

DEVELOPMENT OF TRANSPORT INFRASTRUCTURE AND ASSESSMENT OF ITS REGIONAL EFFICIENCY USING ARTIFICIAL INTELLIGENCE TOOLS

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Abstract: The article examines the development of transport infrastructure and the assessment of its regional efficiency using artificial intelligence methods. The role of railway transport and digital technologies is highlighted. Based on the approaches of E. Engel and Y. Uspensky, DT and DN indicators are proposed to evaluate freight and passenger flows. Integral indices are calculated, regions are clustered, and recommendations for improving efficiency are provided.

Keywords: transport infrastructure, railway transport, artificial intelligence, integral index, regional efficiency, logistics, transport flows.

Аннотация: Мақолада транспорт инфратузилмаси ривожланиши ва унинг ҳудудий самарадорлигини сунъий интеллект асосида баҳолаш масалалари таҳлил қилинган. Темир йўл транспорти ва рақамли технологияларнинг аҳамияти асослаб берилган. Э.Энгел ва Ю.Успенский ёндашувлари асосида ҳудудий баҳолаш усуллари ёритилиб, юк ва йўловчи оқимлари учун DT ва DN индикаторлари таклиф этилган. Шунингдек, интеграл индекслар орқали ҳудудлар кластерларга ажратилган ва самарадорликни ошириш бўйича таклифлар берилган.

Таянч сўзлар: транспорт инфратузилмаси, темир йўл транспорти, сунъий интеллект, интеграл индекс, ҳудудий самарадорлик, логистика, транспорт оқимлари.

Аннотация: В статье анализируется развитие транспортной инфраструктуры и оценка её региональной эффективности с использованием методов искусственного интеллекта. Обоснована роль железнодорожного транспорта и цифровых технологий. На основе подходов Э. Ангеля и Ю.Успенского предложены показатели DT и DN для оценки грузо- и пассажиропотоков. Рассчитаны интегральные индексы, проведена кластеризация регионов и даны рекомендации по повышению эффективности.

Ключевые слова:

транспортная инфраструктура, железнодорожный транспорт, искусственный интеллект, интегральный индекс, региональная эффективность, логистика, транспортные потоки.

Introduction. Railway transport plays a key role in strengthening interregional economic ties,

improving logistics, and ensuring efficient freight, passenger flows, and population mobility. In recent years, digital technologies— especially artificial intelligence (AI)—have been widely used in transport system management. AI expands capabilities for analyzing flows, assessing network load, optimizing logistics, and planning infrastructure, while enabling comprehensive evaluation of regional transport efficiency.

Railway infrastructure development across Uzbekistan is uneven: some regions have well-developed networks, while others lag behind. This creates regional disparities and highlights the need to identify major transport hubs and underdeveloped areas and define their development priorities. The study is relevant as it provides a scientific basis for assessing infrastructure efficiency and guiding regional development strategies and investments. The approaches of E. Engel, Y. Uspensky, S. Henderson, and J. Rodrigue form the theoretical foundation. The object of the study is the railway infrastructure of Uzbekistan's regions.

Methodology. The Engel–Uspensky method evaluates the correspondence between railway infrastructure and regional demand using proportional indicators of territory, population, and transport flows. The main indicators are:

- $D_1 = L/S$ — railway density;
- $D_2 = L/\sqrt{(S \cdot P)}$;
- $D_3 = L/\sqrt[3]{(S \cdot P \cdot Q)}$.

Where L is railway length, S is area, P is population, and Q is freight volume. Based on this approach, two additional indicators are proposed:

- $D_T = T/L$ — freight load per km;
- $D_N = N/L$ — passenger load per km.

Here, T is freight volume and N is number of passengers. Higher values indicate greater network utilization and demand. These indicators complement D_1 – D_3 and allow a comprehensive assessment of how well railway infrastructure meets regional economic and demographic needs.

