Integrated assessment of urban public transport using accessibility indices and user perceptions in Aktobe, Kazakhstan

Aigul SERGEYEVA, Sergey PASHKOV, Yerkin TOKPANOV

***Abstract*: *This article presents the results of a comprehensive investigation into the transport and infrastructural conditions influencing the development of public transportation in the city of Aktobe, Republic of Kazakhstan. The central aim of the study is to conduct an integrated spatial-functional assessment of urban public transport services in a context of rapid demographic growth, increasing motorization, and peripheral urbanization. The rationale arises from the limited availability of empirical research focused on second-tier post-Soviet urban centers where public transport remains under strain. Methodologically, the study employs a mixed-methods approach comprising geographic information systems (GIS)-based spatial analysis, stratified sociological surveying of 501 residents, and a set of statistically derived transport accessibility indices. Two composite indicators – the Public Transport Availability Index (PTCI) and the Integrated Transport Service Index (IPTSI) – were calculated based on service frequency, stop density, population coverage, and average waiting time. The results of the study reveal pronounced spatial asymmetries in transport provision: whereas central districts demonstrate a high level of accessibility and user satisfaction (over 80%), peripheral and suburban territories remain significantly underserved (below 30%). Although certain digital innovations (such as fare card systems and vehicle monitoring) have been introduced, systemic deficiencies persist – namely, insufficient network coverage, irregular service intervals, infrastructural degradation, and weak modal integration. The study argues for the necessity of a strategic reconfiguration of the route network, coupled with the introduction of environmentally sustainable transit solutions. Among the strengths of the study is its synthesis of spatial, perceptual, and infrastructural data into a single analytical framework capable of supporting evidence-based policy recommendations. However, its temporal scope limits dynamic forecasting potential. The findings possess broad applicability for medium-sized urban centers in transition economies and may serve as a reference point for rethinking public transport modernization strategies under conditions of constrained institutional and financial capacity.*

***Keywords*: *public transport systems, spatial inequality, urban infrastructure, sustainable mobility, Aktobe*

Introduction

Urban public transport constitutes an integral component of urban infrastructure and plays a key role in the spatial organization of the urban environment. Its development has a direct impact on population mobility, access to essential services, the reduction of social inequality, and the sustainability of urbanized areas. As noted by Utkin (2008) and Yannis and Chaziris (2022), the effectiveness of public transport systems is closely linked to the overall quality of urban life and the functional balance of the urban system.

Contemporary research emphasizes the importance of distinguishing between the factors that determine the quality of public transport services. Several parameters – such as the technical condition of the vehicle fleet, service regularity, driver discipline, passenger service standards,

https://doi.org/10.33542/GC2026-1-02

and operational reliability – are directly dependent on transport operators (Fomin et al. 2020). In contrast, issues such as route network planning, integration of different transport modes, fare regulation, infrastructure investment, and the implementation of environmentally sustainable solutions fall within the domain of transport policy and strategic governance (Rasca and Saeed 2022, Gabor and Pregi 2023).

Amid rapid urbanization and increasing motorization, the issue of accessibility and efficiency of public transport systems has become particularly acute in medium-sized and large regional centers across the post-Soviet space. Similar challenges are observed not only in Kazakhstani cities such as Karaganda and Pavlodar, but also in neighboring countries – in Tashkent (Uzbekistan), Bishkek (Kyrgyzstan), as well as Omsk and Orenburg (Russia). In these urban agglomerations, as in Aktobe, there is a clear mismatch between the pace of spatial expansion and the modernization of transport infrastructure. Common problems include insufficient route coverage in peripheral areas, limited investment, aging vehicle fleets, and a low level of digitalization.

Ongoing scholarly debate centers on the extent to which the persistence of these challenges is shaped by the institutional legacy of the post-Soviet period or driven by contemporary processes of urban transformation (Sorokina 2014, Molgazhdarov and Bazarbekova 2017, Volkova et al. 2022). The post-Soviet model of urban planning, inherited from a centralized administrative system, is characterized by a rigid linkage of transport services to formal administrative boundaries, a lack of operational flexibility, and inertia in infrastructure renewal. However, emerging challenges – such as uneven population growth, accelerated suburban development, and environmental pressures – underscore the need to revise entrenched governance models.

Numerous studies have confirmed a direct correlation between improvements in the quality of public transport services and increases in both passenger ridership and user satisfaction (Ibrahim 2003, Hampshire 2017, Tahmasseby 2022). The introduction of electronic fare systems, digital route monitoring, fleet renewal, and enhanced travel comfort contribute to greater public trust in public transportation – particularly among residents of suburban areas.

In this context, Aktobe serves as a representative example of a rapidly growing medium-sized city where the need for systemic modernization of the public transport system is especially acute. Its geographical location, industrial capacity, and demographic dynamics generate sustained demand for accessible and high-quality transport services, especially in newly developed residential districts and suburban zones. However, weak institutional coordination and limited resource availability continue to hinder the implementation of long-term strategic solutions.

The objective of this study is to conduct a spatial and functional analysis of the public transport system in the city of Aktobe through the application of GIS-based modeling, sociological surveys, and the calculation of composite transport accessibility indices. Particular attention is given to identifying spatial inequalities, assessing user satisfaction, and formulating practical recommendations for the sustainable transformation of the transport system in the context of urban digitalization and environmental modernization.

Literature Review

The development of public transport systems is shaped by a wide range of factors, typically divided into operational and strategic categories. Operational parameters – such as the technical condition of rolling stock, service regularity, driver behavior, passenger comfort, and safety – fall within the domain of transport operators. In contrast, strategic factors – including network planning, fare policy, infrastructure investment, modal integration, and sustainability priorities – are determined at the level of transport authorities, municipal governments, and national transport policy frameworks (Krüger et al. 2021, Kreindler et al. 2024).

The issue of measuring and integrating accessibility into transport planning has been the subject of active research for several decades. In the European context, scholars emphasize that accessibility instruments are increasingly applied not only in academic studies but also in practical urban planning (Papa et al. 2015). The authors highlight the diversity of methodological approaches, ranging from classical cumulative indices to complex integrated models that link transport and socio-economic data.

Curl et al. (2011) point out that formal accessibility indicators often ignore the subjective priorities of residents and fail to account for actual behavioral factors. As a result, planning frequently diverges from the real needs of the population, thereby reducing the practical value of such instruments.

The problem of methodological elaboration of accessibility indicators is addressed in detail by El-Geneidy and Levinson (2006), who, within the Access to Destinations project for Minnesota, proposed a system of accessibility indices. The authors developed a set of measures that capture the reachability of key destinations while taking into account travel time and transport modes. Similarly, Geurs and Van Eck (2001), in their review, classify accessibility measures and demonstrate their applicability for assessing spatial inequality and the sustainability of transport systems.

Alongside accessibility measures, another important area of research concerns the efficiency of public transport systems. De Borger et al. (2002), applying frontier analysis methods, demonstrated that the performance of public transport cannot be evaluated solely in terms of network size and coverage. Efficiency should be assessed comprehensively, incorporating institutional and managerial factors.

Collectively, these studies indicate a transition from simple spatial indicators (such as the number of stops or accessibility radius) toward integrated models that incorporate both transport supply and user perceptions. At present, the key challenge remains the adaptation of these indices to the conditions of medium-sized and peripheral cities, where infrastructure is limited and social expectations are particularly acute.

The issue of whether public transportation in Kazakhstan meets high international standards requires a comprehensive and critically grounded analysis that considers both institutional specificities and the spatial-social characteristics of the country's development. At the current stage of transport system formation in the Republic of Kazakhstan, it can be stated that, despite certain positive changes in specific sectors and regions, public transportation as a whole does not reach the level corresponding to internationally recognized standards in the domains of sustainable mobility, transport equity, and inclusive infrastructure.

