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Article

Section-Level Rail Freight Efficiency: An Integral Index and Factor Ranking for the Bukhara–Misken Line, Uzbekistan

Ravshan Ramazonov[1] *

1. *Lecturer, Asman University; Researcher, Bukhara State University, Bukhara, Uzbekistan*

* Correspondence : ravshanramazonov086@gmail.com

Abstract: Railway efficiency is usually measured for whole networks or companies, while investment and operating decisions are taken for individual sections. This paper develops and tests a section-level method for assessing rail freight efficiency, using the Bukhara–Misken section of Uzbekistan Railways (392 km, single track, opened in 2017 and electrified in 2025) as the case. Twenty partial indicators are grouped into operational, economic, service-quality and socio-environmental blocks, normalised by the min–max method against the section's worst value for 2018–2025 and the national best-practice benchmark, and weighted by the Analytic Hierarchy Process (AHP) with 14 experts. The integral efficiency index rose from 0.406 in 2018 to 0.621 in 2025, moving the section from the "medium" to the "above medium" level, but it remains 9% below the national average (0.682) and 16% below the Bukhara–Qarshi benchmark section (0.741). Data envelopment analysis (DEA) confirmed the ranking of years (Spearman $\varrho = 0.95$). A multiple regression on 28 quarterly observations ($R^2 = 0.912$) shows that wagon dwell time at freight stations ($\beta = -0.412$) and the empty-running ratio ($\beta = -0.318$) have the strongest effect, ahead of freight volume, electronic documentation and section speed, while the real tariff level is not significant. Organisational and technological levers therefore take priority over capital-intensive ones. Under the baseline scenario, the proposed measures raise the index to 0.752 by 2030, with an annual effect of 152.6 billion UZS and a discounted payback period of 3.1 years.

Keywords: rail freight efficiency, integral index, analytic hierarchy process, data envelopment analysis, Uzbekistan

1. Introduction

Transport costs weigh heavily on landlocked economies. For such countries, rail is the only land mode that can move bulk freight over long distances at low unit cost and low energy use, which makes the efficiency of rail freight a direct factor of national competitiveness [1,2]. Uzbekistan, a doubly landlocked country, has made the transport and logistics system a priority of its development strategy: the "Uzbekistan – 2030" Strategy sets the tasks of reducing logistics costs, using the country's transit potential and modernising the rail network [3], and Presidential Resolution PQ-329 of 2023 launched a structural reform of the railway sector [4].

Between 2015 and 2025 freight carried by Uzbekistan Railways grew from 67.2 to 77.6 million tonnes, and freight turnover from 22.9 to 29.6 billion tonne-km. Growth has come mainly from long-haul international, transit and container traffic. The results of the reforms, however, are not evenly visible across the network. Efficiency is usually measured at the level of the national operator, while bottlenecks and reserves are located on particular sections and stations [5,6,7,8]. A section-level assessment can show where a given unit of investment or organisational effort will give the highest return.

The Bukhara–Misken section is a useful case. It is the shortest internal route between the centre of the country and the Khorezm–Karakalpakstan region and links the Bukhara junction with the Trans-Caspian and Kazakhstan–Russia corridors. Its freight base combines a high share of transit and through traffic (over 50%), cheap bulk cargo, unbalanced flows by direction and seasonality. The objective of this study is to develop an integral method for assessing freight efficiency at the section level and to use it to rank the factors that limit efficiency on the Bukhara–Misken section.

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2. Materials and Methods

The study draws on three groups of data: annual operating, financial and quality reports of the Bukhara regional railway junction for 2018–2025; quarterly data for 2019–2025 (n = 28); and comparable indicators for the national network and two neighbouring sections. Efficiency is understood as the unity of technical, economic, social and environmental results of the transport service, adapted to the features of a section: short haul, unbalanced flows and a large transit share.

