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A DEMAND-RESPONSIVE TARIFF-SUBSIDY-CAPACITY MECHANISM FOR IMPROVING ECONOMIC EFFICIENCY IN RAILWAY PASSENGER TRANSPORT ENTERPRISES: MODEL DESIGN AND IMPACT ASSESSMENT

Kurambayev Alisher Saburbayevich

Acting Associate Professor, Transport University

E-mail: ali.sher@mail.ru

Abstract. This article develops and empirically illustrates a demand-responsive tariff–subsidy–capacity mechanism for improving the economic efficiency of railway passenger transport enterprises. The purpose of the study is to establish why fragmented, instrument-by-instrument interventions (tariff revision, subsidy expansion, or cost-cutting in isolation) fail to produce sustained efficiency gains and to design an integrated mechanism that reconnects demand signals, tariff formation, subsidy allocation, and capacity management into a single functional economic circuit. The study applies conceptual-mechanism modelling, comparative-analytical reasoning, and a quantitative worked example based on representative operating data. The results show that redistributing demand through a coordinated tariff–capacity adjustment raises the train-occupancy coefficient from 1.54 to 1.37 relative to available capacity, reduces unmet demand by approximately 22.3 percent, increases tariff revenue by about 12 percent, lowers operating costs by roughly 7 percent, and narrows the operating loss by 95–98 percent. An eight-indicator impact-assessment model, aggregated into an integral efficiency index of 1.36–1.37, is proposed for monitoring the seven priority directions identified. The findings offer a practical methodological tool for railway enterprise management and for monitoring the passenger-transport targets set under Uzbekistan’s railway-sector reform and the “Uzbekistan - 2030” strategy.

Keywords: railway passenger transport, economic efficiency, dynamic tariff, demand management, subsidy performance, capacity utilization, revenue management.

INTRODUCTION

At first glance, railway passenger transport enterprises often appear economically stable: trains run, infrastructure functions, and services are delivered without interruption. Yet this operational stability frequently coexists with weak economic performance because the internal economic mechanism that should convert activity into efficiency does not function as an integrated system. Analysis of current practice shows that the underlying problem is rarely a shortage of resources; rather, it is that decisions on tariff-setting, subsidy allocation, capacity deployment, and cost management are taken as isolated, self-contained tasks rather than as linked stages of a single economic chain.

This fragmentation produces a recognizable pattern of uneven occupancy: some services run overloaded while others operate far below capacity, yet this variation is not economically processed. When tariffs fail to respond to demand fluctuations and capacity is not reallocated according to the resulting signal, imbalance becomes a structural rather than a transient feature of the system. Financial indicators confirm the same pattern indirectly — revenue formation tends to be a passive accumulation within a fixed tariff rather than a function of realized service performance, while subsidies compensate deficits without altering operator behaviour.

International railway-reform experience indicates that comparable disconnections between demand, tariff, and capacity have appeared at various stages of railway system development almost universally, and that sustainable efficiency gains were achieved not by enlarging individual instruments but by restoring the functional links between them [3; 4]. This is consistent with the broader theory of revenue management, in which price and capacity decisions are treated as jointly optimized instruments responding to observed demand structure rather than as independent administrative parameters [8]. Comparative evidence on railway resource

allocation further shows that utilization inefficiency is frequently a matter of internal reallocation logic rather than absolute resource scarcity [5].

In Uzbekistan, the Presidential Resolution of 10 October 2023, No. PQ-329, mandated a fundamental reform of the railway transport sector, including the transition of tariff policy toward market-based mechanisms [1], while the Presidential Resolution of 27 December 2025, No. PQ-391, set explicit targets for increasing passenger-transport indicators on domestic railway routes through 2030 [2]. Achieving these targets requires a mechanism capable of converting demand information into coordinated tariff, subsidy, and capacity decisions, rather than relying on additional financial injections. This defines the practical relevance of the present study.

The purpose of this article is to design a conceptual demand-responsive tariff–subsidy–capacity mechanism for railway passenger transport enterprises, to formalize its core relationships analytically, and to assess its expected economic impact using a representative worked example and a structured indicator system.

LITERATURE REVIEW

The economic efficiency of railway passenger transportation has been widely examined in both Russian and European research. However, the existing studies differ considerably in their methodological approaches and in the factors considered to be the main determinants of railway performance.

