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Silesian University of Technology
Faculty of Transport and Aviation Engineering

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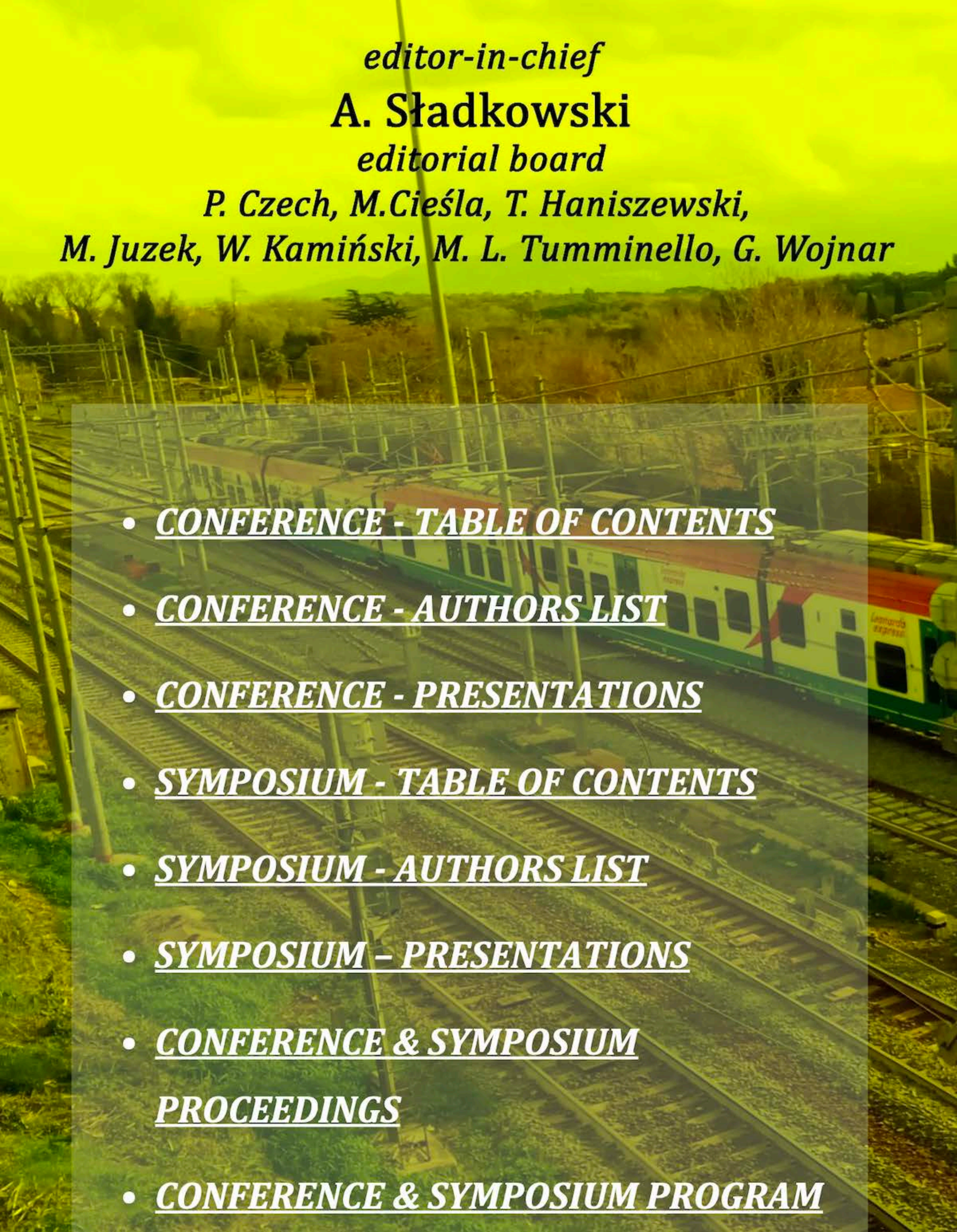

Keywords: railway sector capability index, principal component analysis, railway infrastructure assessment, regional transport development, Uzbekistan, data-driven modelling

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ASSESSING REGIONAL RAILWAY SECTOR CAPABILITY IN UZBEKISTAN USING PRINCIPAL COMPONENT ANALYSIS

Summary. This study introduces the Railway Sector Capability Index, a composite metric designed to evaluate the performance and development readiness of Uzbekistan's regional railway systems. By integrating socio-economic and infrastructure-related indicators and applying Principal Component Analysis for objective weighting, the Railway Sector Capability Index captures the multi-dimensional nature of railway performance. The index is computed annually from 2013 to 2022 across 14 regions, enabling clear regional comparisons and identifying disparities. The methodology is implemented using MATLAB for transparency and scalability. The study is contextualized by recent infrastructure initiatives, such as the China–Kyrgyzstan–Uzbekistan railway, which underscores Uzbekistan's strategic role in Eurasian connectivity. The findings contribute to policymaking by offering a data-driven tool to support balanced infrastructure investment and long-term transport planning.

1. INTRODUCTION

Railway transport plays a crucial role in supporting regional development, logistics capacity, and national economic growth—particularly in expansive and developing countries like Uzbekistan. As Uzbekistan intensifies its focus on modernizing transport infrastructure and boosting international connectivity, there is a growing need for comprehensive and objective methods to assess railway sector capability across regions. Traditional assessment approaches, often based on isolated indicators or qualitative judgement, fail to reflect the multi-dimensional nature of railway performance.

