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Efficiency assessment of the Mongolian railway industry using data envelopment analysis: a comparative analysis with CAREC railways

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Abstract:
This study aimed to assess the efficiency of the railway industry in Central Asia Regional Economic Cooperation (CAREC) 10 member countries. Using data from 2016 to 2018, we set the ten CAREC countries as DMUs and applied the DEA (Data Envelopment Analysis) method to analyze the relative efficiency of each country's railway industry. Input factors considered were railway extension length, number of workers, freight cars, and expenses. Output factors included revenue and total cargo volume. The results revealed that the China Railway Corporation and the Afghanistan Railway Authority consistently demonstrated efficiency over three years, with an efficiency value of 1(100%). Kazakhstan and Uzbekistan also achieved 100% efficiency for one year each. While the Mongolian railway industry showed a slightly higher efficiency index, it was less efficient than China, Afghanistan, Kazakhstan, and Uzbekistan. Findings reveal that the Mongolian railway sector faces significant challenges due to outdated infrastructure, rolling stock, and equipment, which hinders profitability. According to the results of DEA's analysis, it is helpful for Mongolia to choose optimal benchmarking targets to reduce operating costs, improve infrastructure and facilities, and optimize operations to enhance railway efficiency.

1 Introduction

Mongolia spans an area of 1,564,116 square kilometers in Central Asia. This landlocked nation shares its northern border with Russia and its southern border with China. Despite limited international trade and logistic networks via its neighbors, Mongolia is traversed by a continental railway line that connects Eurasia. The history of Mongolia's railway industry dates back to 1938, with an initial railway line stretching 43 kilometers and featuring a 750 mm gauge. This line facilitated train travel between Ulaanbaatar and Nalaikh. In 1946, the Mongolian and Russian governments negotiated a contract establishing the Mongolian Railway joint venture. By 1955, the ownership was split evenly at 50:50. The Russian government completed a 400 km railway line connecting Ulaanbaatar to Naushki in 1949, and a 700 km line linking Ulaanbaatar to Zamiin-Uud was finished in 1955. In 1952, an agreement was reached among Russia, China, and Mongolia to operate interconnecting direct trains through Mongolia, leading to the opening of the Trans-Mongolian Railway (TMGR) in 1956.

As of 2023, Mongolia's railway network extends to 2,413 km, primarily comprising two main and eight branch lines. A 1,110 km route connects Sükhbaatar on the Russian border, passing through the capital Ulaanbaatar to Zamiin-Uud on the Chinese border. As a landlocked country, Mongolia's nearest port to the capital, Ulaanbaatar, is Tianjin Port in China, approximately 1,700 km away. The Mongolian railway shares the same broad gauge (1520 mm) as Russia, but when trading with China, which uses the standard gauge (1435 mm), transshipment is necessary due to the gauge difference. This gauge difference significantly impacts logistic flow and the time and cost of Mongolia's trade with China.

Mongolia's transportation sector encompasses railways, roads, and aviation. According to the Ministry of Road and Transport of Mongolia, the freight volume continues to rise annually, with an average annual cargo volume of 174 million tons as of 2023, reflecting a 76.6% increase from the previous year. The distribution of cargo transport among the different sectors is as follows: road transport accounts for 66.36%, railways for 33.63%, and air transport for 0.01%. In 2023, most of the international cargo (96.3%) was transported through the border with China, while the remainder (3.7%) passed through the border with Russia. Of the cargo handled at the Chinese border, 95.4% was exported transportation, whereas 88.9% was imported transportation at the Russian border.

Despite significant efforts, Mongolia's transportation efficiency needs to catch up to that of advanced countries. The aging railway infrastructure and a shortage of freight cars and locomotives necessitate extensive repairs and upgrades to enhance operational efficiency [1]. Furthermore, most railway routes are single-track, leading to increased freight transportation time due to delays at intermediate stations as train frequency rises. This inefficiency hinders the ability to meet the growing demand for freight transport. To address these challenges, the Mongolian government has devised a multi-stage plan to construct new railways, aiming to improve the overall transportation infrastructure and boost the competitiveness and efficiency of railway transportation. Additionally, several international organizations are investing in and implementing projects within the railway sector to support these improvements.