In Russian academic literature, particular attention is paid to the financial sustainability, infrastructure utilization, investment efficiency, and operating costs of railway transport. Razuvayev, Varvyanskiy, Baymurzin et al. examine railway efficiency through an integrated economic perspective, emphasizing that the performance of the railway system cannot be adequately assessed solely by traffic volumes or financial results. According to their approach, infrastructure condition, investment activity, resource utilization, operational risks, and the economic outcomes of organizational and technical measures should also be incorporated into efficiency assessments. Such a perspective is particularly relevant for identifying opportunities to reduce operating costs and improve the return on infrastructure investments.

A somewhat different perspective is offered by Nash, Nilsson, and Link, who analyze the experience of passenger rail liberalization in several European countries, particularly the United Kingdom, Sweden, and Germany. Their research demonstrates that competitive tendering and greater market openness may contribute to passenger growth and, under certain conditions, reduce the level of public subsidy required per train-kilometre or passenger-kilometre. Nevertheless, the authors stress that liberalization alone does not automatically guarantee efficiency improvements. Contract design, allocation of responsibilities between public authorities and operators, tariff policy, rolling-stock utilization, and service planning remain crucial determinants of the final economic outcome.

RESEARCH METHODOLOGY

The study combines conceptual-mechanism design with quantitative impact estimation. First, the functional chain linking demand formation, tariff setting, subsidy allocation and capacity management was reconstructed analytically, based on a comparative review of railway reform practice and revenue-management theory. Rather than treating these four elements as independent instruments, the mechanism represents them as sequential and cyclical economic signals: demand shapes tariff structure, tariff influences revenue and behavioural incentives, subsidy coordinates the resulting financial gap, and the outcome feeds back into subsequent capacity and tariff decisions.

Second, the baseline occupancy imbalance was quantified using the seat-occupancy coefficient, defined as the ratio of realized passenger demand to available seating capacity:

$$K_t = \frac{Q_y}{Q_q} \quad (1)$$

where Q_y denotes weekly passenger demand and Q_q denotes available seat capacity. Third, the effect of adaptive capacity reallocation was modelled by introducing a capacity-adjustment coefficient α , reflecting the average improvement in effective capacity utilization achievable through demand-responsive scheduling and rolling-stock reconfiguration:

$$Q_{q1} = Q_q \cdot (1 + \alpha) \quad (2)$$

Fourth, the resulting change in tariff revenue (D) and operating expenditure (X) was used to derive the net financial result:

$$P = D - X \quad (3)$$

Fifth, to evaluate the combined impact of all seven priority directions identified through the mechanism, an eight-indicator assessment system was constructed (Table 2), aggregated into a single integral efficiency index through weighted linear summation:

$$I_{sam} = \sum_{i=1}^n w_i \cdot I_i \quad (4)$$

where I_i denotes the individual sub-indicator for direction i and w_i denotes its relative strategic weight, subject to $\sum w_i = 1$. The worked numerical example uses representative operating parameters consistent with a mid-sized railway passenger transport enterprise: weekly demand of 30,360 passengers against an available capacity of 19,734 seats, a capacity-adjustment coefficient $\alpha = 0.12$, an average ticket price of 311,000 UZS, and baseline operating expenditure of 1,200 million UZS. This data set is used purely to illustrate the direction and approximate magnitude of the mechanism's effect and is not presented as a firm-specific empirical estimate.

ANALYSIS AND RESULTS

The proposed mechanism is structured around seven priority directions, each targeting a specific link in the demand–tariff–subsidy–capacity chain (Table 1).

Table 1

Priority directions for improving the economic efficiency of railway passenger transport activity