To address this gap, the current study introduces the Railway Sector Capability Index (RSCI), a composite index developed to evaluate the performance of Uzbekistan's regional railway systems. The RSCI integrates socio-economic and infrastructure-related variables and applies Principal Component Analysis (PCA) to assign objective weights to each indicator. By computing a single annual score for each region from 2013 to 2022, the index enables regional comparisons, identification of disparities, and formulation of policy recommendations for more balanced infrastructure development.

The methodology is implemented using MATLAB to ensure transparency, scalability, and reproducibility. It captures the alignment between regional railway infrastructure and socio-economic needs, thereby serving as a strategic planning tool.

Recent regional developments further underscore the relevance of this study. On 27 December 2024, the China–Kyrgyzstan–Uzbekistan (CKU) railway construction officially began in Jalal-Abad, Kyrgyzstan. The 523-kilometer railway, passing through mountainous terrain, is expected to feature 20 stations, 42 bridges, and 27 tunnels, with completion targeted for 2030 [15].

This project represents a major effort to enhance Eurasian connectivity. Once operational, the CKU line is projected to reduce freight transit times between China and Europe by up to one week and support up to 15 million tons of annual cargo volume. Plans include future passenger services and integration with the Trans-Afghan corridor, opening access to South Asian markets [16]. These initiatives confirm Uzbekistan's strategic ambition to become a pivotal hub in regional and global trade networks [17].

In this context, the RSCI offers a timely and practical framework for evaluating regional railway development readiness in Uzbekistan, aligned with long-term transport goals and emerging international connectivity corridors.

2. LITERATURE REVIEW

This section reviews important studies that support the design and methodology of the RSCI, especially the use of PCA, multi-criteria decision-making (MCDM), and railway performance evaluation.

The Trans-Caspian International Transport Route (TITR) – Middle Corridor study [1], where Uzbekistan is a key transit country, highlights that strong institutions, good policies, and well-planned infrastructure are just as important as having physical railway tracks. The effectiveness of the corridor depends on smooth logistics, customs coordination, and well-equipped terminals—an approach that matches the RSCI's focus on socio-economic and institutional indicators [1].

Another study on Uzbekistan's freight transport shows how rail is widely used for transporting small and packaged goods [2]. This growth is linked to the rise of small and medium-sized businesses. However, the study also identifies problems like outdated terminals and poor scheduling. These findings support the use of indicators such as industrial output, retail turnover, and infrastructure access in the RSCI model [2].

To reflect Uzbekistan's rapid development, Turaev and Sładkowski [3] ranked regions based on railway passenger services using the Analytical Hierarchy Process (AHP). While AHP uses expert judgment, our study uses PCA to provide objective weights, making the RSCI more data-driven and transparent.

A Chinese study used Principal Component Regression (PCR) to analyze how economic and transport factors influence railway passenger numbers. By grouping related indicators, PCA improved the model's accuracy and interpretation [4]. Another Chinese study combined PCA with neural networks to explore how economic indicators affect transport emissions and sustainability. This supports the use of PCA for planning and policy analysis [5].

In Africa, a Roads Funding Priority Index (RFPI) was built using PCA to rank infrastructure needs across technical, economic, and social indicators. This structured approach is similar to how the RSCI combines PCA and AHP to assess railway capacity and ensure fair investment across regions [6].

Building on this, Duleba and Farkas [19] applied PCA to study railway competitiveness in East-Central Europe. They reduced 21 rail indicators into key components like economic efficiency and service quality. This helps guide investment planning similar to our study's regional analysis. Stoilova and Nikolova [20] used PCA and clustering to group 98 Bulgarian railway stations based on urban potential and infrastructure. Their method is similar to how we categorize Uzbek regions using PCA. In another study, Lasisi and Attoh-Okine [21] created a Track Quality Index (TQI) from rail geometry data using PCA and machine learning, showing PCA's power in simplifying complex rail data for maintenance planning.

Linking transport systems with economic indicators is a common theme. For example, a study in Brazil [7] used a hybrid TOPSIS-genetic algorithm model to measure railway section efficiency. Research on the Belt and Road Initiative (BRI) [8, 9] emphasized how infrastructure reliability and multimodal integration impact trade. In Uzbekistan, regression-based models forecast cargo volumes [10], while qualitative research from Turkey pointed to key freight logistics issues like limited terminal access and inconsistent regulations [11].

Advanced prediction methods also support data-driven rail analysis. Indian studies [12, 13] used hybrid GCN-LSTM-Kalman models to predict travel times in real time. Other studies used PCA for online transport demand forecasting [14] and highway safety risk assessment [15].

Together, these studies show how PCA can serve as a strong foundation for building the RSCI. They demonstrate the value of using integrated, evidence-based methods to assess railway infrastructure and guide development decisions.

3. METHODS

This study aims to assess the regional performance of the railway sector in Uzbekistan by developing a RSCI. The index integrates key socio-economic and infrastructure-related indicators and applies PCA to assign objective weights to each variable.

The analysis is based on 10 years regional data from 2013 from Uzbekistan and includes 14 regions, including the capital. 10 indicators were selected to reflect socio-economic and railway infrastructure development. So, the study undertakes the analysis of 140 year-region observation for 10 socio economic and railway infrastructure metrics. All the data were obtained from Annual statistical collection 2013-2022 of the Statistical Agency under the Republic of Uzbekistan.

