THE IMPACT OF DIGITAL INTEGRATION ON SERVICE EFFICIENCY IN RAILWAY TRANSPORT

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Abstract. The article examines how digital integration affects the efficiency of services in railway transport. Digital integration is treated not as the introduction of separate information systems, but as the linking of data and processes within the railway company and with customers, partner carriers, ports, customs and other stakeholders. Based on a review of scientific literature, international practice and data on the reform of Uzbekistan's railway sector, the study distinguishes four levels of digital integration and identifies the channels through which each level influences service efficiency: reduction of transaction and document-processing time, higher reliability and availability of rolling stock, better use of capacity, and improved customer experience. International evidence shows, for example, that predictive maintenance has allowed a major European operator to cut maintenance costs by 20% and halve technical failures. A system of indicators for assessing the effect of digital integration is proposed, together with recommendations for Uzbekistan Railways JSC.

Keywords: *railway transport, digital integration, service efficiency, digital transformation, electronic consignment note, predictive maintenance, digital twin, e-ticketing, Uzbekistan.*

Introduction. Digital transformation has become one of the main directions for raising the competitiveness of railway transport. Compared with road transport, railways offer lower costs and emissions per ton-kilometre, but they often lose customers because of slow document processing, limited information on the location of cargo, and inconvenient interaction with the carrier. Digital technologies make it

possible to eliminate many of these disadvantages; however, as research on digital transformation shows, the effect is achieved not by technology as such but by the reorganisation of processes and the integration of data across organisational boundaries [1; 2].

Uzbekistan is actively pursuing this agenda. The reform of Uzbekistan Railways JSC, supported by the World Bank, includes improvements in business processes, corporate governance, financial transparency and passenger service planning [3]. The company has moved from a significant loss in 2023 to break-even in 2024 [4], and its development plans envisage the use of artificial intelligence-based management systems that are expected to reduce service costs by up to 20% [5]. Passenger tickets are sold through the online platform eticket.railway.uz, and in international freight transport the region is testing the electronic CIM/SMGS consignment note [6].

At the same time, digital projects in railways are often implemented in isolation — a ticketing system, an accounting system, a separate tracking tool — and do not form an integrated whole. As a result, the expected gains in service efficiency are only partly realised. The aim of this article is to determine the impact of digital integration on the efficiency of railway services and to propose a methodological basis for assessing this impact.

Methods. The research is based on the theory of digital transformation [1], the concept of IT productivity [2] and service quality theory [7]. The following methods were used: (1) systematic review of scientific publications on the digitalisation of railway transport, including studies on digital twins and predictive maintenance [8]; (2) analysis of international practice, in particular the results published by SNCF [9] and the TRACECA pilot of the electronic CIM/SMGS consignment note [6]; (3) analysis of reform documents and statistical data on Uzbekistan’s railway sector [3–5]; (4) classification and comparative analysis; (5) construction of an indicator system for assessing effects.

Service efficiency is understood as the ratio of the result of a service (volume, speed, reliability and quality perceived by the customer) to the resources spent on it (time, labour, capital, operating costs). Accordingly, digital integration is considered effective if it increases the result with the same resources or reduces resources while maintaining or improving the result.

Results. Levels of digital integration. Analysis of international practice made it possible to distinguish four levels of digital integration in railway transport (Table 1). Each subsequent level builds on the previous one and gives a broader effect.

Table 1

Levels of digital integration in railway transport

Level	Content	Main effect on service efficiency
1. Digitisation	Conversion of documents and operations into electronic form: e-tickets, electronic waybills, electronic accounting	Lower paper and labour costs; faster processing of individual operations
2. Internal integration	Linking of operational, commercial, maintenance and financial systems into a single data environment of the company	Real-time management; accurate cost accounting by service; better use of wagons and locomotives
3. External integration	Data exchange with customers, foreign railways, ports, customs and logistics operators (API, e-CIM/SMGS, single window)	Shorter border and terminal dwell time; transparent tracking; fewer intermediaries

4. Intelligent ecosystem	Use of big data, AI, IoT and digital twins for forecasting, predictive maintenance, dynamic pricing and personalised services	Higher reliability and availability; optimised capacity; new value-added services

Source: developed by the author on the basis of [1; 6; 8; 9].

Channels of impact on efficiency. The analysis revealed four main channels through which digital integration affects the efficiency of services.