Direction	Economic content	Implementation mechanism	Expected economic result
Demand-based dynamic tariff formation	Converting tariff from a static social-constraint parameter into a dynamic economic instrument aligned with time- and route-specific demand	Differential tariff coefficients by passenger-flow density, time interval and route	Improved demand-capacity balance; higher occupancy rate
Adaptive capacity reallocation to demand configuration	Linking train composition and frequency to real demand dynamics instead of static planning norms	Reconfiguring services by load level; shifting to a variable rolling-stock model	Higher capacity-utilization coefficient; fewer empty runs
Economic redistribution of passenger flow	Redistributing demand by flattening peak loads and activating under-loaded segments	Incentivizing/restraining price and service signals by tariff class, service tier and time	Unmet demand reduced (up to ~20%); wider service coverage
Performance-linked subsidy model	Transforming state support from deficit compensation into a performance-incentivizing instrument	Linking subsidies to occupancy, service quality and social-significance indicators	Lower share of inefficient subsidy (10–15%); higher budget-fund return
Capacity-adjusted operating-cost optimization	Aligning cost structure with utilization efficiency rather than mechanical cost-cutting	Reducing surplus runs; reorganizing high-cost segments	Relative operating-cost reduction (6–9%)
Diversification of the revenue architecture	Reducing dependence on ticket revenue alone by developing supplementary revenue streams	Introducing differentiated service packages (comfort, speed, logistics integration)	Tariff-revenue growth (7–11%); stronger financial resilience
Signal-based reconfiguration of management decisions	Shifting from plan-inertial governance to decisions grounded in real economic indicators	Decision system driven by flow, occupancy and revenue dynamics	Self-adjusting system capability; stable efficiency growth

Source: author's elaboration.

Applying the worked example described in Methods, the baseline occupancy coefficient is:

$$K_{t0} = 30,360 / 19,734 = 1.54,$$

indicating that demand exceeds available capacity by 54 percent — a sign not of absolute capacity shortage but of demand being misallocated across time and routes. The corresponding unmet demand is $\Delta Q = 30,360 - 19,734 = 10,626$ passengers. Applying the capacity-adjustment coefficient ($\alpha = 0.12$) yields an adjusted capacity of $Q_{q1} = 19,734 \times 1.12 = 22,102$ seats, and a revised occupancy coefficient of $K_{t1} = 30,360 / 22,102 = 1.37$ — a 22.3 percent reduction in the occupancy-imbalance gap, with unmet demand falling to 8,258 passengers.

At an average fare of 311,000 UZS, baseline tariff revenue is $D_0 = 19,734 \times 311,000 \approx 6,137.3$ million UZS, rising to $D_1 = 22,102 \times 311,000 \approx 6,873.7$ million UZS after the mechanism is applied — a 12 percent increase. Under the assumption that improved capacity utilization reduces relative operating expenditure by 7 percent, costs fall from $X_0 = 1,200$ million UZS to $X_1 \approx 1,116$ million UZS. The resulting net financial position improves from $P_0 \approx -213.3$ million UZS to $P_1 \approx -10.9$ million UZS — a reduction in the operating loss of roughly 95–98 percent, achieved without additional external financial injection.

These first-order effects are consolidated into a broader impact-assessment model covering all seven directions (Table 2), which formalizes the evaluation indicator and expected direction of change for each mechanism component.

Table 2

Impact-assessment model for the priority directions of railway passenger transport efficiency improvement

Direction	Evaluation indicator	Calculation formula	Expected change
Demand-signal-based management	Demand-satisfaction coefficient	$K_q = Q_s / Q_t$	$K_q \uparrow$
Dynamic tariff formation	Tariff-revenue index	$ID = D_1 / D_0$	$ID = 1.07\text{--}1.11$
Adaptive capacity reallocation	Capacity-utilization coefficient	$K_f = Q_h / Q_m$	$K_f \uparrow$
Economic redistribution of flow	Unmet-demand index	$l_{qt} = Q_{u1} / Q_{u0}$	$l_{qt} < 1$
Performance-linked subsidizing	Subsidy-return coefficient	$K_s = (D + P) / S$	$K_s \uparrow$
Operating-cost optimization	Cost index	$IX = X_1 / X_0$	$IX = 0.91\text{--}0.94$
Revenue diversification	Diversification coefficient	$K_d = D_q / D_j$	$K_d \uparrow$
Signal-based management	Integral efficiency index	$Isam = \sum w_i \cdot l_i$	$Isam = 1.36\text{--}1.37$

Source: author's elaboration. Q_s — satisfied demand; Q_t — total demand; D_0 , D_1 — baseline and updated tariff revenue; Q_h — utilized capacity; Q_m — available capacity; Q_{u0} , Q_{u1} — baseline and updated unmet demand; S — subsidy volume; P — net financial result; X_0 , X_1 — baseline and updated operating cost; D_q — revenue from supplementary services; D_j — total revenue; w_i — weighting coefficients; l_i — individual sub-indices.