Tashkent City and Tashkent Region were reported together in the railway length data. To estimate the share for Tashkent City separately, 20% of the total railway length for Tashkent region was assigned.

3.1. Data Preprocessing – building the dataset

To begin the analysis and construct the RSCI, the first step involved compiling a complete dataset that includes all relevant indicators for each region and year.

The dataset includes information from 14 regions of Uzbekistan over a 10-year period (2013–2022). For every region and year, values for 10 key socio-economic and infrastructure indicators were collected. These indicators were carefully selected to reflect both the demand and supply side of railway services.

Table 1

Regional socio-economic indicators from 2013 to simplify visualization

Regions	Pop	Emp_Pop	GDP	GDP_PerCap	ORG	Industry_Prod	Good_Prod_PerCap	Retail_Turover	Inv	Lengths
Karakalpakstan	1736.5	610.5	4,366.7	2,532.8	13,177.0	1,368.1	335.8	1,568.3	2,415.0	844.3
Andijan	2805.5	1,210.7	9,918.6	3,566.7	25,553.0	9,278.6	2,415.5	3,671.1	1,462.3	155.8
Bukhara	1756.4	818.4	8,325.9	4,776.5	14,722.0	3,073.9	764.0	2,958.2	2,998.7	270.0
Jizzakh	1226.8	415.1	4,517.9	3,715.7	10,453.0	933.3	363.6	1,542.6	1,128.5	277.7
Kashkadarya	2895.3	1,072.3	12,308.3	4,298.6	24,292.0	6,849.4	523.2	3,443.7	3,667.8	492.7
Navoiy	901.1	419.6	7,708.5	8,614.8	8,465.0	7,087.3	1,225.0	1,932.0	1,696.9	469.3
Namangan	2504.1	903.5	72,172.0	2,908.5	18,243.0	1,892.1	448.6	2,853.5	1,205.1	144.6
Samarkand	3445.6	1,357.3	12,383.0	3,627.9	19,056.0	3,880.1	727.7	3,846.7	2,127.6	283.8
Surkhandarya	2308.3	871.2	7,436.4	3,255.2	14,237.0	1,321.4	235.4	3,070.4	1,371.0	368.6
Sirdarya	763.8	342.3	3,446.4	4,552.1	8,701.0	1,929.3	884.6	806.4	852.8	163.9
Tashkent	2725.9	1,244.9	15,420.7	5,688.6	25,025.0	10,418.3	1,126.3	4,907.5	3,195.2	279.0
Fergana	3386.5	1,431.1	10,966.4	3,265.7	23,169.0	5,290.8	584.1	4,117.7	2,130.0	228.6
Khorezm	1684.1	660.4	5,815.3	3,484.3	13,069.0	1,297.2	408.9	1,959.6	1,256.9	138.7
Tashkent City	2352.9	1,165.3	19,838.9	8,453.3	48,235.0	15,531.3	2,746.9	10,185.3	4,977.1	69.8

The list of the indicators with the respective measuring units include:

1. **Pop** - population (thousand people)
2. **Emp_Pop -** employed people (thousand people)
3. **GDP** - GDP (milliard UZS)
4. **GDP_PerCap -** GDP per capita (thousand UZS)

5. **ORG -** total number of registered organizations (units)
6. **Industry_Prod -** industrial production (milliard UZS)
7. **Good_Prod_PerCap -** consumer goods production per capita (thousand UZS)
8. **Retail_Turover -** total retail turnover (billion UZS)
9. **Inv -** investments in fixed capital (billion UZS)
10. **Lengths -** operational length of public railways (kilometers)

Each row in the dataset corresponds to a specific region in a specific year, and each column represents one of the above indicators. For example, the data entry for "Andijan in 2013" contains values for all 10 indicators in that year.

Table 1 shows data for 2013 as an example. This format was followed for every year up to 2022 to form a complete panel dataset of 140 observations (14 regions × 10 years), which was later used for analysis.

Before applying PCA, the data for all indicators were standardized to ensure they are on the same scale. This was necessary because indicators like population (in thousands) and investment (in billions) have very different units. Standardizing ensures that no single indicator dominates the analysis due to its size.

3.2. Data Standardization (Z-Score Normalization)

Since the indicators are measured in different units (e.g., people, kilometers, currency), they were standardized using Z-score normalization to make them comparable. This step ensures that no single indicator dominates the analysis due to scale.

The Z-score for each value is calculated using the formula [22]:

$$z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \tag{1}$$

where:

- z_{ij} is the original value,
- μ_j is the mean of column,
- σ_j is the standard deviation of column,
- x_{ij} is original value of the j^{th} indicator for the j^{th} observation.

This produces matrix Z, where all columns have mean 0 and standard deviation 1.

The Tab. 2 below presents a sample Z-score matrix for the year 2013 as generated in MATLAB. The full dataset (2013–2022) includes all region-year combinations but is not shown in full due to space constraints.

3.3. Principal Component Analysis (PCA)

To construct the Railway Sector Capability Index (RSCI), Principal Component Analysis (PCA) has been used on the normalized data. PCA is a statistical technique that helps simplify a dataset by identifying patterns and reducing the number of variables while keeping as much meaningful information as possible.

In this study, the dataset includes:

- 140 observations: one for each *region-year* (14 regions × 10 years),
- 10 variables: socio-economic and railway infrastructure indicators.