In particular, major urban centers such as Almaty, Astana, and to a certain extent, Shymkent, have implemented initiatives aimed at fleet modernization, the introduction of electronic fare collection systems, improvement of transport services, and the integration of digital platforms for navigation and real-time monitoring. However, these cities still face systemic challenges: high congestion during peak hours, irregular service schedules, limited accessibility for persons with reduced mobility, the absence of dedicated bus lanes, and underdeveloped transfer and multimodal hubs. These factors significantly reduce the efficiency and attractiveness of public transport compared to private car use.

The situation in small and medium-sized cities, as well as in rural areas, is even more critical. These territories are characterized by an aging and deteriorated vehicle fleet, the lack of reliable scheduling, and minimal or entirely absent digital services. This creates a high degree of transport vulnerability, especially for socially disadvantaged groups and residents of peripheral areas, thereby exacerbating spatial inequalities in access to essential services.

It should be emphasized that the development of transport infrastructure should not be the exclusive prerogative of large cities, although in practice, metropolises often receive priority attention from both state policies and international donors. In the context of pronounced spatial disparities – typical for Kazakhstan and other post-Soviet states – there is a pressing need to shift from a selective (fragmented) approach to an integrated model of transport infrastructure development. This model should be oriented toward ensuring connectivity across the entire settlement system (Kosherbay et al. 2022).

Systemic challenges stemming from this dichotomy are also evident in Kazakhstani cities such as Karaganda, Pavlodar, and Shymkent, where urban expansion has been accompanied by growing spatial inequalities in public transport accessibility, particularly in suburban areas (Kenespaeva et al. 2023, Ramazan and Nokhatov 2023). In such cases, isolated interventions – for instance, upgrading the bus fleet or introducing electronic fare collection systems – have proven insufficient in the absence of a strategic revision of route planning and overall network logic. Similar issues persist across Central Asian cities: in Tashkent and Bishkek, public transport systems continue to suffer from outdated rolling stock and fragmented route networks, despite partial implementation of digital tools (ITF 2022). In Central and Eastern Europe, post-socialist inertia and limited institutional flexibility hinder the adoption of integrated sustainable mobility models, especially in small and medium-sized cities that still face modal fragmentation and financial constraints (Pojani and Stead 2015).

At the opposite end of the spectrum are Western European cities such as Vienna, Gothenburg, and Freiburg, which have achieved a high degree of integration between public transport, cycling and pedestrian infrastructure, digital mobility services, and environmental standards (Buehler and Pucher 2011). City size also plays a significant role in shaping the nature of transport solutions. As noted by Rode (2023), large metropolitan areas benefit from economies of scale, institutional capacity, and access to investment resources, whereas small and medium-sized cities face challenges related to the financial unsustainability of route networks and limited public subsidies, reinforcing spatial inequalities in transport provision.

Public transport accessibility is a key indicator of spatial equity and sustainable territorial development. In cities such as Aktobe, rapid expansion of residential areas has been accompanied by inertial development of the route network, resulting in insufficient coverage of peripheral districts and growing transport vulnerability. Analyzing these dynamics requires the use of validated indices that capture both the spatial configuration of the network and its functional capacity.

Accessibility assessment is based on a variety of index types, each reflecting specific dimensions of transport supply and demand. One of the most widely used approaches is the Cumulative Opportunity Index (COI), which calculates the number of destinations (jobs, services, institutions) reachable from a given location within a predefined time threshold (typically 30-45 minutes). These indices are intuitive and well-suited for visualization through isochrone mapping (Gutiérrez et al. 2011). However, their limitation lies in the fixed time cut-off, which may distort accessibility estimations, especially in areas with irregular service frequency. In the southern districts of Aktobe, it has been found that after 8:00 PM, approximately 28% of residents lack access to key urban destinations within a 30-minute window, despite the formal presence of public transport routes (Mussagaliyev 2023, Sergeyeva et al. 2025).

Dynamic accessibility models, such as the Time Cube and Frequency Weighted Accessibility (FWA) proposed by Levinson and Wu (2020), account for temporal fluctuations in public transport schedules and route availability throughout the day. This is particularly relevant for cities with marked asymmetries between peak and off-peak service intervals.

Despite recent advancements in transport planning in Kazakhstan's largest cities (Almaty and Astana), the academic literature lacks systematic applications of comprehensive accessibility models in secondary cities. In the case of Aktobe, for instance, there is a notable absence of studies integrating spatial indices (COI, PTAL), functional models (FWA), and social equity metrics (coefficient of variation, CV). Furthermore, there is minimal adaptation of existing methodologies to local climatic conditions and behavioral mobility patterns.

The current scientific agenda increasingly calls for a shift from single-factor assessments toward hybrid models that incorporate spatial network configuration, temporal variability, institutional context, and social justice. Such an approach is essential for identifying "transport deserts," prioritizing infrastructure investment, and developing a resilient and inclusive mobility framework for cities like Aktobe.

Materials and Methods

Context and Programmatic Framework

This research was conducted within the framework of the Strategic Development Plan of the Republic of Kazakhstan until 2025, which emphasizes the advancement of an efficient and competitive transport infrastructure, the improvement of transit and urban transport services, and the digital transformation of the transport and communication complex (GovRK 2010).

For comparative purposes, additional data from the cities of Almaty and Astana were reviewed. This included selected transport indicators such as average waiting times, fleet renewal measures, and accessibility indices. The data were obtained from official sources, including the Master Plan of Almaty 2030 ACMD 2023) and reports of the Akimat of Astana (AA 2023).). These secondary materials were not analyzed statistically but were used to contextualize and interpret the results for Aktobe within a broader national framework.

The development of Aktobe as one of the largest regional centers is accompanied by population growth, the expansion of administrative boundaries through the incorporation of rural districts, and an increase in the level of motorization. According to the city administration, the population of Aktobe grew from 512.4 thousand in 2021 to 556.1 thousand in 2022 (BNS RK 2024). This demographic growth has led to increased transport demand, rising traffic congestion, deterioration of environmental indicators, and has highlighted the urgent need for improvements in the public transport system (GovRK 2018).

At present, the city operates 53 bus routes, serving both the urban area and suburban zones, including garden and dacha settlements. Passenger transport services are provided by four companies: "Avtopark," "Tabys Aktobe," "Qala Trans," and "Aqzhaiyq Avtopark." The first bus line in Aktobe was launched in 1927 and remained the only mode of public transportation until the introduction of trolleybus services in 1982. However, since the early 2000s, the number of trolleybuses steadily declined, and their operation was completely discontinued in 2013. In 2021, a cashless fare payment system was introduced, which contributed to increased revenues of transport companies and created favorable conditions for investors. As a result, carriers from other cities entered the market: "Qala Trans" from Almaty in 2021 and "Aqzhaiyq Avtopark" from Atyrau in 2022. This led to greater competition, which in turn stimulated fleet renewal and service quality improvements.

To assess public perception of the quality and accessibility of public transport services, a sociological survey was carried out among residents of the city of Aktobe and adjacent suburban settlements in March 2024. A total of 501 respondents participated in face-to-face interviews based on a structured questionnaire consisting of 13 questions on transport behavior, service quality, and user satisfaction.

The sample was formed using the method of stratified random sampling, ensuring representativeness across three main criteria: territorial location, age, and social status. The stratification was structured as follows: Territorial coverage (Central urban districts – 40% of respondents; Peripheral (outlying) residential areas – 35%; Suburban settlements (Sazdy, Zhana konys, Kyzylzhar, Kargaly, Altyn Orda, etc.) – 25%); Gender and age distribution (Men – 59.4%;

Women – 40.6%); Age groups (18-34 years – 34%, 35-54 years – 36%, 55 years and above – 30%); Social status (Employed persons – 65%, Students – 20%, Retired individuals – 15%).

A ten-point scale was used to assess subjective satisfaction with public transport services. In addition, open-ended questions were included to collect qualitative data for content analysis.

