IMPROVING THE URBAN PUBLIC TRANSPORT SYSTEM THROUGH THE STUDY OF POPULATION TRANSPORT MOBILITY: THE CASE OF JIZZAKH CITY

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Abstract

This paper presents a comprehensive engineering study of the urban public transport system of Jizzakh city, Uzbekistan, based on an experimental investigation of population transport mobility. Using a combination of GPS-monitoring (Geo Tracker application), on-board passenger counting, stop-level observation, and geographic information system (GIS) analysis in QGIS, the current state of the city's bus network was assessed. The study found that 14 of the city's 17 bus routes (82.4%) overlap along the central Sh. Rashidov Avenue, reducing the effective bus headway to only 42 seconds — a phenomenon termed the "headway paradox" — while 30 of 67 surrounding neighborhoods remain served at a coverage level of 0.3% or lower, giving an overall network coverage of just 26.2%, far below the 60–80% benchmark typical of developed cities. To resolve these interlinked problems, the internationally recognized hub-and-spoke model was applied to Jizzakh for the first time. Two transit hubs, HUB A (Kok Bozor) and HUB B (Eski Shahar Buyum Bozori), were scientifically selected using A. Seder's criteria system, and routes No. 1, 16, and 46 were split into six shorter sub-routes. This "cost-free expansion" solution frees 13 buses with zero additional capital investment, enabling service to 5–8 previously unserved neighborhoods. Quantitative assessment shows an annual economic and environmental benefit of about 1.68 billion soums (or up to 2.85 billion soums in additional fare revenue if the freed buses are redeployed), together with an annual reduction of 877.4 tons of CO_2, 5,331.6 kg of NO_x, and 29.6 kg of PM2.5. The results provide a scientifically grounded, replicable methodology for planning sustainable and internationally compliant public transport systems in Jizzakh and other medium-sized cities of Uzbekistan.

Keywords: population transport mobility, urban public transport, hub-and-spoke model, GPS-monitoring, GIS analysis, headway paradox, transit hub, cost-free expansion, transport planning, Jizzakh city.

1. Introduction

The sustainable development of modern cities depends critically on the level of population transport mobility. Public transport demand grows continuously as urban residents commute to work, education, healthcare, and commercial facilities. In the Republic of Uzbekistan, improving urban public transport systems has become one of the priority directions of state policy: Presidential Resolution No. PQ-59 of 16 February 2023 "On measures for the radical improvement of the public transport system" and Resolution No. PQ-276 of 2 June 2022, together with the 2030 Sustainable Development Goals decree (PF-6155) and the "Strategy for Transition to a Green Economy" decree, form the legal basis for reform in this sector. However, the scientific re-planning of public transport systems and optimization of resources at the level of regional centers remains insufficiently studied.

Jizzakh city currently operates 17 intra-city bus routes. The research identified three closely interlinked systemic problems:

- Route overlap: 14 of the 17 routes (82.4%) run along the city's main thoroughfare, Sh. Rashidov Avenue, compressing the effective bus arrival interval to about 42 seconds — 4.3 to 7.1 times shorter than the international norm of 5–8 minutes during peak hours (V. Vuchic). Transport economics literature terms this the "headway paradox": multiple buses running simultaneously along the same corridor do not increase system efficiency but instead waste resources.
- Low public transport coverage: out of 67 neighborhoods in and around the city, 30 have a coverage level of 0.3% or lower; the overall coverage stands at only 26.2%, well below the 60–80% typical of developed cities.
- Low bus load factor: the average load factor across the system is only 41%, compared with 65–85% in developed countries, meaning that on average 60% of bus capacity runs empty — an inefficient use of fuel, maintenance, and driver-related costs.

These three problems are causally linked: the excessive concentration of routes and resources on Sh. Rashidov Avenue starves peripheral areas of service, which lowers overall coverage and depresses the average load factor. Resolving this systemic problem through the internationally established hub-and-spoke model, and providing scientific justification for its application to Jizzakh, constitutes the central aim of this research.

2. Aim, objectives and scientific novelty

The aim of the study is to scientifically substantiate an engineering solution for improving the Jizzakh city public transport system based on the hub-and-spoke model, and to quantitatively evaluate its economic, environmental and social effectiveness.

To achieve this aim, the following objectives were addressed: (1) study the theoretical foundations of population transport mobility and public transport planning models; (2) analyze international and domestic experience in improving public transport networks; (3) examine the operating mechanism of the transit-hub model and the principles of route splitting; (4) experimentally study the current state of the Jizzakh public transport system through a combination of passenger-flow measurement and GIS analysis; (5) identify transit hubs (HUB A and HUB B) on the basis of headway, load-factor and coverage data; (6) design a sub-route splitting scheme for routes No. 1, 16 and 46 and technically verify the resulting headways; (7) assess the economic effectiveness of the proposed solution.