Since this is a relatively large and multi-variable dataset, PCA is ideal for: reducing dimensionality (simplifying the data), identifying key underlying patterns, calculating objective weights for each indicator based on how much it contributes to variation in the data.

This helps ensure that the final index is data-driven and not based on arbitrary weights.

PCA transforms the normalized data matrix Z into new uncorrelated variables called principal components (PCs). Each PC is a linear combination of the original indicators [22].

The first principal component (PC1) is the most important:

- it explains the maximum possible variance in the dataset,

- the weights (called loadings) from PC1 are used to construct the RSCI.

$$\mathrm{PC}_1 = w_1^{(1)} z_1 + w_2^{(1)} z_2 + \cdots + w_{10}^{(1)} z_{10} \tag{2}$$

where:

- z_j is the Z-score for indicator j,
- $w_j^{(1)}$ is the PC1 loading (weight) for indicator j,
- PC1 is a new variable representing the weighted sum of all indicators.

Table 2

Normalized data matrix *Z* for the year 2013

	Pop	Emp_Pop	GDP	GDP_PerCap	ORG	Industry_Prod	Good_Prod_PerCap	Retail_Turover	Inv	Lengths
Karakalpakstan	-0.5143	-0.778	-0.5486	-1.027	-0.5679	-0.8349	-0.7534	-0.7812	0.2026	2.736
Andijan	0.7309	0.8664	-0.2292	-0.4819	0.6333	0.9782	1.959	0.1422	-0.61	-0.7188
Bukhara	-0.4912	-0.2084	-0.3208	0.1554	-0.418	-0.4439	-0.195	-0.1709	0.7004	-0.1458
Jizzakh	-1.108	-1.313	-0.5399	-0.4034	-0.8323	-0.9346	-0.7171	-0.7924	-0.8947	-0.1072
Kashkadarya	0.8355	0.4872	-0.09168	-0.09634	0.5109	0.4214	-0.509	0.0423	1.271	0.9716
Navoiy	-1.487	-1.301	-0.3563	2.177	-1.025	0.4759	0.4061	-0.6215	-0.4099	0.8542
Namangan	0.3798	0.02474	3.353	-0.8287	-0.07622	-0.7148	-0.6063	-0.2168	-0.8293	-0.775
Samarkand	1.476	1.268	-0.08738	-0.4497	0.002683	-0.2592	-0.2423	0.2193	-0.04255	-0.07655
Surkhandarya	0.1517	-0.06376	-0.372	-0.646	-0.465	-0.8456	-0.8843	-0.1216	-0.6879	0.3489
Sirdarya	-1.647	-1.513	-0.6015	0.0372	-1.002	-0.7063	-0.03774	-1.116	-1.13	-0.6781
Tashkent	0.6381	0.9601	0.08739	0.6359	0.582	1.239	0.2774	0.685	0.868	-0.1006
Fergana	1.408	1.47	-0.1689	-0.6405	0.4019	0.06418	-0.4296	0.3382	-0.04051	-0.3535
Khorezm	-0.5754	-0.6413	-0.4653	-0.5253	-0.5784	-0.8512	-0.6581	-0.6093	-0.7852	-0.8046
Tashkent City	0.2037	0.742	0.3416	2.092	2.835	2.411	2.391	3.002	2.388	-1.15

Indicators

3.4. Railway sector capability index calculation

The RSCI was calculated using the PC1 derived from PCA applied to a standardized dataset of socio-economic and infrastructure indicators. For each region and year, the RSCI provides a single composite score that summarizes the railway sector's performance based on ten indicators.

This approach follows the methodology applied in other transport-related studies, such as the Roads Funding Priority Index (RFPI) by Kaba and Assaf [6], who used PCA to prioritize road investments in Sub-Saharan Africa, and the Track Quality Index (TQI) developed by Lasisi and Attoh-Okine [21] to evaluate railway infrastructure using multivariate data. Similarly, Duleba and Farkas [19] applied PCA to assess rail competitiveness across 11 East-Central European countries using over 20 performance indicators. These works demonstrate that PCA can effectively reduce dimensionality while preserving explanatory power, enabling the construction of robust composite indices.

In this study, all calculations were carried out in MATLAB. PCA was used to extract objective weights (loadings) from the first principal component, which were then used to weight each standardized indicator:

$$\mathrm{RSCI}_i = \sum_{j=1}^{10} z_{ij} \cdot w_j \tag{3}$$

where,

- for each indicator j (such as population, GDP, railway length, etc.), first calculated its standardized value z_{ij} for region-year i. This puts all indicators on the same scale,

- each standardized value is then multiplied by a corresponding weight w_j, which was derived from PCA specifically, from the first principal component,
- the weights w_j reflect the importance or influence of each indicator in explaining differences across all regions and years.

This procedure ensures that indicators like GDP, population, railway length, and investment are normalized and weighted based on their contribution to the total variance in the data. The RSCI score was calculated for each of the 14 regions from 2013 to 2022, resulting in 140 total values. To assess long-term performance, the average score over the 10-year period was also computed:

$$\text{Average RSCI}_r = \frac{1}{10}\sum_{t=2013}^{2022}\text{RSCI}_{r,t} \tag{4}$$

where,

- average RSCI_r is the average RSCI score for region r,
- average $\text{RSCI}_{r,t}$ is the RSCI score for region r in year t.