The assessment follows five stages. First, a system of 20 partial indicators was formed in four blocks: operational (7 indicators), economic (5), service quality (5) and socio-environmental (3). Second, each indicator was normalised by the min–max method:

$$z_{ij} = (x_{ij} - x_{j,worst}) / (x_{j,best} - x_{j,worst}), \quad (1)$$

where the worst value of indicator j in 2018–2025 is set to 0 and the national best-practice value is set to 1 (for indicators where lower is better the formula is reversed). This base allows the index to be read both over time and as distance to the benchmark. Third, block and indicator weights were obtained by pairwise comparison with the Analytic Hierarchy Process (AHP) [9]. Fourteen experts took part: six managers of the Bukhara junction and section stations, five logistics managers of large shippers and three researchers of Tashkent State Transport University. The consistency ratio of all matrices was 0.04–0.08, below the 0.10 threshold. The block weights are 0.30 (operational), 0.30 (economic), 0.25 (quality) and 0.15 (socio-environmental). Fourth, the integral index was calculated as

$$I = \Sigma_k W_k \Sigma_i w_{ki} z_{ki}, \quad (2)$$

where W_k is the weight of block k and w_{ki} the weight of indicator i within the block. The result is interpreted on a five-level scale: low (below 0.20), below medium (0.20–0.39), medium (0.40–0.59), above medium (0.60–0.79) and high (0.80 and above). Fifth, the sources of change were decomposed by block.

Two checks were applied. The block weights were varied by ±0.05 to test sensitivity. An input-oriented DEA model [10,11] was estimated on the annual observations, with operating costs, locomotive-days and wagon-days as inputs and freight turnover and revenue as outputs; the DEA scores were compared with the index by Spearman rank correlation. Finally, the quarterly index was regressed on eight candidate factors: wagon dwell time at freight stations (x1, hours), empty-running ratio (x2), quarterly freight volume (x3, thousand t), share of shipments with electronic documents (x4, %), section speed (x5, km/h), share of rolling stock past its standard service life (x6, %), seasonality index (x7) and real tariff index (x8). Stepwise selection was used because of multicollinearity; all retained variables had VIF below 4.2. Freight volumes for 2026–2030 were forecast under inertial, baseline and target scenarios by trend extrapolation, regression on macroeconomic drivers and expert adjustment, following approaches used for neighbouring Kazakhstan [12]. Calculations were made in Statistica and MS Excel.

3. Results

Over 2018–2025 freight carried on the section grew 2.7 times, from 1.9 to 5.1 million tonnes, and freight turnover 3.1 times. Wagon turnaround fell from 4.9 to 3.9 days, section speed rose from 31.0 to 38.3 km/h, the empty-running ratio fell from 0.62 to 0.48, and profitability rose from 11.7% to 18.5%. At the same time, wagon dwell time per freight operation (41.3 hours) remains 72% above the standard, and the customer satisfaction index is 69.6%. Table 1 shows the normalised values of the indicators by block.

Table 1. Normalised block values, weights and integral efficiency index of the Bukhara–Misken section

Block	Block weight	2018	2022	2025	Weighted 2025
Operational (7 indicators)	0.30	0.42	0.54	0.64	0.192
Economic (5 indicators)	0.30	0.36	0.49	0.59	0.177
Service quality (5 indicators)	0.25	0.45	0.56	0.66	0.165
Socio-environmental (3 indicators)	0.15	0.40	0.47	0.58	0.087

Block	Block weight	2018	2022	2025	Weighted 2025
Integral index	**–**	**0.406**	**0.519**	**0.621**	**0.621**

Note: block values are weighted sums of min–max normalised indicators (0 = worst value in 2018–2025, 1 = national benchmark); weights from AHP with 14 experts. Source: author's calculations based on data of the Bukhara regional railway junction.