The scientific novelty of the research lies in the following: population transport mobility in an Uzbek regional city was, for the first time, studied through a combination of GPS-monitoring, direct passenger counting and GIS analysis; the hub-and-spoke model was applied to Jizzakh city for the first time using A. Seder's criteria system; transit hubs were selected on the basis of empirical data and sub-routes verified against V. Vuchic's headway standards; and the "cost-free expansion" principle was practically demonstrated, whereby 13 buses are freed for redeployment with zero additional capital investment.

3. Materials and methods

The study combined five complementary methods recommended in international practice: (1) GPS-monitoring — all 17 existing bus routes were tracked using the Geo Tracker mobile application, recording arrival/departure times, dwell times, running speed and actual distance covered; (2) direct on-board passenger counting — boarding and alighting passengers were recorded at every stop, following A. Seder's methodology; (3) stop-level observation — conducted at 8 key stops along Sh. Rashidov Avenue over at least 5 working days each, from 06:00 to 21:00; (4) GIS analysis — carried out in QGIS 3.34, where a 400-meter pedestrian service buffer was built around every route and overlaid with the population density map of the city's 67 neighborhoods (36 within the city and 31 in the surrounding area); (5) economic-environmental modeling — the effectiveness of the proposed engineering solution was evaluated across five components, using emission factors from the IPCC 2006 Guidelines, the ICCT 2009 CNG Bus Emissions Roadmap, and the EMEP/EEA 2023 Air Pollutant Emission Inventory Guidebook. Data reliability was confirmed by the fact that direct-count results differed from stop-observation results by less than 5%. Field observation was carried out on working days throughout 2024.

4. Results and discussion

4.1. Current state of the Jizzakh public transport system

Jizzakh city, the administrative center of Jizzakh region, had a population exceeding 195,800 by early 2024 (up from 163,000 in 2014 and 174,000 in 2019). The public transport network comprises 17 intra-city bus routes totaling 323 km, serviced by 174 buses of average capacity 45–60 passengers (ISUZU NP37, ANKAI, ZONG TONG and other models) across roughly 80 stops. Route lengths vary widely, from 10.2 km (route 14) to 30.3 km (route 16), indicating an unevenly planned network.

Applying the headway formula $H = T/N$ (Vuchic, 2017), where $T = 10$ minutes is the average route-level interval and $N = 14$ is the number of routes overlapping on Sh. Rashidov Avenue, the effective bus arrival interval on the avenue is $H \approx 42$ seconds — 4.3 to 7.1 times shorter than the internationally recommended 3–5-minute headway for high-quality bus corridors. While a very short wait time (≈21 seconds on average) may appear beneficial to passengers at first glance, this concentration of resources leaves peripheral neighborhoods without adequate service — the "headway paradox".

GIS-based coverage analysis confirmed that of 67 neighborhoods (MFY) in and around the city, only 37 have meaningful public transport access; 30 neighborhoods have a coverage level at or below 0.3%, and the overall coverage across the city and surrounding area is only 26.2% — far below the 60–80% benchmark of developed cities.

4.2. Transit-hub selection and route restructuring

Applying A. Seder's criteria system (daily passenger flow ≥ 2,000 persons/day; at least 5 intersecting routes; proximity to key destinations such as markets, education and healthcare facilities; convenient interchange conditions), two transit hubs were identified from the experimental data:

- HUB A (Kok Bozor): 3,539 passengers/day, 15 intersecting routes, located at the northern part of Sh. Rashidov Avenue near the city's main bazaar — ranked first in passenger flow.
- HUB B (Eski Shahar Buyum Bozori): 2,509 passengers/day, 12 intersecting routes, located at the southern part of the avenue near the old bazaar — ranked second in passenger flow.

The 7.6-km segment of Sh. Rashidov Avenue between HUB A and HUB B was identified as a redundant, overlapping corridor for three long routes — No. 1 (24.5 km, one-way), No. 16 (30.3 km) and No. 46 (23.6 km) — whose load factors (0.43–0.49) confirmed that shortening them would not compromise passenger service quality. Each of the three routes was split into two independent sub-routes terminating at HUB A and HUB B respectively, removing duplicated running along the shared corridor. Technical verification (H = (2×L/v)×60/N, with v = 19.6 km/h) confirmed that all six resulting sub-routes maintain headways of 8–14 minutes, fully within Vuchic's recommended daytime range of 10–15 minutes.