This index reflects how effectively a region's railway sector aligns with its socio-economic development, using the same analytical rationale as previous composite models in infrastructure performance studies [6, 19, 21].

In this context, the RSCI is an original contribution, grounded in widely accepted practices of data-driven index construction using PCA. It provides a replicable, objective framework for evaluating railway development potential across regions similar to how PCA-based indices have been used in road planning, station classification [20], and sustainability assessments [5].

4. RESULTS

This section presents the key findings of the study based on the application of PCA and the computation of the RSCI across Uzbekistan's regions from 2013 to 2022. Principal Component Analysis was applied to the standardized data matrix consisting of ten socio-economic and infrastructure indicators. The scree plot (Fig.1) revealed that the PC1 accounted for the largest proportion of variance in the dataset, justifying its importance.

Table 3

PCA loadings (weights) of the first principal component (PC1)

Indicator	PC1_Weight
Pop	0.146212
Emp_Pop	-0.01939
GDP	0.245503
GDP_PerCap	0.369264
ORG	0.427148
Industry_Prod	0.424847
Good_Prod_PerCap	0.379896
Retail_Turover	0.430791
Inv	0.275681
Lengths	-0.11299

The loadings (weights) of PC1 for each indicator are shown in Tab.3 are the indicators with the highest weights were Retail Trade Turnover (0.4308), Number of Organizations (0.4272), and Industrial Production (0.4249). Indicating that these variables contributed most to the variation across regions.

4.1. RSCI Values by Region-Year

RSCI scores were calculated for each of the 14 regions for every year from 2013 to 2022, resulting in a total of 140 index values. These scores represent the relative railway sector capability of each region per year. Tab. 4 below displays RSCI values for the years 2013-2022.

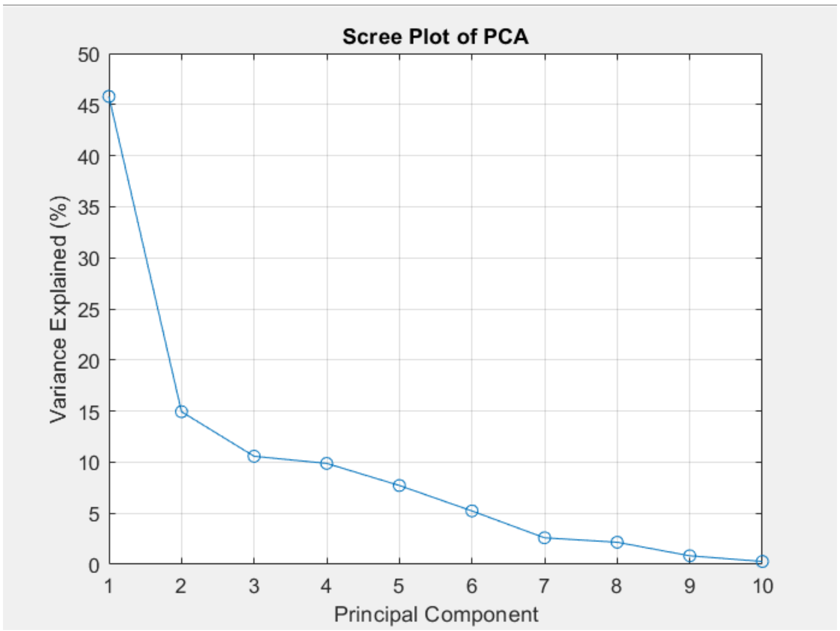

Fig. 1. Scree plot of CPA calculations

Table 4

Table shows the RSCI calculated annually for each region from 2013 to 2022

Regions	RSCI 2013	RSCI 2014	RSCI 2015	RSCI 2016	RSCI 2017	RSCI 2018	RSCI 2019	RSCI 2020	RSCI 2021	RSCI 2022
Karakalpakstan	-2.30	-2.20	-2.07	-1.99	-1.89	-1.51	-1.16	0.04	-0.70	-0.43
Andijan	-0.82	-0.66	-0.58	-0.63	-0.18	1.02	1.74	2.20	2.26	1.59
Bukhara	-1.66	-1.51	-1.34	-1.16	-1.03	-0.73	-0.11	0.35	0.98	1.05
Jizzakh	-2.10	-2.01	-1.90	-1.80	-1.65	-1.36	-0.97	-0.60	-0.34	-0.01
Kashkadarya	-1.32	-1.29	-1.16	-1.01	-0.85	-0.48	0.08	0.25	2.99	0.96
Navoiy	-1.83	-1.72	-1.50	-1.30	-1.08	-0.33	1.04	2.17	2.77	5.28
Namangan	-1.35	-1.46	-1.34	-1.44	-1.19	-0.72	-0.21	0.14	0.65	0.97
Samarkand	-1.29	-1.11	0.62	-0.71	-0.63	0.00	0.49	1.11	1.76	2.31
Surkhandarya	-1.84	-1.73	-1.65	-1.55	-1.42	-1.18	-0.83	-0.52	-0.22	0.06
Sirdarya	-2.06	-1.97	-1.84	-1.70	-1.61	-1.37	-0.85	-0.72	-0.39	-0.45
Tashkent	-0.92	-0.68	-0.41	-0.18	0.13	1.06	3.93	3.66	4.32	5.07
Fergana	-1.18	-1.06	-0.90	-0.76	-0.55	-0.12	0.48	1.06	1.62	1.98
Khorezm	-1.86	-1.73	-1.60	-1.54	-1.54	-1.02	-0.56	-0.39	0.23	0.79
Tashkent City	0.41	0.68	1.21	1.90	2.66	4.27	6.00	7.16	9.37	10.83

This heatmap Fig. 2 displays the Railway Sector Capability Index values for each region of Uzbekistan across a 10-year period. Higher values (red) indicate stronger alignment between socio-economic development and railway infrastructure capability. Tashkent City exhibits the most significant growth trend, while regions such as Karakalpakstan and Jizzakh show persistent underperformance.