(a) Transaction time and costs. When documents are exchanged electronically between railways and with customs, the time for preparing and checking documents at borders is reduced. The TRACECA pilot of 2024 involving Azerbaijan, Georgia, Kazakhstan, Türkiye and Ukraine demonstrated the automated exchange of the digital consignment note via API and its potential for significant improvements in data exchange and processing [6]. In the EU, Regulation (EU) 2020/1056 obliges authorities to accept electronic freight transport information [10].

(b) Reliability and availability of rolling stock. Integration of on-board sensor data with maintenance systems enables a transition from scheduled to predictive maintenance. According to SNCF, predictive maintenance has made it possible to cut maintenance costs by 20%, reduce visits to maintenance centres by 30% and more than halve breakdowns on trainsets with remote diagnostics [9]. Scientific studies also show that condition-based maintenance can extend service intervals, in some cases from 10,000 to 20,000 km [8].

(c) Use of capacity. Integrated planning of train paths, wagons and locomotives on the basis of real-time data increases the throughput of the existing infrastructure without new construction, which is particularly important for a network with bottlenecks on transit corridors.

(d) Customer experience. Online booking, electronic tickets, mobile payment, real-time information on train movements and cargo tracking reduce the time the customer spends interacting with the carrier and increase satisfaction. For freight customers, visibility of the whole supply chain is often as important as the tariff.

Indicator system. To assess the impact of digital integration, a system of indicators grouped by the four channels is proposed (Table 2).

Table 2

Indicators for assessing the impact of digital integration on service efficiency

Group	Indicators	Data source
Transaction efficiency	Time for processing a shipment; border dwell time; share of electronic documents; cost of document processing per shipment	Information systems; customs data
Asset efficiency	Availability of rolling stock; failures per million train-km; maintenance cost per train-km; wagon turnaround time	Maintenance and operational systems
Operational efficiency	Punctuality of trains; average commercial speed; capacity utilisation of key sections	Traffic control systems
Customer efficiency	Share of online sales; time to purchase a ticket or place an order; customer satisfaction index (SERVQUAL-based); share of shipments with real-time tracking	Sales platforms; surveys

Source: developed by the author.

An integral assessment can be carried out by comparing each indicator before and after the implementation of a digital project and weighting the results by their importance for the company's strategy, which allows the contribution of digital integration to be separated from other factors.

Discussion. The results confirm the conclusion of Brynjolfsson and Hitt that investment in information technology produces a significant return only when accompanied by changes in organisation and processes [2]. In railway transport this means that the main effect comes from moving to the second and third levels of integration — linking systems inside the company and with external partners — rather than from digitising individual operations. A railway can have an electronic ticket and an electronic waybill, but if data on wagons, maintenance and costs remain in separate systems, managers cannot optimise the use of assets or set cost-based prices.

International experience also shows that the highest effects are achieved at the fourth level, where data are used for prediction [8; 9]. However, this level requires reliable data from the lower levels, qualified staff and investment in sensors and computing infrastructure. Research also points to the risks of digitalisation — cybersecurity threats, personal data protection and dependence on suppliers [8] — which must be managed from the outset.

For Uzbekistan, the following priorities seem justified: (1) creation of a single corporate data platform of Uzbekistan Railways JSC integrating operational, commercial and maintenance data; (2) participation in regional projects for the electronic CIM/SMGS consignment note and integration with customs information systems along transit corridors; (3) gradual introduction of condition-based and predictive maintenance, starting with high-speed and electric trains; (4) development of a single digital interface for freight customers with ordering, tracking and payment functions; (5) regular measurement of results using the proposed indicators, so that digital investment is evaluated by its actual effect on service efficiency.

The limitations of the study relate to the use of international and aggregated data. Further research should estimate the effect of specific digital projects on the indicators of Uzbekistan Railways JSC.

Conclusion. Digital integration has a significant impact on the efficiency of railway services, but this impact depends on the level of integration achieved. Digitising individual operations reduces paper and labour costs; internal integration makes real-time management and accurate cost accounting possible; external integration shortens border and terminal procedures and makes the supply chain transparent; and intelligent ecosystems based on AI and digital twins increase the reliability and availability of assets. International evidence, such as a 20% reduction in maintenance costs from predictive maintenance, confirms the size of the potential gains. For Uzbekistan, the consistent movement from digitisation to integration, supported by an indicator system for measuring results, will help to increase service efficiency, attract cargo and transit flows, and strengthen the competitiveness of railway transport.

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