Perception-based indicators were analyzed at two spatial scales: the settlement level and the administrative district level. Respondents evaluated public transport services at each scale using separate sets of questions. Settlement-level indicators reflect assessments of transport conditions within the immediate residential environment, whereas district-level indicators represent independent evaluations of transport infrastructure and mobility conditions across the administrative district as a whole. Accordingly, district-level perception scores are based on direct survey responses and are not derived from aggregation or averaging of settlement-level values.

Importantly, district-level perception scores are not arithmetic averages of settlement-level values. They reflect assessments of functionally shared infrastructure (arterial roads, bridges, inter-district corridors) used by residents across multiple settlements and may therefore exceed individual settlement-level scores.

The stratified sampling quotas by territorial location, gender, age, and social status were established in accordance with the latest demographic data for the city of Aktobe (BNS RK 2024). The gender and age structure of the sample is close to the official population structure, with deviations not exceeding 3-5%. Territorial quotas (central districts, peripheral areas, suburban settlements) reflect the actual distribution of residents within the urban agglomeration. Social status quotas were based on official employment data, with the share of students and elderly residents increased, as these groups are more frequent users of public transport.

This stratified sampling framework ensured the representativeness of the data and enabled the identification of differences in evaluations across various social and spatial population groups.

The normative walking distance of 500 m was used only for validation purposes, in accordance with widely accepted standards in urban transport planning (Transport for London 2010, Mavoa et al. 2012, Shah and Adhvaryu 2016). However, due to the climatic conditions of Aktobe – characterized by long winters, limited pedestrian comfort, and a low-density urban structure – the 200 m walking radius was applied as the primary threshold for calculating the K_{access,d} coefficient and the Public Transport Coverage Index (PTCI_d). The 500 m buffer was employed exclusively for supplementary sensitivity analysis, which showed that although K_{access,d} values increase under the wider threshold, the relative ranking of districts remains unchanged (tab. 1). The Integrated Public Transport Service Index (IPTSI_d) does not depend on walking distance and was therefore calculated independently of buffer radii.

Tab. 1. *K values for 200 m and 500 m walkable distances in the districts of Aktobe*

District	K (200 m)	K (500 m)
Astana district		
Sazdy	0.75	0.92
Zhana Konys	0.65	0.88
City Center	0.95	0.98
Almaty district		
Kyzylzhar	0.60	0.85
Kargaly	0.70	0.90

The Public Transport Coverage Index (PTCI) is used to quantify the spatial availability of public transport infrastructure within the urban environment. In contrast to conventional stop-density measures, the PTCI incorporates the accessibility coefficient K, which denotes the proportion of residents located within a 200 m walkable distance of the nearest public transport stop. Integrating this parameter provides a more accurate representation of effective accessibility by correcting for potential overestimations in areas where formal stop density is high but functional accessibility remains limited due to physical barriers (rail lines, industrial zones) or a fragmented street network.

For cartographic visualization, the 200 m and 500 m accessibility zones shown in fig. 2 were constructed as Euclidean (circular) buffers rather than network-based walksheds. This approach was adopted to ensure spatial comparability between districts and to provide a clear illustration of standardized walkable thresholds. The analytical interpretation in the text relies on the normative walking-distance criteria rather than detailed network-distance modelling. Euclidean buffers serve an illustrative function only and do not substitute for functional accessibility assessment.

Accordingly, the PTCI for each administrative district d was calculated as follows:

$$PTCI = \frac{N_d}{A_d} \times K \qquad (1)$$

where:

N_d – number of public transport stops in district *d*,

A_d – area of district *d* (km²),

K – proportion of residents situated within 200 m of the nearest stop.

To evaluate the functional capacity of the public transport system relative to population demand, the IPTSI was developed. This indicator reflects the intensity of scheduled public transport services by measuring the number of departures per hour per 1,000 residents.

The index was computed in three stages.

Step 1. Departure frequency per stop

$$dep_s = \sum_r f_{r,s} \qquad (2)$$

where $f_{r,s}$ – hourly departures of route *r* at stop *s*.

Step 2. Total departure frequency at the district level

$$D_d = \sum_{s \in S(d)} dep \qquad (3)$$

where S(d) – set of all stops located within district *d*.

Step 3. District-level IPTSI

$$IPTSI = \frac{D_d}{P_d} \times 1000 \qquad (4)$$

where P_d – resident population of district *d*.

In this study, the formulas for PTCI and IPTSI were applied at two spatial levels. First, settlement-level indicators (PTCI and IPTSI were calculated for each individual settlement using the same computational procedures. Second, aggregated district-level values of objective accessibility indicators (PTCI and IPTSI were derived through population-weighted aggregation of settlement-level indicators within each administrative district. This two-stage approach ensures methodological consistency between spatial units and provides comparability across both settlement and district scales.

This formulation integrates both infrastructural (spatial distribution of stops) and operational (service frequency) characteristics, producing a comprehensive indicator of transport supply relative to demographic load. The index was calculated separately for morning (07:00-09:00) and evening (17:00-19:00) peak hours to capture intraday fluctuations in service availability.

The proposed formula represents an original adaptation of existing approaches to composite public transport indices, as applied in international research (Saghapour et al. 2016). Methodologically, this index integrates supply-side parameters with demographic pressure, making it applicable for analyzing service balance in medium-sized cities with constrained resources.

The IPTSI is a composite measure combining indicators of transport supply (number of routes, service frequency) with demographic load. This index reflects the balance between route availability and the intensity of their use. In contrast to PTCI which captures geographical proximity to stops, IPTSI demonstrates the functional capacity of the transport system to meet passenger demand.

Together, the two indices provide a comprehensive identification of spatial inequalities and functional deficits within the city's public transport network.

In this study, an integrated approach to transport accessibility assessment was applied, grounded in the principles of the Urban Accessibility Index (Bhat et al. 2000). The proposed indices (PTCI and IPTSI) combine spatial (stop density, coverage radius) and functional parameters (frequency, waiting intervals, demographic load), thus allowing for a multidimensional evaluation of public transport availability.

Spatial analysis was conducted using ArcGIS Desktop 10.8. The following cartographic layers served as the primary data sources: public transport stop locations provided by the municipal akimat (city administration); administrative boundaries and residential building polygons based on OpenStreetMap (OSM 2024) and cadastral data (DCATP AR 2023).

The assessment of public transport provision across city districts was based on aggregated indicators calculated within administrative boundaries. Pedestrian accessibility to stops was additionally analyzed using 200 m and 500 m buffer modelling to represent walkable catchment areas. Key indicators included stop density, population coverage ratios (BNS RK 2024), and service parameters such as route frequency and average waiting times (AAC 2024).

Based on the calculation of the PTCI and IPTSI, districts of Aktobe were ranked by the level of public transport accessibility. The results were visualized using thematic maps and analytical tables, highlighting spatial differentiation in transport service density and operational load across the urban territory.

The sociological survey results (n = 501) were analyzed using descriptive statistics (frequency distributions, means, standard deviations) and intergroup comparison (chi-square test, t-test). A ten-point Likert scale was applied to assess perceptions of service quality, and expert interviews with municipal officials and operators were examined through content analysis.

Further, data from the Territorial Development Program of the City of Aktobe (2016-2020) were utilized, including official 2018 statistics on the condition of the street network, characteristics of the rolling stock, and volumes of passenger transportation (AAC 2015). This enabled a retrospective comparative analysis of the spatial and temporal dynamics of the city's transport infrastructure development.

Results

The assessment of public transport accessibility in Aktobe demonstrates clear spatial inequality, structured along a core-periphery gradient: central districts exhibit high stop density and service frequency, while peripheral and newly urbanized areas remain systematically under-served. The analysis – combining quantitative indices, survey-based perceptions, and expert interviews – is contextualized by ongoing infrastructural transformation. Although the road network expanded from 651 km to 831 km between 2015 and 2022, only 46.1% had a hard surface by 2020 (AAC 2020). The municipal development program plans 30 projects totaling 48 km of new or reconstructed roads by 2024 (DPTH AR 2024), underscoring the transitional state of the city's transport infrastructure.