4.2. Average RSCI and regional rankings

To assess long-term performance, the average RSCI was calculated for each region over the ten-year period. Fig. 3 displays the average RSCI per region from 2013 to 2022. Tashkent City emerged as the top performer, with a significantly higher average RSCI than other regions, followed by Tashkent Region and Andijan.

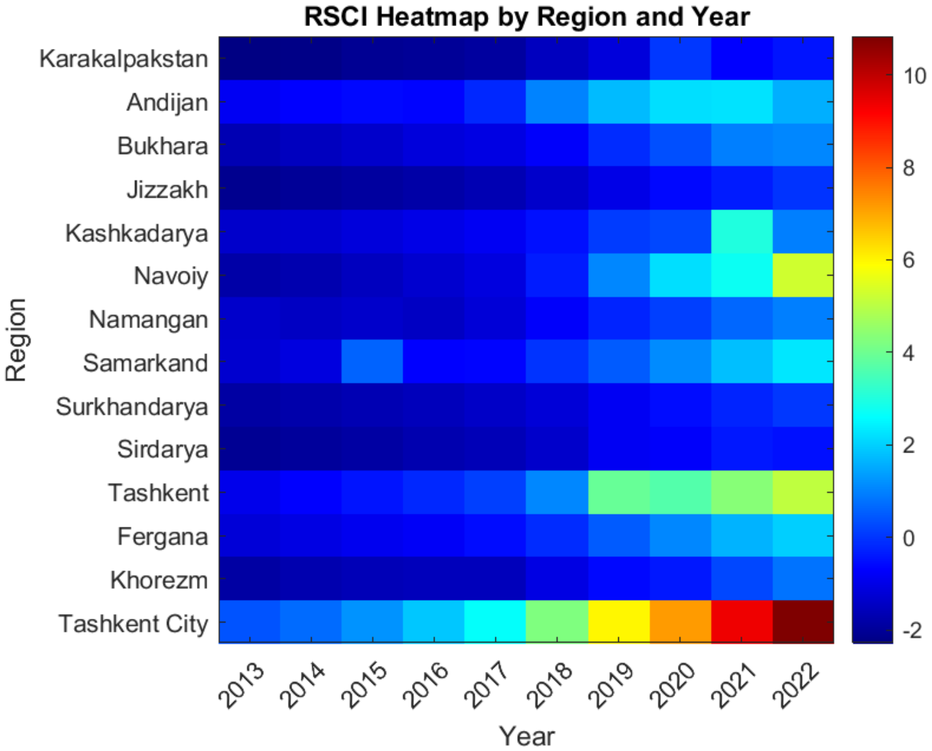

Fig. 2. RSCI heatmap by region and year

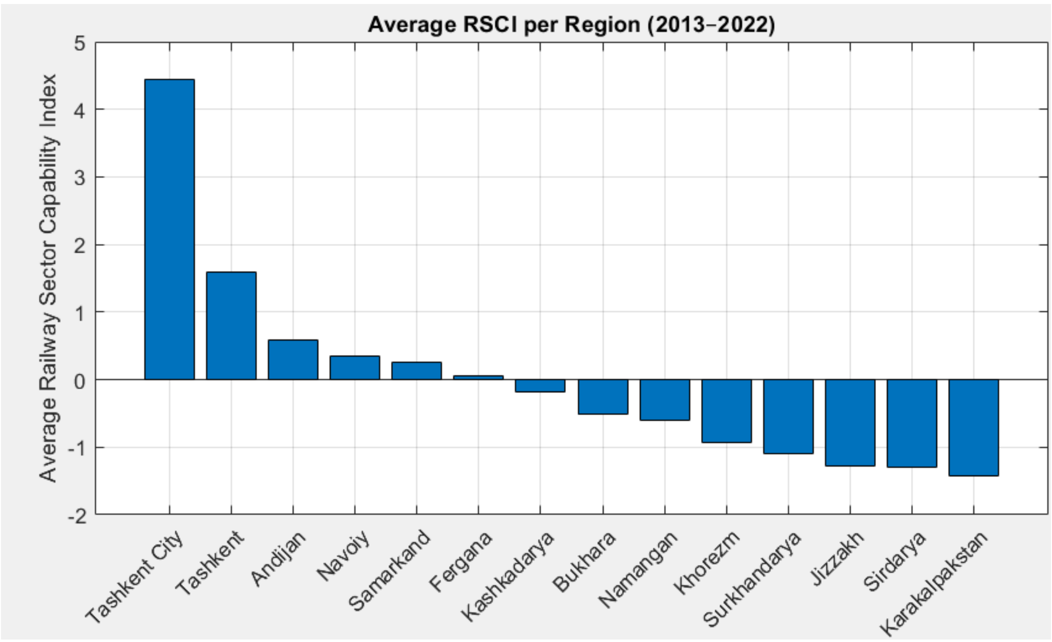

Fig. 3. Average RSCI per region (2013-2022)

Tab. 5 provides the regional rankings based on average RSCI scores. Regions such as Karakalpakstan, Sirdarya, and Jizzakh were found to have the lowest average scores, indicating weaker alignment between infrastructure and socio-economic development. This average reflects the overall capability and development alignment of the railway sector within each region across the full study period.

