collects, processes and distributes real-time operational data including train movements, delays, infrastructure restrictions and timetable updates. Unlike the former architecture, where PIS constituted a separate operational layer, KIS integrates operational control, planning data and interoperability interfaces within a single platform. Its main objective is to provide uniform access to operational data for both internal users and railway undertakings. KIS also represents a technical interface enabling the implementation of European interoperability requirements defined by TSI TAF and TSI TAP. Through KIS, selected data sets are exported in standardized formats to external systems and international platforms. (Čamaj, 2018; Mestický, Krásenský, 2010; Šulko, 2024)

Auxiliary operational systems – APMDK

The APMDK system functions as an electronic operational logbook within the infrastructure management environment. It contains structured records of operational events, traffic measures, restrictions and dispatcher decisions. (Čamaj, 2018; Šulko, 2024)

Data recorded in APMDK are subsequently transferred to higher-level information systems used for reporting, performance analysis and incident investigations. Although APMDK does not directly control train movements, it plays a crucial role in maintaining traceability of operational processes and serves as an essential data source for post-operational evaluations. (Čamaj, 2018; Šulko, 2024)

Interaction with railway undertaking systems – VDS

Although VDS primarily belongs to the railway undertaking information environment, it maintains active interfaces with the infrastructure manager's systems. Data exchange between KIS and VDS ensures synchronisation of operational information, particularly in relation to train status, delays and vehicle circulation. (Čamaj, 2018; Čamaj, 2020)

From the perspective of the infrastructure manager, VDS serves as an external system that receives validated operational data and, in selected cases, returns operational feedback related to rolling stock utilisation. This bidirectional exchange highlights the importance of harmonised data models and communication protocols. (Čamaj, 2018; Čamaj, 2020)

3.2. Structure of Infrastructure Data

Infrastructure-related data form the core database of information systems operated by the infrastructure manager. These data include the physical characteristic of the railway network such as track sections, stations, signalling devices, traction systems, operational restrictions and capacity parameters. (Gašparík, Čamaj, 2010)

The infrastructure database is structured hierarchically, beginning with network elements (lines, stations) and extending to detailed infrastructure objects (switches, platforms, block sections). Each element is characterised by technical, geographical and operational attributes, which are essential for path construction, timetable configuration and real-time traffic control. (Gašparík, Čamaj, 2010)

Consistency and accuracy of infrastructure data are critical, as errors at the database level directly affect timetable feasibility and dispatching decisions. The analysis confirms that infrastructure data represents the fundamental reference framework for all planning and operational processes. (Gašparík, Čamaj, 2010)

3.3. Train Data Structures

Operational train data consists of both static and dynamic attributes. Static data include train identifiers, planned routes, traction characteristics and operational category, while dynamic data represents shifting operational parameters such as actual train position, delay values, changes in routing and track occupancy. (Pepevnik, Belšak, 2011; Čamaj, 2018)

Train data are closely linked to timetable records and serve as the primary reference for monitoring operational performance. Data structures distinguish between planning datasets (timetable paths) and execution datasets (real-time movement logs). (Pepevnik, Belšak, 2011; Čamaj, 2018) Changes in train attributes are propagated automatically across relevant information systems, ensuring data consistency across operational environments. Train data therefore represent the dynamic layer of the infrastructure manager's information ecosystem. (Pepevnik, Belšak, 2011; Čamaj, 2018)

3.4. Data Exchange Between Systems

Data Exchange between information systems is based on defined interfaces operating in near real-time or batch modes. Internal data flows ensure synchronization between the MK module within KIS and the operational layers, while APMDK functions as a supporting documentation tool for recording dispatcher actions. (Čamaj, 2018; Šulko, 2024)

KIS represents the central integration platform enabling standardised communication compliant with European interoperability requirements. Selected operational datasets are exported through KIS toward railway undertakings and external platforms in structured data formats. (Čamaj, 2018; Šulko, 2024)
The analysis shows that data exchange is predominantly automated but partially supported by manual verification procedures, reflecting the incomplete integration of legacy systems. Ensuring data integrity remains a core operational requirement. (Čamaj, 2018; Šulko, 2024)