The spatial structure of Aktobe and its administrative districts forms the fundamental analytical framework for subsequent accessibility modeling (fig. 1).

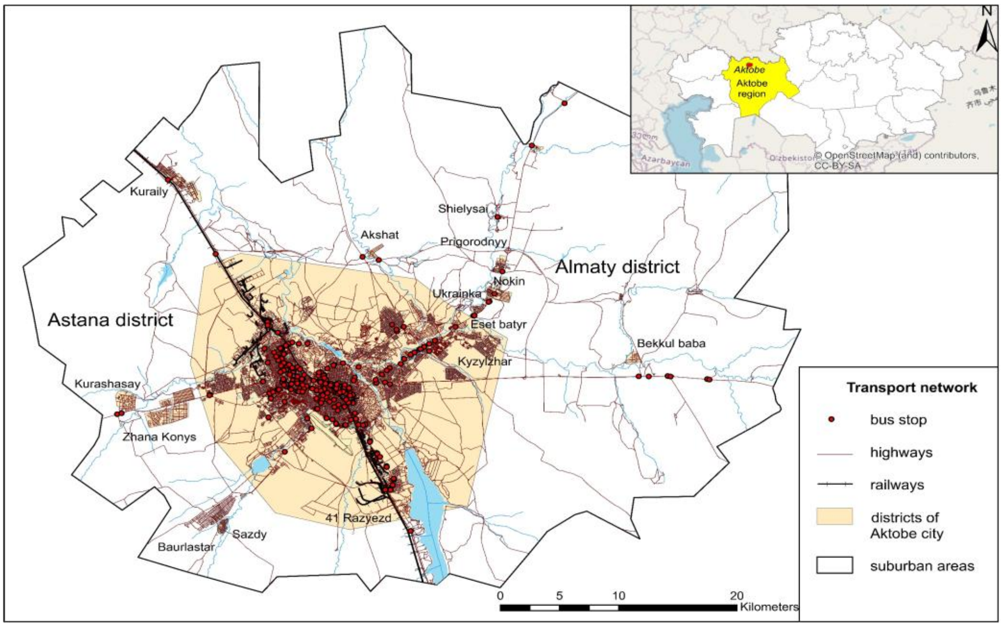

Fig. 1. *Public transport infrastructure and road network of Aktobe City; Source: Compiled by the authors based on cadastral data (DCATP AR 2023) and OpenStreetMap (OSM 2024)*

The city exhibits a polycentric yet strongly hierarchical urban morphology, with population, key services, and transport infrastructure concentrated in the historical core. Recent urban expansion has proceeded predominantly along the northwest-southeast axis, driven by intensive residential development, the incorporation of peri-urban territories, and the conversion of previously undeveloped land into urban fabric.

Pedestrian accessibility was modelled using 200 m and 500 m Euclidean buffers around public transport stops (fig. 2).

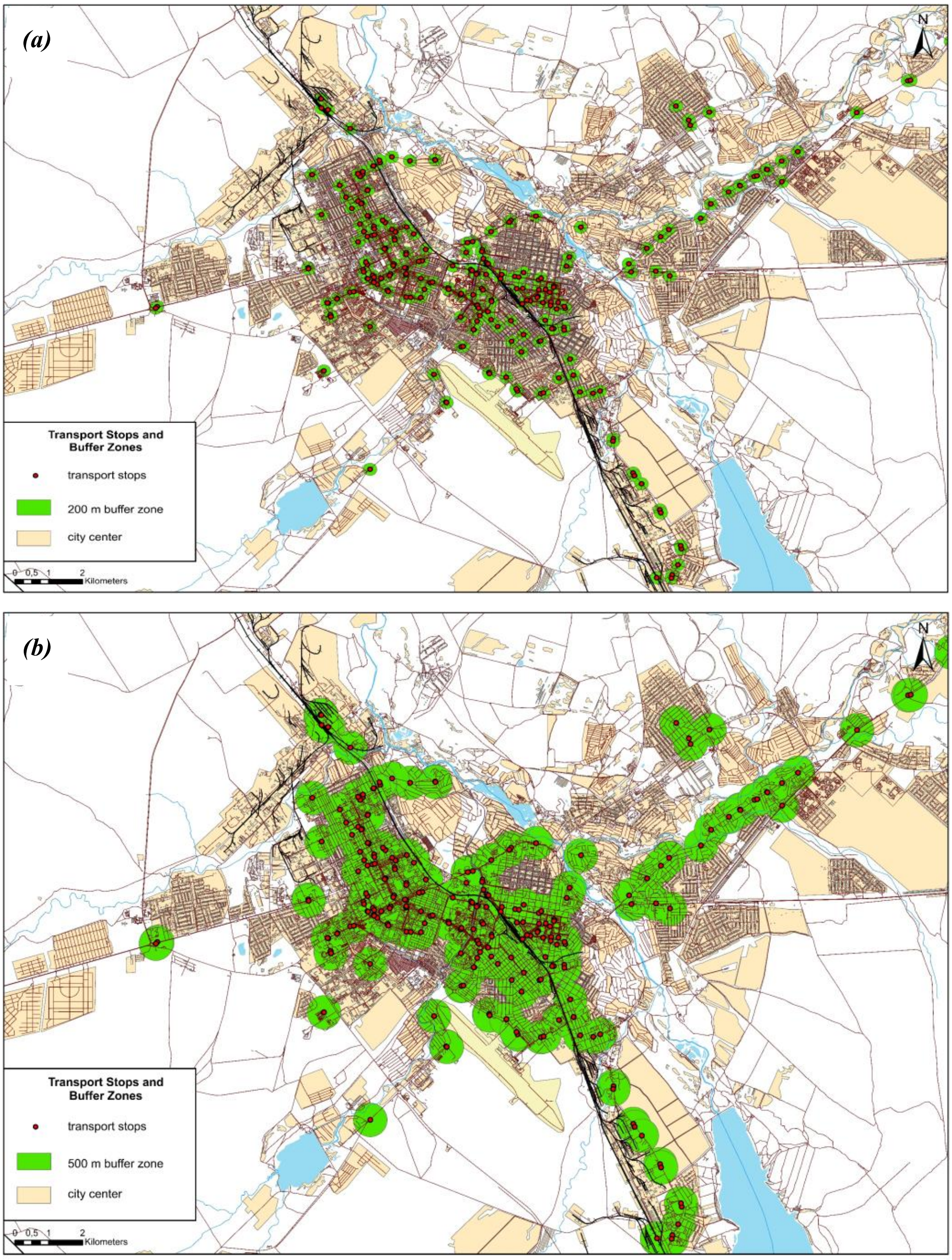

Fig. 2. *Pedestrian accessibility to public transport stops in Aktobe: (a) 200 m normative buffer; (b) 500 m extended buffer for sensitivity analysis;*
Source: Compiled by the authors based on data from OpenStreetMap (OSM 2024) and Akimat of Aktobe City (AAC 2024)

The 200 m buffer – used as the primary operational threshold for calculating K – covers only a small share of peripheral neighborhoods, indicating substantial deficits in short-distance pedestrian access. By contrast, the City Center demonstrates almost continuous coverage, consistent with its dense and coherent stop network. The 500 m buffer, applied solely for sensitivity testing, enlarges nominal catchment areas but does not alter the relative accessibility hierarchy between districts, thereby confirming the stability of the observed spatial patterns.

Travel mode preferences of Aktobe residents reveal pronounced contrasts between the central urban core and newly urbanized peripheral areas, reflecting differences in public transport availability and service performance (fig. 3). The City Center and adjacent residential blocks exhibit the highest concentration of routes and stops, forming a dense and well-integrated grid with short inter-stop distances and high route redundancy – features typical of mature transport nodes shaped by long-term infrastructural development.