The index rose by 0.215 points (53%) in eight years, an average of 0.031 points a year, and in 2025 crossed into the "above medium" level. The economic block contributed 0.069 points of the increase (32.1%), the operational block 0.066 (30.7%), quality 0.053 (24.7%) and the socio-environmental block 0.027 (12.5%). The weakest indicators in 2025 were the technical condition of rolling stock (0.50), the real revenue rate (0.52), the empty-running ratio (0.54) and energy use per tonne-km (0.58). The unused reserve relative to the benchmark is 1 − 0.621 = 0.379 points, or 38%.

The result is robust. With block weights changed by ±0.05, the 2025 index stayed within 0.605–0.637 and in the same level, and the ranking of years did not change. In the DEA model, 2025 lies on the efficiency frontier ($\theta = 1.00$), compared with 0.96 in 2024, 0.91 in 2023 and 0.68 in 2018; the Spearman correlation between DEA scores and the index is 0.95.

All factors are correlated with the index in the expected direction: strongly positive for freight volume (r = 0.84), electronic documents (0.79) and speed (0.73), strongly negative for dwell time (−0.81) and empty running (−0.76). Table 2 reports the final regression model.

Table 2. Multiple regression of the quarterly integral index on efficiency factors (2019–2025, n = 28)

Factor	Coefficient b	Std. error	t	p	Beta
Constant	0.412	0.061	6.75	0.000	–
x1 Wagon dwell time at freight stations, h	−0.0038	0.0009	−4.22	0.000	−0.412
x2 Empty-running ratio	−0.296	0.087	−3.40	0.003	−0.318
x3 Quarterly freight volume, thousand t	0.000094	0.000031	3.03	0.007	0.286
x4 Share of electronic documents, %	0.0011	0.0004	2.75	0.012	0.241
x5 Section speed, km/h	0.0042	0.0017	2.47	0.023	0.198
x6 Share of over-aged rolling stock, %	−0.0015	0.0007	−2.14	0.045	−0.163
x7 Seasonality index	−0.048	0.026	−1.84	0.081	−0.121

Note: $R^2 = 0.912$; adjusted $R^2 = 0.881$; $F = 29.6$ ($p < 0.001$); Durbin–Watson = 1.92. The real tariff index (x8) was not significant and was excluded. Source: author's calculations.

The model explains 91.2% of the variation in the index. Reducing dwell time by one hour adds 0.0038 points; bringing it down to the 24-hour standard would add about 0.066 points. A 0.1 fall in the empty-running ratio adds 0.030 points, and a 10 percentage point rise in electronic documents adds 0.011 points. By standardised coefficients, the two strongest factors, dwell time and empty running, are both organisational and technological.

Benchmarking against comparable sections confirms where the gap lies (Table 3). The section lags the national average on 11 of 12 indicators; the largest gaps are empty running (33% worse), dwell time (25%) and wagon turnaround (15%).

Table 3. Bukhara–Misken compared with the national average and neighbouring sections, 2025

Indicator	Bukhara–Misken	National average	Navoi–Uchkuduk–Misken	Bukhara–Qarshi
Wagon turnaround, days	3.9	3.4	4.2	3.2
Dwell time per freight operation, h	41.3	33.0	43.5	29.8
Empty-running ratio	0.48	0.36	0.51	0.33
Section speed, km/h	38.3	40.1	35.4	43.6
Cost per 10 tonne-km, UZS	968	912	1,045	861
Profitability, %	18.5	19.4	14.2	22.7
On-time delivery, %	86.5	89.6	84.1	91.3
Customer satisfaction index, %	69.6	72.4	66.8	75.1
Integral index	**0.621**	**0.682**	**0.563**	**0.741**

Note: indices of the neighbouring sections were calculated with the same weights and normalisation base. Source: author's calculations based on data of Uzbekistan Railways JSC and the Bukhara, Navoi and Qarshi regional junctions.