4. Discussion

The analysis of information systems used by the railway infrastructure manager in Slovakia confirms that the current information environment is built upon a functional but partially fragmented architecture. Individual systems fulfil clearly defined tasks within timetable planning, operational management and reporting; however, their integration remains incomplete in certain areas. (Mestický, Krásenský, 2010; Čamaj, 2020)

A key strength of the Slovak infrastructure managers system environment is the existence of specialised platforms for core operational activities. The MK module within KIS provides advanced support for timetable construction and conflict detection, while KIS also enables real-time monitoring of train movements across the network. The replacement of PIS by KIS significantly reduced system fragmentation and improved data consistency across operational layers. (Šulko, 2024)

However, this architecture also reveals limitations typically associated with legacy systems. The partial separation of databases and heterogenous data formats causes redundancy and increases dependence on human intervention. Several processes require manual validation to ensure data consistency, which increases operational workload and introduces risks related to information delay and correctness. (Čamaj, 2020)

From a European perspective, the increasing importance of interoperability standards highlights the need for improved system harmonisation. The implementation of TSI TAF and TSI TAP implies a shift from closed national systems towards interoperable information platforms. While KIS represents a crucial step in this direction, its integration with internal systems remains incomplete, particularly with regard to real-time data synchronisation. (Šulko, 2024)

Another critical issue is the dependence of operational quality on data accuracy. All planning and dispatching processes rely on consistency between infrastructure records, timetable data and operational logs. The analysis indicates that data governance is not yet applied systematically across all systems, leading to potential discrepancies between planning-level and operational-level datasets. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

In addition, the increasing volume of operational data presents new challenges in terms of data management and system scalability. Modern railway operations demand continuous monitoring and processing of high-frequency data streams. Without adequate modernization of IT infrastructure, system growth could compromise responsiveness and reliability.

In the international context, advanced infrastructure managers increasingly adopt integrated platforms based on unified data models and central control centres. The Slovak environment currently reflects a transitional stage between isolated applications and vertically integrated systems. Progress toward comprehensive integration would significantly improve data quality, process efficiency and system resilience. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

Overall, the findings suggest that future development should focus on standardization of data models, deeper system integration and automation of information flows. Strategic investment in information system modernization represents not only a technological necessity but also a prerequisite for maintaining network performance and safety in a digital environment. (European Union Agency for Railways, 2023a; European Union Agency for Railways, 2023b)

Conclusion

This paper analysed the architecture and data structures of information systems used by the railway infrastructure manager in Slovakia, with a particular focus on timetable planning, operational management and system integration. The performed analysis demonstrates that the information environment is functionally mature but still constrained by partial system fragmentation and uneven levels of integration.

The results confirmed that the MK module integrated in KIS constitutes the central planning platform, while KIS itself provides real-time operational data essential for traffic control and interoperability. KIS acts as the primary interoperability layer enabling data exchange with external entities and compliance with European standards, and APMDK ensures reliable operational documentation and traceability of decisions. The interaction with railway undertaking systems, such as VDS, further illustrates the importance of system bridging and data consistency across organisational boundaries. (Šulko, 2024; Čamaj, 2020; Mestický, Krásenský, 2010)

Despite the existence of specialised systems for key operational functions, full data harmonisation has not yet been achieved. The persistence of isolated datasets, combined with manual verification process, limits operational efficiency and increases the risk of data inconsistencies. These findings emphasise the need for a unified data model and improved governance mechanisms. From a strategic perspective, the future development of information systems in the Slovak railway infrastructure sector should prioritise system integration, automation of data flows and adoption of interoperability frameworks. Alignment with European regulations, particularly TSI TAF and TSI TAP, represents a significant opportunity to modernise national railway IT infrastructure.

In conclusion, information systems constitute a critical component of railway infrastructure management, directly influencing operational safety, capacity utilisation and service quality. Systematic investment in digital platforms and data governance is therefore a prerequisite for sustainable development of railway infrastructure in a data-driven environment.

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