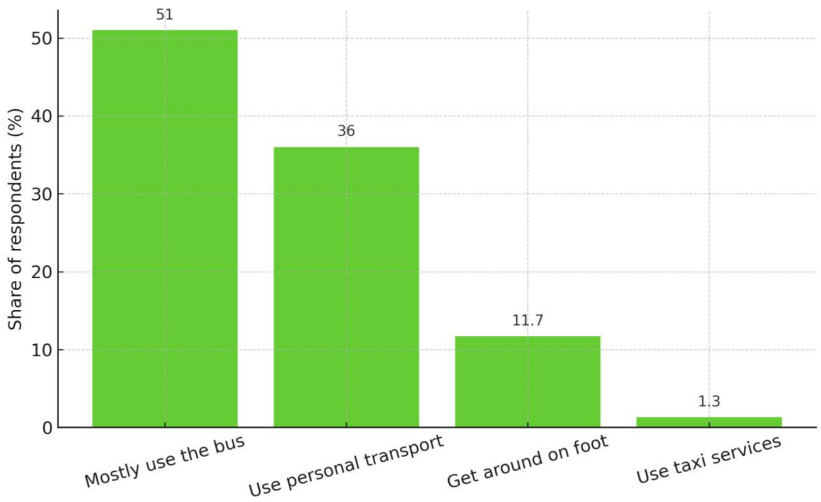

Fig. 3. *Travel mode preferences of Aktobe residents (%); Source: based on survey results*

Newly developed suburban settlements demonstrate sparse stop distribution and fragmented route connectivity, which constrains walkable access and service intensity. These structural limitations result in systematically lower PTCI and IPTSI values compared with the central districts, where dense and historically consolidated infrastructure ensures higher accessibility.

The perception-based assessment summarized in the radar chart reveals a clear and consistent spatial differentiation across districts and settlements (fig. 4). The City Center and, more broadly, the Astana district demonstrate the highest evaluation scores across most service-quality indicators, reflecting more mature infrastructure and better operational conditions. In contrast, peripheral settlements – particularly Zhana Konys and Kyzylzhar –register noticeably lower ratings, with persistent deficits in road surface quality, parking availability, and pedestrian infrastructure.

Intermediate settlements such as Sazdy and Kargaly occupy a transitional position, combining moderate strengths with several structural shortcomings. Importantly, the spatial pattern depicted in the radar chart closely mirrors the results of the objective accessibility indicators (PTCI, IPTSI), underscoring the strong alignment between residents' mobility experiences and measured accessibility levels.

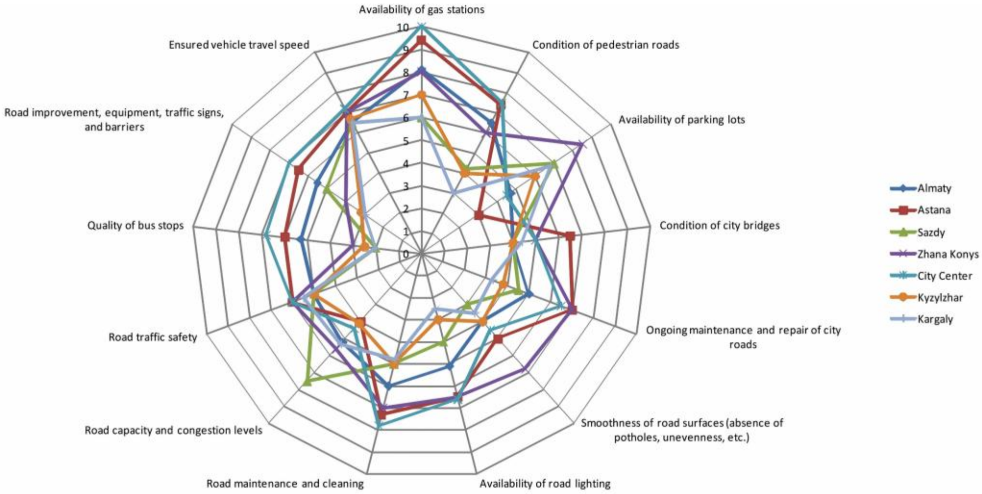

Fig. 4. *Key problems of the public transport system based on residents' perceptions at settlement and district scales; Source: Compiled based on survey results*

District-level values reflect aggregated perceptions of functionally shared infrastructure and are based on independent district-scale survey questions; consequently, they are not directly comparable to, nor mathematically constrained by, settlement-level scores.

The survey results indicate that public transport is the primary mode of daily mobility for 51% of respondents, while 36% rely on private cars. The most frequently reported problems include overcrowding (61%), long service intervals (59%), and low travel comfort (48%), particularly in peripheral settlements. More than half of respondents (56%) reported insufficient stop availability within walking distance, and 72% identified route network expansion as a priority for improving public transport services. These perceptions are spatially differentiated and align closely with the calculated accessibility indicators.

Tables 2 and 3 present settlement-level and aggregated district-level public transport accessibility indicators. The highest accessibility is observed in the City Center, driven by dense stop distribution and high service frequency, whereas peripheral settlements consistently exhibit lower values due to structural deficits in network coverage and service intensity.

Tab. 2. *Settlement-level public transport accessibility indicators (PTCI, IPTSI) in Aktobe*

Settlement	PTCI	IPTSI (07:00-09:00)	IPTSI (17:00-19:00)	Accessibility level
Sazdy	1.17	1.00	0.88	Medium
Zhana Konys	0.51	0.35	0.32	Low
City Center	5.09	2.50	2.30	High
Kyzylzhar	0.45	0.44	0.38	Low
Kargaly	0.93	0.60	0.52	Medium

Tab. 3. *Aggregated district-level public transport accessibility (PTCI, IPTSI) in Aktobe*

District	Population (analyzed settlements)	PTCI	IPTSI (07:00-09:00)	IPTSI (17:00-19:00)	Accessibility profile
Astana	61,000	aggregated value	aggregated value	aggregated value	mixed accessibility
Almaty	24,000	aggregated value	aggregated value	aggregated value	mixed accessibility

At the district scale, the same spatial gradient is evident: The Astana district records higher composite accessibility values largely because it encompasses the high-performing City Center. However, pronounced intra-district variation persists, indicating heterogeneous levels of service provision and reinforcing the need for more spatially differentiated planning.

The spatial differentiation of district-level accessibility (PTCI, IPTSI) reveals a pronounced central–peripheral gradient: high-accessibility zones cluster in the historical core, where stop density, network connectivity, and service frequency are greatest (fig. 5). Transitional districts display intermediate values, whereas low-accessibility areas dominate the northwestern and southeastern peripheries, where sparse stop distribution and limited route coverage significantly constrain mobility opportunities.

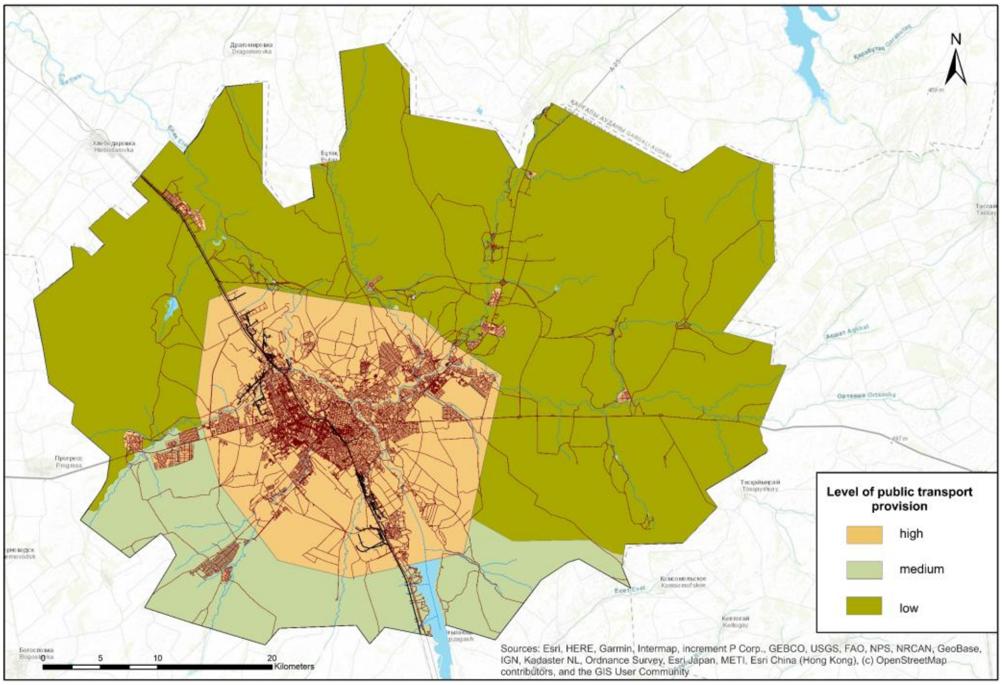

Fig. 5. *Spatial differentiation of public transport provision in Aktobe based on PTCI and IPTSI indicators; Source: Compiled by the authors based on survey data, cadastral information (DCATP AR 2023), and OpenStreetMap (OSM 2024)*