Research Results. To assess the level of railway transport provision across regions, an economic model was developed based on the indicators D_1 , D_2 , D_3 , D_T , and D_N , reflecting the efficiency of using regional transport potential. Within this model, the following integral indices were formed:

B₁ index – a composite indicator of transport infrastructure development in a region:

$$B_1 = \frac{D_1 + D_2 + D_3}{3}$$

B₂ index – reflects the efficiency and intensity of transport network utilization:

$$B_2 = D_T + D_N$$

- **K integral index** – the key indicator providing a comprehensive assessment of how

effectively a region utilizes its transport potential.

The **K index** is calculated as the ratio B_2/B_1 and reflects the relationship between the level of infrastructure availability and its functional efficiency. Scientifically, B_1 captures the level of infrastructure development (network density, territorial coverage, and condition), while B_2 reflects actual usage intensity and economic efficiency (freight and passenger volumes, transport activity).

According to the results, the average K index for Uzbekistan was **9.60 in 2024**. Significant variation in K values across regions necessitated their typological grouping. Therefore, regions were classified into **four main clusters** using a clustering method based on similar values of the integral index. This approach ensured internal homogeneity within clusters and revealed differences between them (Table 1).

Table 1.

Clustering of regions based on railway transport provision indicators.

Cluster	Development level	Region	K index
1	Highly developed	Tashkent, Navoi	20,14 - 21,34
2	Developed	Ferghana, Jizzakh, Bukhara, Samarkand	Between 4–13
3	Moderately developed	Kashkadarya, Syrdarya, Surkhondarya	Between 1,7–
4	Low-developed	Karakalpakstan, Andijan, Namangan, Khorezm	Between 0,6– 1,5

The table was developed by the author. Considering that there is no railway track length within Tashkent city, this area was not included in the table.

1. Highly developed cluster. This group includes Tashkent and Navoi regions, which have highly developed transport infrastructure. Tashkent region has the highest K index in the country at **20.14**, reflecting dense railway networks, developed transport hubs, and large freight volumes. Navoi region also shows a high value (**21.34**), driven by international transport corridors, major industrial centers, and strong logistics infrastructure.

2. Developed cluster. This cluster includes Fergana, Jizzakh, Bukhara, and Samarkand regions, with K index values ranging from **4 to 13**. For example, Jizzakh (12.85), Fergana (8.41), Bukhara (7.75), and Samarkand (4.34). These regions have relatively well-developed railway networks and serve as key economic and transport centers.

3. Moderately developed cluster. This group includes Kashkadarya, Syrdarya, and Surkhondarya regions, with K values between **1.7 and 5.0** (e.g., Kashkadarya – 5.04, Syrdarya – 3.06, Surkhondarya – 1.75). Although railway infrastructure exists, its density and efficiency are lower than

in more developed regions.

4. Low-developed cluster. Regions with low railway provision include the Republic of Karakalpakstan, Andijan, Namangan, and Khorezm, with K values around **0.6–1.5** (e.g., Karakalpakstan – 1.36, Andijan – 1.54, Namangan – 0.94, Khorezm – 0.62). This is due to low network density and insufficient infrastructure development.

Conclusion and recommendations. The analysis shows that the K index reflects not only the availability of infrastructure but also its economic and functional efficiency. A high K value indicates effective use of transport infrastructure and strong support for economic activity, while a low value signals underdevelopment or inefficient utilization. Thus, the K index serves as an important scientific tool for comparing regional infrastructure development, identifying disparities, and shaping transport policy.

Significant differences exist across Uzbekistan's regions: well-developed infrastructure is concentrated in industrial and logistics centers, while remote and less developed areas lag behind.

Recommendations:

- reduce regional disparities by developing major transport and logistics hubs;
- expand railway networks in underdeveloped regions, modernize infrastructure, and increase freight and passenger volumes;
- use AI technologies to monitor transport flows and optimize investment allocation;
- develop evidence-based regional transport policies and infrastructure investment strategies.

Overall, this study can be applied both for assessing current transport infrastructure and for guiding its future development.

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