The CAREC Program is one of ADB's initiatives to foster regional cooperation and trade. It was launched in 2001 and is a partnership of 11 member countries. This study analyzes Mongolia's railway industry's efficiency by comparing it with the efficiency of the other ten Central Asia Regional Cooperation (CAREC) countries using open data from 2016 to 2018 from the Asian Development Bank (ADB)—Mongolia, which joined CAREC in 2003.

The efficiency research maximizes the benefits of investment and improvements in the railway industry; by measuring efficiency, the study seeks to identify inefficiencies in input factors and propose strategies for improvement, enabling the industry to achieve higher efficiency through benchmarking. In the case of rail transportation, the process for obtaining output is very complex, and according to [2-4], there are limitations in clearly identifying the input elements and costs. Considering the characteristics of the industry, we decided to apply the Data Envelopment Analysis (DEA) model, a linear programming method (LP).

This study comprises the following chapters: Chapter 1 introduces the study, Chapter 2 introduces related literature studies, and Chapter 3 briefly explains the methodology, specifically the DEA. Chapter 4 discusses efficiency, summarizes the analysis and results, presents opinions on Mongolia's efficiency, problems, and directions for improvement, and provides a simple interpretation of each country's efficiency. It concludes in Chapter 5.

2 Literature review

Much of the existing research on the railway sector was conducted on operational efficiency using various methodologies targeting routes and operating organizations. The efficiency of the railway systems in 19 Organization for Economic Cooperation and Development (OECD) countries was studied from 1978 to 1989 using DEA analysis. Tobit regression was used to ascertain the impact of public subsidies and the level of management autonomy while controlling for various operating characteristics and market environments, such as traffic density, average load per train, average travel distance, and electrification ratio. The study determined that railway systems heavily reliant on public subsidies exhibited significantly lower efficiency than those with lower dependency, and systemized countries tended to achieve higher efficiency levels [2].

This paper evaluates the performance of rail transport services by examining the comprehensive concept of service delivery from the perspective of railroads. Considering the limitations imposed by data availability and employing Data Envelopment Analysis (DEA), we have selected specific quality of service metrics. These metrics include punctuality, the frequency of severe train accidents (safety), and the volume of public complaints (customer satisfaction). The study identifies exemplary zones and assesses the efficiency of 16 Indian Railways (IR) zones based on these criteria [3]. In a study by [4], the causes and magnitudes of inefficiencies in the input structure were analyzed by applying DEA (DEA-AR) to evaluate the efficiency of the Chinese railway industry. The analysis results spanning 1985 to 2004 indicated an overall inefficiency within the Chinese railway industry, with a notable increase in efficiency observed after 2000. The study identified excessive workforce and outdated facilities as primary factors contributing to inefficiency. [1] analyzed the efficiency of railway transportation in Korea using DEA techniques based on railway transportation service data provided by 22 national railway operating companies from 2000 to 2006. The analysis showed that Korea's railway transportation operates more efficiently than other countries and that productivity has increased since 2004. [5] analyzed productivity changes in European railways from 1970 to 1995. The paper applied a non-parametric approach that could subdivide production changes into efficiency and technological changes. The results of the analysis confirmed that most companies focused on increasing productivity from 1985 to 1995 when they carried out the renovation process. Researchers of [6] analyzed the determinants of efficiency and found that, unlike other papers, the higher the autonomy and financial independence, the higher the efficiency level and technological change. [7] assesses the efficiency of 18 railway lines operated by seven major companies in Tokyo, factoring in financial performance and in-vehicle congestion. Using 2017 data on congestion rates, line specifics, passenger metrics, revenue, and expenses, the study applies data envelopment analysis and Tobit regression. Results show that adding congestion data improves service quality measurement in efficiency scores. Higher congestion lowers cost efficiency but boosts revenue efficiency, with improvement strategies proposed for different line types. [8], investigated the impact of CO2 emissions on railway efficiency in China, utilizing a Malmquist–Network DEA model with data from 18 railway bureaus from 2006 to 2020. Also, [9] examined railway transport in 16 nations between 2010 and 2018 using a three-stage DEA modeling approach. The 16 nations under consideration have comparable pure efficiencies but differing scale efficiencies, suggesting little chance of increasing efficiency through technical advancement.