Table 5

Region	Average RSC Index
Tashkent City	4.44852
Tashkent	1.596665
Andijan	0.593567
Navoiy	0.35077
Samarkand	0.255281
Fergana	0.056711
Kashkadarya	-0.1849
Bukhara	-0.51684
Namangan	-0.5943
Khorezm	-0.92231
Surkhandarya	-1.08883
Jizzakh	-1.2752
Sirdarya	-1.29704
Karakalpakstan	-1.4221

Table 6

Region	RSCI Growth Rate
Tashkent City	1.201682
Tashkent	0.742746
Navoiy	0.736278
Andijan	0.389676
Kashkadarya	0.370942
Fergana	0.370071
Samarkand	0.359082
Bukhara	0.325909
Namangan	0.286867
Khorezm	0.285548
Karakalpakstan	0.246606
Jizzakh	0.241429
Surkhandarya	0.21695
Sirdarya	0.204976

4.3. Growth and decline trends (2013–2022)

The annual RSCI scores were used to compute the slope of performance trends over the 10-year period for each region. RSCI growth trajectories are illustrated in Fig. 4, and Tab. 6 lists the top five and bottom five regions based on RSCI growth rates. Tashkent City showed the highest growth rate (+1.20), followed by Tashkent Region (+0.74) and Navoiy (+0.73). On the other hand, Sirdarya (+0.20), Jizzakh (+0.24), and Karakalpakstan (+0.25) exhibited the slowest growth, indicating persistent underperformance.

These results highlight regional disparities and offer a data-driven basis for policy recommendations targeting infrastructure and investment improvements in lagging regions.

5. DISCUSSION AND RECOMMENDATIONS

The Railway Sector Capability Index (RSCI) analysis reveals substantial regional disparities in Uzbekistan's rail transport development between 2013 and 2022. These differences reflect varying degrees of alignment between socio-economic conditions and railway infrastructure performance. The following discussion synthesizes the key findings and proposes strategic recommendations to improve railway sector equity, effectiveness, and resilience.

5.1. Regional Performance Insights

Tashkent City emerged as the top-performing region, demonstrating consistently high RSCI scores and steady growth. Its well-integrated infrastructure and dynamic economy reinforce its role as the country's key administrative and commercial hub. Similarly, Tashkent Region, Navoiy, and Andijan showed strong upward trajectories, suggesting the positive impact of regional investment and multimodal connectivity — particularly in Navoiy, where a freight airport strengthens logistics efficiency.

At the other end of the spectrum, Karakalpakstan, Surkhandarya, and Sirdarya recorded persistently low RSCI values with minimal improvement over the decade. These regions appear underserved in terms of railway service capacity and connectivity, pointing to a mismatch between infrastructure provision and regional socio-economic potential.

Jizzakh, while currently underperforming, offers untapped potential due to its designation as a Free Economic Zone (FEZ) and the presence of growing industrial activity. Better integration with railway networks could unlock this potential and enhance export capacity.