The losses caused by the seven main constraints — ageing rolling stock, wagon idle time, seasonality and imbalance, tariff policy, road competition, lack of logistics infrastructure and staffing — were estimated at about 100 billion UZS in 2025 after removing overlaps, or 55% of the section's revenue. More than 60% of these losses are organisational and technological. On this basis, nine measures were grouped into technological-organisational, digital and infrastructural-institutional packages, with total investment of 98.3 billion UZS, of which 39 billion would come from private partners. Table 4 summarises the scenario forecast.

Table 4. Scenario forecast for the Bukhara–Misken section, 2030

Indicator	Inertial	Baseline	Target
Freight carried, million t	6.6	8.8	11.0
Integral efficiency index	0.680	0.752	0.785
Efficiency level	Above medium	Above medium	Near high

Note: 2025 actual values: 5.1 million t and an index of 0.621. Source: author's forecast.

In the baseline scenario, single-process contracts with large shippers, a progressive wagon-use charge, additional pick-up trains and a second shunting locomotive cut dwell time from 41.3 to 28 hours and wagon turnaround from 3.9 to 3.1 days; backhaul cargo and container trains bring the empty-running ratio down to 0.38–0.41. Together with a unified digital platform, these station-level measures alone raise the index from 0.621 to 0.712. The annual effect of the full programme reaches 152.6 billion UZS in 2030, removing 62.6% of the estimated losses; the ten-year net present value at a 16% discount rate is 191.2 billion UZS and the discounted payback period is 3.1 years.

4. Discussion

The finding that dwell time and empty running dominate the efficiency of the section supports the view, set out by Hansen and Pachl, that organisational factors such as timetable reliability and station processes often limit rail performance more than infrastructure does [5]. It is also in line with DEA studies of rail freight in Brazil, where efficiency differences between operators were explained mostly by how assets were used rather than by their amount [13], and with work on wagon fleet size, which shows that fleet needs depend directly on turnaround time [14]. The insignificance of the tariff factor matches evidence of low price elasticity of rail freight demand for bulk cargo [15]. The energy and emission gains from electric traction observed after 2025 are consistent with

European case studies [16], while the potential of container trains and backhaul cargo depends on competitive rail-road combined transport and smooth cross-border documentation [17], [18].

The comparison with the Bukhara–Qarshi section, which has automatic block signalling, electric traction and balanced flows, shows the target state for Bukhara–Misken. Electrification was completed in 2025, but the semi-automatic block system on the Poykent–Misken part (capacity 15 train pairs a day) remains the main technical bottleneck. The capacity forecast indicates that, without re-signalling, the section will face a shortage of freight paths from 2026 and that demand will exceed what any technological measure can provide from 2028. Organisational measures are therefore the first step, not a substitute for re-signalling, which should start no later than the first half of 2028.

The method has limits. Expert weights reflect the views of a small panel, and the benchmark values depend on the best sections of one network. The regression uses a short quarterly series, so the coefficients should be read as indicating priorities rather than as precise elasticities. Applying the method to other sections of the network would allow the weights and thresholds to be tested on a larger sample.

5. Conclusion

The study set out to develop a section-level method for assessing rail freight efficiency and to use it to rank the factors limiting efficiency on the Bukhara–Misken section. The four-block integral index, built on min–max normalisation and AHP weights and checked by DEA, shows that the section's efficiency rose from 0.406 to 0.621 in 2018–2025 but still has a 38% reserve against the national benchmark.

Regression analysis shows that wagon dwell time and empty running are the strongest limiting factors, and both can be improved without large capital spending. The recommended sequence is "technology first, then investment": single-process contracts with large shippers, a progressive wagon-use charge, backhaul cargo and digital documentation in 2026–2027, followed by re-signalling of the Poykent–Misken part and a dry-port logistics centre at the Bukhara junction. The method can be used by Uzbekistan Railways and regional junctions to monitor section efficiency and to choose investment priorities.

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Conflict of interest

The author declares no conflict of interest.

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