In this study, we analyze the railway operation efficiency of CAREC countries, including Mongolia, based on DEA, find countries corresponding to the efficient frontier based on DEA, and benchmark the efficiency of the efficient frontier to suggest directions for improving Mongolia's efficiency. The summary of the literature review is shown in (Table 1).

Table 1 Summary of the relevant literature on Railway

Author	Subject	Input / Output	Methodology
Cantos, P., Pastor, J.M., and Serrano, L. (1999)	European Railway (1970~1995)	Number of workers, consumption of energy and materials, number of passenger carriages, number of freight cars, number of kilometers of track	DEA, MPI
		Passenger-km and tonnes-km	
Ha, H., C, Y., and Na, J. (2009)	China's Railway Industry (1985~2004)	Labor, power, capital, fuel consumption, GDP, railway length	DEA-AR
		Passenger-km, freight ton-km	
Kim, H., Kwang H., et al., (2009)	OECD 30 countries and Korean railways (2000~2006)	Workforce, fuel, vehicle, mainline extension, management cost	DEA, MPI
		Distance of traffic, train transport performance, transportation income data	
Sharma,M.G., Debnath,R.M., et al., (2016)	Indian Railway Passenger Transportation (2004~2009)	Working expense, financial performance, asset utilization, Number of employees, Equated Track kilometers	DEA, MPI,
		Loading of revenue-earning goods traffic, passenger traffic, punctuality of mail/express and suburban trains, mean kilometers per accident, number of satisfied passengers per complaint, reliability	
Kutlar, A., Kabasakal, A., and Torun, P. (2013)	World Railway firms (2000~2009)	Annual cost of operation, the average annual number of employees, the length of the main line, the number of traction vehicles, the number of passenger cars, the number of cargo cars	Panel data, DEA CCR – BCC, MPI
		Annual total revenues earned, total number of passengers transported, total number of passengers -km, total cargo ton transported, total cargo ton-km	
Oum, T., Yu C. (2014)	OECD 19 countries (1978~1989)	Labor, energy consumption, ways and structures, materials, number of passenger cars, number of freight wagons, number of locomotives	DEA, Tobit Regression
		passenger-km and freight ton-km, passenger train-km and freight train km	
Le, Y., Oka, M., & Kato, H. (2022)	Urban Railway (2008~2018)	Length of line, the number of stations, labor costs, operating costs, Vehicle kilometers, number of passengers	DEA, Tobit Regression
		Vehicle kilometers, number of passengers, 1/in vehicle congestion rate, fare revenue, miscellaneous transportation revenue	
Niu, Y., Li, X., et al., (2023)	16 Countries Railway (2010~2018)	Length of railway lines, average number of staff, number of locomotives, annual consumption of energy by railway transport, ratio of non-electrified railway tracks to electrified railway tracks	DEA
		Passenger-kilometers, freight-tonnes-kilometers	
Ji, W., & Qin, F. (2024)	China Railway bureaus (2006~2020)	Construction capital, line length, number of locomotives, number of employees, energy consumption of locomotives, population density, passenger delivery, per capital GDP, kilometers travelled by locomotives	Malmquist–NDEA model
		Revenue of railway transport, CO_2 emissions	

3 Methodology

Many researchers introduced efficiency analysis to the economics literature, and since then, many studies have been devoted to measuring efficiency. In particular, the fields of efficiency analysis are increasingly dominated by parametric frontier models and nonparametric techniques. Technical Efficiency (TE) and (Allocative Efficiency) AE use parametric and nonparametric methods in studies where economic efficiency performance assessment is measured. The nonparametric approach uses linear programming to determine the best combination of inputs and outputs, which are then categorized according to their actual performance to assess the relative effectiveness of many decision-making units.