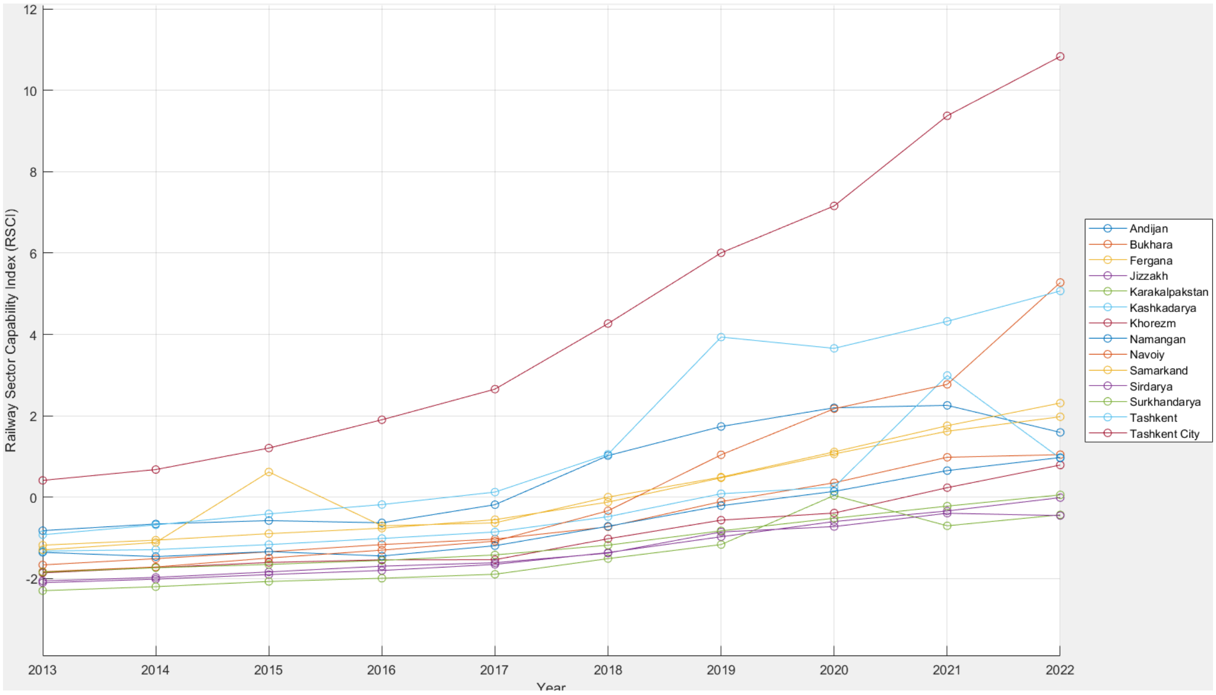

Fig. 4. Regional RSCI Trends (2013-2012)

5.2. Infrastructure and Development Alignment

The PCA loadings used in the RSCI revealed that Retail Turnover, Number of Organizations, and Industrial Production had the highest influence on regional capability scores. This confirms that the performance of railway systems is closely tied to economic activity rather than simply the physical extent of infrastructure. Interestingly, railway length showed low or negative correlation with capability, underscoring that infrastructure quality and strategic placement are more critical than scale alone.

This highlights the need for evidence-based investment in regions where rail development can deliver the greatest economic and social return. Infrastructure policy must consider not just expansion, but the strategic integration of rail with local industrial, logistics, and development planning.

5.3. Strategic Policy Recommendations

To promote a more balanced, resilient, and future-ready railway system in Uzbekistan—particularly in light of anticipated demand growth from international transit routes such as the China–Kyrgyzstan–Uzbekistan (CKU) railway—five strategic directions are proposed, each derived from the insights of the RSCI analysis and regional performance trends.

First, Uzbekistan should prioritize building resilience in its most strategic railway corridors, particularly those in high-traffic and economically vital regions such as Tashkent, Navoiy, and Andijan. These regions are likely to experience significant increases in freight volume due to regional integration and corridor connectivity. Investment should focus on removing infrastructure bottlenecks, upgrading signaling and control systems, and optimizing freight capacity management. These efforts will ensure that the national railway network remains efficient, responsive, and capable of handling growing international transit without service degradation.

Second, modernizing infrastructure in persistently underperforming regions is essential for achieving balanced national development. Regions such as Karakalpakstan, Surkhandarya, and Sirdarya have shown consistently low RSCI scores, indicating a lack of alignment between infrastructure availability and regional economic needs. Strategic investments in these areas should include rail line rehabilitation, electrification of key sections, and the deployment of modern monitoring technologies to improve safety and operational continuity. Bridging this performance gap will enhance regional equity and increase national network resilience.

Third, the government should focus on strengthening system redundancy and expanding multimodal logistics capacity. Upgrading secondary and underutilized corridors will provide alternative routing options in the event of congestion or service disruptions along primary corridors. At the same time, greater integration of rail with road and air logistics is necessary to maximize efficiency. Establishing or upgrading multimodal hubs in regions like Navoiy, Jizzakh, and Samarkand can serve as critical nodes for freight consolidation, storage, and distribution, offering flexibility and efficiency under variable demand conditions.

Fourth, Uzbekistan should institutionalize the Railway Sector Capability Index (RSCI) as a core decision-support tool for national transport planning. The RSCI enables data-driven investment prioritization by quantifying infrastructure effectiveness in relation to socio-economic activity. Used regularly, the index can serve as an early-warning system for identifying regional infrastructure stress, underperformance, or growth potential. Incorporating RSCI findings into national dashboards and investment strategies will promote evidence-based planning and targeted development.

Finally, the country must advance its overall strategic readiness by adopting a comprehensive national railway resilience framework. This should include formal risk assessments, adaptive planning protocols, and coordination mechanisms between central planners, regional governments, and private logistics stakeholders. Equally important is the need to invest in railway workforce training, digital operations centers, and predictive maintenance systems that leverage smart technologies. These actions will not only enhance day-to-day operational performance but also strengthen Uzbekistan's position as a trusted and reliable transit partner within the broader Eurasian transport ecosystem.

6. CONCLUSIONS

This study developed the Railway Sector Capability Index (RSCI) as a data-driven framework to assess how effectively Uzbekistan's regional railway systems align with socio-economic development. By applying Principal Component Analysis (PCA) to ten key indicators across 14 regions from 2013 to 2022, the RSCI revealed clear spatial disparities and helped identify both high-performing and underutilized areas within the national railway network.

The results show that economic activity particularly retail turnover, industrial output, and organizational presence plays a more decisive role in railway effectiveness than infrastructure scale alone. Tashkent City consistently outperformed other regions, followed by upward trends in Navoiy and Andijan. In contrast, Karakalpakstan, Sirdarya, and Surkhandarya exhibited persistent underperformance, highlighting gaps in infrastructure planning and investment alignment.

As Uzbekistan enters a new era of regional integration, with initiatives like the CKU railway and East–West trade corridors, building a resilient, equitable, and responsive rail system becomes a strategic imperative. The RSCI offers a practical tool not only for tracking development progress but also for guiding investment decisions, enhancing regional connectivity, and designing tailored interventions. It provides critical insight for ensuring that future infrastructure growth supports balanced national development while positioning Uzbekistan as a reliable and adaptive player in the evolving Eurasian transport landscape.

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