A key structural feature of Aktobe's urban form is the southwest–northeast railway corridor, which generates significant network discontinuity and constrains cross-district mobility. The limited number of crossing points reduces overall network permeability and produce localized accessibility deficits, particularly in adjacent districts where detours diminish the effective operational reach of public transport. This persistent infrastructural barrier illustrates how fixed transport structures shape spatial inequalities and underscores the need for targeted interventions to improve inter-district connectivity.

Modernization efforts likewise reveal a spatial imbalance: most projects are concentrated in areas already characterized by medium or high accessibility, while peripheral districts with the most severe deficits receive comparatively limited investment. Such asymmetry risks perpetuating disparities in network connectivity and service provision, highlighting the importance of adopting a more equity-oriented and spatially differentiated planning approach.

Survey results corroborate these structural patterns. Residents of low-accessibility settlements consistently reported longer waiting times, fewer route options, and irregular service schedules, whereas respondents in central districts expressed substantially higher satisfaction across all quality indicators. These spatial contrasts in user evaluations correspond closely to the calculated accessibility indices, reinforcing the validity of the quantitative assessment and demonstrating strong alignment between subjective mobility experiences and objective measures of accessibility.

Discussion

The empirical findings of this study reveal a complex and multi-scalar pattern of transport inequality in Aktobe, which aligns closely with well-established theoretical and empirical insights from international urban mobility research. The observed spatial disparities – manifested through pronounced contrasts between the central districts and peripheral settlements – illustrate a classic core-periphery structure that has been documented in both rapidly growing cities of the Global South and medium-sized post-Soviet urban regions.

This scale-dependent perception effect underscores the importance of distinguishing between neighborhood-level and district-level mobility assessments.

The high accessibility values recorded in the City Center correspond with theoretical expectations derived from urban accessibility models, which highlight the concentration of public transport supply, higher network redundancy, and shorter average travel distances in core urban zones (Bhat et al. 2000). Similar patterns have been reported in a wide range of urban contexts, where central locations typically benefit from historic investment, institutional prioritization, and higher land-use densities (Owen and Levinson 2015).

Conversely, low accessibility in suburban settlements such as Zhana Konys and Kyzylzhar reflects the well-known challenges faced by rapidly expanding cities, where urban growth outpaces the provision of basic transport services (Boisjoly and El-Geneidy 2017). These areas often experience fragmented street networks, insufficient stop density, and weak integration with trunk routes–structural limitations that are characteristic of emerging peri-urban landscapes worldwide.

A significant contribution of this study is the demonstration of a strong correspondence between objective accessibility indices and subjective evaluations reported by residents. Districts with low IPTSI values are also those where respondents reported the longest waiting times, irregular schedules, and low satisfaction with service quality. This alignment supports findings from international mobility research, which emphasize that user perception is highly sensitive to operational performance and directly reflects the lived mobility environment (Foth et al. 2013).

The fact that district-level perception values exceed settlement-level objective indicators is consistent with behavioral mobility theory: residents navigate across multiple urban subspaces and evaluate the system not solely based on their immediate neighborhood, but on the functional mobility corridors they routinely use.

Although the introduction of digital tools – GPS tracking, electronic fare payment, and online monitoring – aligns Aktobe with broader global trends in "smart mobility" transition, their practical impact has been modest. This observation echoes findings from studies in developing and transition economies, where technological modernization improves informational transparency but does not substantially enhance service quality in the absence of structural improvements in coverage, frequency, and route integration (Dell'Olio et al. 2011).

In Aktobe, the persistence of low accessibility in peripheral districts demonstrates that technological upgrades cannot compensate for infrastructural deficits. Without network reconfiguration and targeted investment, digitalization alone is insufficient to reduce mobility inequality.

The exclusive reliance on buses as the only operational mode of public transport represents a significant vulnerability in the city's mobility system. International comparative studies underscore that modal diversity – trams, trolleybuses, BRT, or rail – contributes to both operational resilience and environmental sustainability (Newman 2015).

In medium-sized Eurasian cities similar to Aktobe, the dismantling of rail-based modes has historically resulted in increased congestion and higher emissions. The absence of modal alternatives limits the city's capacity to absorb fluctuations in demand or service disruptions and reinforces dependence on private vehicle use.

Analysis of modernization projects shows that planned and ongoing infrastructural interventions are predominantly concentrated in zones that already exhibit medium or high accessibility (fig. 6).

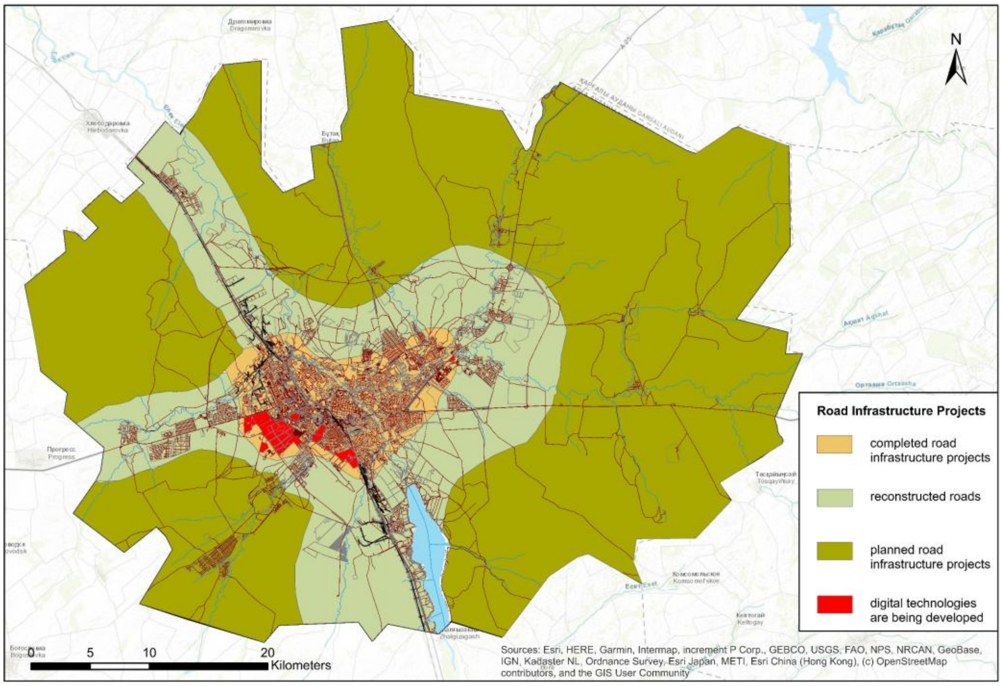

Fig. 6. *Map of Transport Infrastructure Modernization;*
Source: Compiled by the authors based on survey data, cadastral information (DCATP AR 2023), and OpenStreetMap (OSM 2024)

Meanwhile, peripheral districts – where accessibility deficits are greatest – receive comparatively fewer improvements. This spatial misalignment is characteristic of "path-dependent investment bias", a phenomenon identified in both European and Asian urban transport systems, where infrastructure upgrades tend to favour already developed corridors due to lower costs and higher political visibility (Banister 2018).