As a result of eliminating the shared 7.6-km corridor segment from these three routes, N_saved = N × (L_corridor / L_total) buses are released from operation: 5 buses from route 1, 4 from route 16, and 4 from route 46 — 13 buses in total. On the corridor itself, the number of overlapping routes falls from 14 to 11, and the headway normalizes from 42 seconds to about 60 seconds (1 minute), still far shorter than the international 3–5-minute benchmark, so service quality on the corridor is preserved.

4.3. Economic and environmental effectiveness

The 13 buses released from operation cover a combined 987,325 km/year less running distance (2,705 km/day at 4 trips/day per bus). This translates into the following annual savings: CNG fuel — 439.9 million soums (325,817 m^3 saved at 1,350 soums/m^3); technical maintenance (15% of fuel cost) — 66 million soums; and driver salaries (13 drivers × 4,000,000 soums/month × 12) — 624.0 million soums, giving a direct operating saving of 1,129.8 million soums/year.

Using internationally recognized emission factors — IPCC 2006 (2.693 kg CO_2/m^3 of CNG), ICCT 2009 (5.4 g NO_x/km) and EMEP/EEA 2023 (0.03 g PM2.5/km) — the reduced running distance corresponds to annual reductions of 877.4 tons of CO_2 (equivalent to the annual absorption capacity of about 39,883 trees), 5,331.6 kg of NO_x, and 29.6 kg of PM2.5. Valuing the CO_2 reduction at the World Bank's recommended social cost of carbon (50 USD/ton, at an exchange rate of 12,600 soums/USD) adds 552.8 million soums/year, bringing the total annual economic and environmental effect of holding the 13 buses in reserve to approximately 1,682.7 million soums (≈1.68 billion soums).

Alternatively, redeploying the 13 freed buses to establish 5–8 new short routes serving previously uncovered neighborhoods — at a conservative estimate of 200 passengers/bus/day and a fare of 3,000 soums — would generate additional annual fare revenue of about 2,847.0 million soums (≈2.85 billion soums), while raising the city's overall public transport coverage from 26.2% to an estimated 34–36%. In either scenario, the solution requires zero additional capital investment, providing a practical demonstration of the "cost-free expansion" principle.

Table 1. Summary of key indicators before and after the proposed engineering solution

Indicator	Current state	Proposed state	Change
Routes overlapping on Sh. Rashidov Ave.	14 (82.4%)	11	− 3 routes
Corridor bus headway	≈ 42 seconds	≈ 60 seconds (1 min)	+ 18 sec (normalizing)
Overall PT coverage of neighborhoods	26.2%	34–36%	+ 8–10 p.p.

Indicator	Current state	Proposed state	Change
Buses in active operation on routes 1,16,46	42	29 (13 released)	– 13 buses
Average bus load factor (system-wide)	41%	improves with redeployment	—
Annual CO_2 emissions (routes 1,16,46 saved distance)	baseline	– 877.4 t/year	reduction
Annual NO_x emissions	baseline	– 5,331.6 kg/year	reduction
Annual economic effect (reserve scenario)	—	≈ 1.68 billion soums/year	new
Annual fare revenue (redeployment scenario)	—	≈ 2.85 billion soums/year	new

5. Conclusion

The study demonstrates that Jizzakh city's public transport problems — route overlap, low coverage, and inefficient load distribution — are causally interlinked and can be resolved through a single, scientifically grounded engineering solution rather than three separate interventions. The combination of GPS-monitoring, direct passenger counting and GIS analysis, applied for the first time to an Uzbek regional city, provided a reliable empirical basis (with less than 5% divergence between independent methods) for identifying two transit hubs and restructuring three overloaded routes into six sub-routes under the internationally recognized hub-and-spoke model. Verification against V. Vuchic's headway standards confirmed that the proposed sub-routes maintain adequate service quality, while quantitative analysis showed that the solution frees 13 buses at zero additional capital cost, yielding an annual economic and environmental benefit of roughly 1.68–2.85 billion soums together with reductions of 877.4 tons of CO_2, 5,331.6 kg of NO_x, and 29.6 kg of PM2.5 per year — directly supporting Uzbekistan's Green Economy strategy and its climate commitments to 2030. Beyond Jizzakh, the methodology and the hub-and-spoke restructuring approach developed here are directly transferable to other medium-sized cities of Uzbekistan with similar demographic and geographic characteristics. Future research should focus on designing passenger-transfer infrastructure at HUB A and HUB B, introducing real-time schedule information systems, and establishing a 3–5-year monitoring program to track the long-term impact of the reform.

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