Aggregating the eight sub-indicators through the weighted-sum model in equation (4) yields an integral efficiency index in the range $Isam = 1.36\text{--}1.37$, consistent with the combined effect of higher capacity utilization (8–12%, up to 15% on selected routes), reduced relative operating costs (6–9%, up to 10–13% in specific cost segments), improved subsidy targeting (12–18%), tariff-revenue growth (7–11%), higher asset-utilization efficiency (9–14%), and a 4–7 percent (up to 8–10 percent on high-density routes) improvement in the profitability trajectory.

The results confirm that the central constraint on economic efficiency in railway passenger transport is not resource volume but the coordination of resource use. Individual indicators do not automatically move together: high load factors do not guarantee strong financial results, and satisfactory financial results can coexist with poor resource utilization. This confirms, in a railway-specific setting, the general revenue-management principle that price and capacity must be jointly — not independently — optimized against observed demand structure [8].

The mechanism's distinguishing feature is that it does not treat tariff, subsidy and capacity as separate policy levers but as sequential nodes of one economic circuit: a demand signal is converted into a tariff response, the tariff response shapes revenue and behavioural incentives, and the subsidy component coordinates the residual financial gap around performance outcomes rather than compensating for it passively. This reframing

is consistent with the institutional-regulation literature on railway governance [4], which shows that subsidy mechanisms decoupled from performance outcomes tend to entrench inefficiency rather than resolve it, and with international railway-reform evidence that efficiency improvements were achieved primarily by reconnecting previously isolated management functions rather than by expanding any single instrument [3].

The 22.3 percent reduction in unmet demand and the near-elimination of the operating loss illustrated in the worked example should be interpreted as an indicative, order-of-magnitude demonstration of the mechanism's internal logic rather than a firm-level forecast; actual outcomes will depend on route-specific demand elasticity, the calibration of the capacity-adjustment coefficient α , and the institutional constraints particular to each operator. Nonetheless, the direction of the effect — improved occupancy, higher tariff revenue, lower relative cost, and a substantially reduced deficit achieved through internal reallocation rather than external financial support — is robust across the range of parameter assumptions tested.

From a policy perspective, the eight-indicator assessment model and the resulting integral efficiency index provide a practical monitoring instrument for the passenger-transport targets established under Presidential Resolution No. PQ-391 [2], allowing each priority direction to be tracked individually while the aggregate index summarizes overall progress. This positions the mechanism as a tool consistent with, rather than parallel to, ongoing railway-sector reform, and offers a route to translate broad reform objectives into operator-level performance targets that are both measurable and internally coherent.

A limitation of the study is that the weighting coefficients used in the aggregation of sub-indices (w_i) require empirical calibration against enterprise-level panel data or structured expert judgment; the present analysis establishes the analytical architecture of the mechanism rather than its fully calibrated parameter set. Extending the model with route-level demand-elasticity estimation is a natural direction for subsequent research.

CONCLUSION AND RECOMMENDATIONS

This study has developed a demand-responsive tariff–subsidy–capacity mechanism for improving the economic efficiency of railway passenger transport enterprises, grounded in the premise that efficiency is determined not by the volume of available resources but by the degree of functional coordination among demand signals, tariff formation, subsidy allocation and capacity management.

Seven priority directions were identified and organized into a coherent mechanism, and an eight-indicator impact-assessment model was constructed to evaluate their combined effect through an integral efficiency index. The worked numerical example demonstrates that redistributing demand through coordinated tariff and capacity adjustment can raise the occupancy coefficient from 1.54 to 1.37 relative to capacity, reduce unmet demand by approximately 22.3 percent, increase tariff revenue by about 12 percent, lower operating costs by roughly 7 percent, and narrow the operating loss by 95–98 percent — outcomes achieved through the internal reallocation of existing resources rather than additional financial injection.

From an applied standpoint, the proposed mechanism and its assessment model offer railway enterprise management a structured methodological tool for monitoring efficiency, and provide a measurable basis for tracking progress toward the passenger-transport targets set under Uzbekistan's railway-sector reform program and the "Uzbekistan – 2030" strategy. Future research should prioritize empirical calibration of the model's weighting coefficients using enterprise-level operating data across multiple railway routes and seasons.

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