Such an investment pattern risks reinforcing existing inequalities unless accompanied by a deliberate rebalancing of priorities toward underserved areas.

Survey data reveal an emerging trend toward increased private car use in peripheral districts. This behavioral shift is consistent with international evidence demonstrating that inadequate public transport coverage leads to growing car dependency, which in turn exacerbates congestion, parking shortages, and environmental degradation (Litman 2022).

In Aktobe, the limited willingness among respondents to shift from private to public transport signals a broader challenge: without substantial improvements in service reliability, comfort, and travel speed, public transport may face declining modal share despite fleet modernization.

Conclusions

Taken together, the results position Aktobe within the broader global context of medium-sized cities undergoing rapid spatial expansion, increasing motorization, and uneven development of public transport infrastructure. The combined analysis of objective accessibility indicators, perception-based survey data, and expert interviews reveals a structurally imbalanced transport system characterized by a pronounced core–periphery gradient and persistent territorial disparities.

The study identifies several strategic priorities essential for reducing the identified accessibility gaps and improving the overall performance of the urban mobility system:

1. Rebalancing infrastructure investment toward peripheral districts, where accessibility deficits are most pronounced and where residents experience the longest waiting times, the greatest dependence on private vehicles, and the weakest operational performance of public transport;

2. Reconfiguring and optimizing the public transport route network to strengthen connectivity between newly urbanized residential areas, the city center, and major employment nodes. This includes the need for redistributing service supply and addressing structural coverage gaps;

3. Enhancing operational efficiency, particularly through increasing peak-hour service frequencies, reducing irregularities in schedules, and improving reliability – elements that directly shape user perceptions and influence modal choice;

4. Diversifying the modal structure of urban transport–for example, through the restoration of trolleybus services or the introduction of BRT (Bus Rapid Transit) corridors–to reduce systemic vulnerability associated with reliance on a single transport mode and to advance environmentally sustainable mobility;

5. Integrating digital solutions within a broader infrastructure and mobility planning framework, rather than treating them as isolated technological improvements. Digital tools can amplify the effectiveness of the system only when supported by strong physical infrastructure and adequate service supply.

Overall, the findings underscore the need for a comprehensive, multi-dimensional approach to transport planning in Aktobe–one that simultaneously addresses spatial, operational, and user-centered components of mobility. Such an approach is critical for mitigating entrenched territorial inequalities, enhancing transport equity, and supporting the city's long-term transition toward a more sustainable and resilient urban mobility model.

References

AA 2023: *Socio-economic development report of Astana city*. Astana (AA – Akimat of Astana).

AAC 2015: *Territorial Development Program of the City of Aktobe for 2016-2020*. Aktobe (AAC – Akimat of Aktobe city).

AAC 2020: *Territorial Development Program of the City of Aktobe for 2021-2025*. Aktobe (AAC – Akimat of Aktobe city).

AAC 2024: *Public transport stop locations and operational timetables*. Aktobe (AAC – Akimat of Aktobe city).

ACMD 2023: *Master plan of the transport framework of Almaty until 2030*. Almaty (ACMD – Almaty City Mobility Department).

BANISTER, D. 2019: The climate crisis and transport. *Transport Reviews*, 39(5), 565-568. DOI: https://doi.org/10.1080/01441647.2019.1637113

BHAT, Ch. 2000: Incorporating observed and unobserved heterogeneity in urban work travel mode choice modeling. *Transportation science*, 34(2), 228-238. DOI: https://doi.org/10.1287/trsc.34.2.228.12306

BHAT, Ch., HANDY, S., KOCKELMAN, K., MAHMASSANI, H., CHEN, Q., WESTON, L. 2000: *Urban Accessibility Index: Literature Review.* Austin (Center for Transportation Research, the University of Texas at Austin).

BNS RK 2024: *Demographic statistics of Aktobe region*. Astana (BNS RK – Bureau of National Statistics of the Republic of Kazakhstan). Available at: https://stat.gov.kz.

BOISJOLY, G., EL-GENEIDY, A. 2017: How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans. *Transport Policy*, 55, 38-50. DOI: https://doi.org/10.1016/j.tranpol.2017.02.008

BUEHLER, R., PUCHER, J. 2011: Sustainable transport in Freiburg: Lessons from Germany's environmental capital. *International Journal of Sustainable Transportation*, 5(1), 43-70. DOI: https://doi.org/10.1080/15568311003650531

CURL, A., NELSON, J.D., ANABLE, J. 2011: Does accessibility planning address what matters? A review of current practice and practitioner perspectives. *Research in Research in Transportation Business & Management*, 2, 3-11. DOI: https://doi.org/10.1016/j.rtbm.2011.07.001

DCATP AR 2023: *Cadastral and residential building data*. Aktobe (DCATP AR – Department of Construction, Architecture and Town Planning of Aktobe region)

DE BORGER, B., KERSTENS, K., COSTA, A. 2002: Public transit performance: What does one learn from frontier studies? *Transport Reviews*, 22(1), 1-38. DOI: https://doi.org/10.1080/01441640010020313

DELL'OLIO, L., IBEAS, A., CECÍN, P., DELL'OLIO, F. 2011: Willingness to pay for improving service quality in a multimodal area. *Transportation Research Part C: Emerging Technologies*, 19(6), 1060-1070. DOI: https://doi.org/10.1016/j.trc.2011.06.004

DPTH AR 2024: *Aktobe city road development programs*. Aktobe (DPTH AR – Department of Passenger Transport and Highways of Aktobe Region).

EL-GENEIDY, M. A., LEVINSON, D. M. 2006. *Access to Destinations: Development of Accessibility Measures. Report #1 in the series Access to destinations study*. Minnestoa (Minnesota Department of Transportation). Available at: https://hdl.handle.net/11299/638.

FOMIN, E., ZEER, V., AREFIEVA, E., GOLUB, N. 2020: Ensuring priority for public urban passenger transport on urban streets and road network. *The Russian Automobile and Highway Industry Journal*, 17(3), 390-399. DOI: https://doi.org/10.26518/2071-7296-2020-17-3-390-399

FOTH, N., MANAUGH, K., EL-GENEIDY, A. M. 2013: Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of transport geography*, 29, 1-10. DOI: https://doi.org/10.1016/j.jtrangeo.2012.12.008

GABOR, S., PREGI, L. 2023: Spatial differentiation of daily commuting to work in Slovakia by modes of transport. *Geographia Cassoviensis,* 17(2), 150-175. DOI: https://doi.org/10.33542/GC2023-2-04

GEURS, K. T., VAN ECK, J.R. 2001: *Accessibility Measures: Review and Applications. RIMV – Research for Man and Environment; Report 408 505 006*. Utrecht (National Institute of Public Health and the Environment, Utrecht University).

GOVRK 2010: *State program for the development and integration of the transport infrastructure system of the Republic of Kazakhstan until 2020*. Astana (GovRK – Government of the Republic of Kazakhstan).

GOVRK 2018: *On the approval of the interregional territorial development scheme of the Aktobe agglomeration.* Astana (GovRK – Government of the Republic of Kazakhstan).

GUTIÉRREZ, J., CARDOZO, O. D., GARCÍA-PALOMARES, J. C. 2011: Transit ridership forecasting at station level: An approach based on distance-decay weighted regression. *Journal of Transport Geography*, 19(6), 1081–1092. DOI: https://doi.org/10.1016/j.jtrangeo.2011.05.004

HAMPSHIRE, C. 2017: A mixed methods empirical exploration of UK consumer perceptions of trust, risk and usefulness of mobile payments. *International Journal of Bank Marketing*, 35(3), 354-369. DOI: https://doi.org/10.1108/IJBM-08-2016-0105

IBRAHIM, M. F. 2003: Improvements and integration of a public transport system: the case of Singapore. *Cities*, 20(3), 205-216. DOI: https://doi.org/10.1016/S0264-2751(03)00014-3

ITF 2022: ITF *North and Central Asia Transport Outlook*. Paris (OECD Publishing, International Transport Forum Policy Papers, No. 105). Available at: https://www.itf-oecd.org/sites/default/files/docs/north-central-itf-transport-outlook.pdf.

KENESPAYEVA, L.B., RAFIKOV, T.K., KARMENOVA, N.N., MUSAGALIEVA, A.N. 2023: Problems and Prospects for the Development of Transport Infrastructure in the City of Almaty. *Bulletin of VSU. Series: Geography. Geoecology*, 1, 44-53. DOI: https://doi.org/10.17308/geo/1609-0683/2023/1/44-53

KOSHERBAY, K., MUSSAGALIYEV, A., NYUSSUPOVA, G., STROBL, J. 2022: Analysis of the state of public transport in Almaty. *GeoJournal of Tourism and Geosites*, 45, 1534-1542. DOI: https://doi.org/10.30892/gtg.454spl01-972

KREINDLER, G. 2024: Peak-hour road congestion pricing: Experimental evidence and equilibrium implications. *Econometrica*, 92(4), 1233-1268. DOI: https://doi.org/10.3982/ECTA18422

KRÜGER, F, TITZ, A, ARNDT R, GROß, F, MEHRBACH, F, PAJUNG, V, SUDA, L, WADENSTORFER, M, WIMMER, L. 2021: The Bus Rapid Transit (BRT) in Dar es Salaam: A Pilot Study on Critical Infrastructure, Sustainable Urban Development and Livelihoods. *Sustainability*, 13(3),1058. DOI: https://doi.org/10.3390/su13031058

LEVINSON, D., WU, H. 2020: Towards a general theory of access. *Journal of Transport and Land Use*, 13(1), 129-158. DOI: https://doi.org/10.5198/jtlu.2020.1660

LITMAN, T. M. 2022: Evaluating transportation equity: Guidance for incorporating distributional impacts in transport planning. *ITE Journal*, 92(4), 43-49.

MAVOA, S., WITTEN, K., MCCREANOR, T., O'SULLIVAN, D. 2012: GIS based destination accessibility via public transit and walking in Auckland, *New Zealand. Journal of Transport Geography*, 20(1), 15-22. DOI: https://doi.org/10.1016/j.jtrangeo.2011.10.001

MOLGAZHDAROV, A.S., BAZARBEKOVA, M.M. 2017: Main Aspects and Problems of Road Transport in the City of Almaty. *Bulletin of the Kazakh Academy of Transport and Communications named after M. Tynyshpaev*, 1, 82-89.

MUSSAGALIYEV, A. 2023: How could the development of public transport in Aktobe influence the citizens' life? *SSRN Electronic Journal*. DOI: https://doi.org/10.2139/ssrn.4450217

NEWMAN, P. W. 2015: Transport infrastructure and sustainability: a new planning and assessment framework. *Smart and Sustainable Built Environment*, 4(2), 140-153. DOI: https://doi.org/10.1108/SASBE-05-2015-0009

OSM 2024: *OpenStreetMap contributors*. (OSM – OpenStreetMap). Available at: https://www.openstreetmap.org.

OWEN, A., LEVINSON, D. M. 2015: Modeling the commute mode share of transit using continuous accessibility to jobs. *Transportation Research Part A: Policy and Practice*, 74, 110-122. DOI: https://doi.org/10.1016/j.tra.2015.02.002

PAPA, E., SILVA, C., TE BRÖMMELSTROET, M., HULL, A. 2015: Accessibility instruments for planning practice: a review of European experiences. *Journal of Transport and Land Use*, 9(3), 57-75. https://doi.org/10.5198/jtlu.2015.585

POJANI, D., STEAD, D. 2015: Sustainable urban transport in the developing world: Beyond megacities. *Sustainability*, 7(6), 7784–7805. DOI: https://doi.org/10.3390/su7067784

RAMAZAN, B., NOKHATOV, M. 2023: Characteristics of Traffic Flow Capacity in Street-Road Network Unloading. KazATC Bulletin, 1(124), 136-142. DOI: https://doi.org/10.52167/1609-1817-2023-124-1-136-142

RASCA, S., SAEED, N. 2022: Exploring the factors influencing the use of public transport by commuters living in networks of small cities and towns. *Travel Behaviour and Society*, 28, 249-263. DOI: https://doi.org/10.1016/j.tbs.2022.03.007

RODE, P. 2023: Fairness and the sufficiency turn in urban transport. *Journal of City Climate Policy and Economy*, 2(1), 37-54. DOI: https://doi.org/10.3138/jccpe-2023-0006

SAGHAPOUR, T., MORIDPOUR, S., THOMPSON, R. G. 2016: Public transport accessibility in metropolitan areas: A new approach incorporating population density. *Journal of Transport Geography*, 54, 273-285. DOI: https://doi.org/10.1016/j.jtrangeo.2016.06.019

SERGEYEVA, A., AKBAR, I., KARAKULOV, Y. 2025: Optimization of urban spatial planning considering isochrones of transport accessibility: The case of Aktobe city, Kazakhstan. *Journal of the Bulgarian Geographical Society*, 52, 183-204. DOI: https://doi.org/10.3897/jbgs.e152149

SHAH, J., ADHVARYU, B. 2016: Public transport accessibility levels for Ahmedabad, India. *Journal of Public Transportation*, 19(3), 19-35. DOI: https://doi.org/10.5038/2375-0901.19.3.2

SOROKINA, T.E. 2014: Transport Complex of the City of Astana. *Issues of Geography and Geoecology*, 3, 3-9.

TAHMASSEBY, S. 2022: The implementation of smart mobility for smart cities: A case study in Qatar. *Civil Engineering Journal*, 8(10), 2154-2171. DOI: http://dx.doi.org/10.28991/CEJ-2022-08-10-09

TRANSPORT FOR LONDON 2010: *Measuring Public Transport Accessibility Level (PTALs) Summary.* London. Available at: http://data.london.gov.uk/documents/PTAL-methodology.pdf.

TRANSPORT FOR LONDON 2010: Measuring Public Transport Accessibility Level PTALS Summary. Available at: http://data.london.gov.uk/documents/PTAL-methodology.pdf

UTKIN, A. A. 2008: Methodology for Studying the Territorial Organization of Public Transport in a Large City. *Bulletin of Voronezh State University. Series: Geography-Geoecology*, 1, 43-49.

VOLKOVA, I.N., KRYLOV, P.M., EVDOKIMOV, M.YU. 2022: Problems and Prospects of Territorial Organization and Territorial Planning of the Regional Transport System (on the Example of Sverdlovsk Region). *Bulletin of Udmurt University. Series "Biology. Earth Sciences"*, 2(32), 192-204.

YANNIS, G., CHAZIRIS, A. 2022: Transport system and infrastructure. *Transportation research procedia*, 60, 6-11. DOI: https://doi.org/10.1016/j.trpro.2021.12.002

Authors´ affiliations

Aigul Sergeyeva
L.N. Gumilyov Eurasian National University
Faculty of Natural Sciences, Department of Physical and Economical Geography
Satpayev 2, 010008 Astana
Kazakhstan
sergeyeva.aigul@gmail.com

Sergey Pashkov
M. Kozybayev North Kazakhstan University
Department of Geography and Ecology
Pushkin 86, 150000 Petropavl
Kazakhstan
sergp2001@mail.ru

Yerkin Tokpanov
Zhetysu University named after I. Zhansugurov
Faculty of Natural Sciences and Technology
Zhansugirov 187a, 040000 Taldykorgan
Kazakhstan
tokpanov60@mail.ru