The nonparametric approach has the advantage of imposing no a priori parametric restrictions on the underlying technology. DEA is an effective non-parametric method for evaluating the relative efficiency of the decision-making units, which can be different from the exact functional form between the inputs and outputs approach. The model measures the efficiency of all DMUs without requiring prior weights for the inputs and outputs. As a result, DEA computations are made to optimize each unit's relative efficiency score, with the caveat that the weights determined in this way for each DMU must also be practical for every other DMU in the sample. The DEA technique allows each DMU to set its variable weight more favorably than other DMUs and can identify reference units for each DMU. The DEA is more flexible and applicable than other methods [10].

In this study, the Data Envelopment Analysis (DEA) method is used to measure the overall efficiency of the railway systems.

3.1 Data Envelopment Analysis

Efficiency is defined as the ratio between outputs and inputs, and we can describe it as the distance between the quantity of input and output. Efficiency refers to the extent to which output can be produced with minimal input or the extent to which maximum output can be achieved with a given amount of input. Efficiency is measured by evaluating performance by comparing two or more production systems. It is a significant tool for analysis and improvement. It can be expressed as shown in equation (1).

$$Efficiency = \frac{OUTPUT}{INPUT} \quad (1)$$

The DEA model is an efficiency measurement method first developed based on the concept of relative efficiency by Farrell (1957), the CCR model by Charnes, Cooper, and Rhodes (1978) [11] developed the Farrell view, and they provided a fractional and nonlinear mathematical programming model to measure efficiency with multiple inputs and outputs. The BCC model by Banker, Charnes, and Cooper (1984) presented a new little changed model [12]. This method measures efficiency by calculating the production frontier, the minimum input combination required to produce a given output, the cost curve, and the distance between actual observation points. DEA models also require input- and output-oriented solutions to achieve an efficient frontier.

The input-oriented model offers recommendations for lowering inputs to reach the efficient frontier. The output-oriented model suggests ways to boost output to achieve an efficient frontier. The efficient frontier may be reached in the output-oriented model by increasing outputs without drawing in more inputs. The output-oriented paradigm makes sense when the inputs are roughly constant. Furthermore, the input-oriented paradigm works well when the outputs closely match the organization's objectives or are constrained by outside variables [13].

The DEA model is the most efficient method for evaluating input and output by applying each analysis target, or Decision-Making Unit (DMU), to both input and output. This model has the advantage of measuring the relative efficiency of DMUs with multiple inputs and outputs, enabling the assessment of both efficiency and inefficiency. These measurement results help analyze the causes of inefficiency and set goals for efficiency improvement. The DEA model is widely used for evaluating the efficiency of public service organizations [1]. In general, the CCR model is a fundamental model of the DEA technique, which can be explained as follows: The ratio of the weighted sum of output variables to the weighted sum of input variables in a DMU must not exceed 1, with the constraint that the weight of each input variable is greater than 0. The relative efficiency is evaluated based on this constraint. The DMU is considered inefficient if the calculated efficiency score is less than one.

The CCR model assumes that there are $n\ DMU_j\ (j = 1,2 \dots . s)$ that produce s outputs for $y_{rj}(r = 1,2 \dots . m)$, using inputs $x_{ij}(i = 1,2 \dots . n)$, to be evaluated. The efficiency of a specific decision-making unit DMU_o is the ratio of the weighted sum of outputs divided by the weighted sum of inputs. In mathematical forms, it is shown in equation (2).

$$Max\ E_o = \frac{\sum_{r=1}^{m} u_r\ y_{r0}}{\sum_{i=1}^{n} v_i\ x_{io}}$$

$$s.t. \quad \frac{\sum_{r=1}^{m} u_r\ y_{rj}}{\sum_{i=1}^{n} v_i\ x_{ij}} \leq 1 \quad j = 1,2,\dots,s$$

$$and\ u_r, v_i > 0,\ (r = 1,2,\dots,m)\ (i = 1,2,\dots,n) \quad (2)$$

Where the x_{ij}, y_{rj} are the known inputs and outputs of the j^{th} DMU. The models presented in above ratio form are a fractional programming problem. Nevertheless, since $\sum_{i=1}^{n} v_i\ x_{ij} \geq 0$, if we let $\sum_{i=1}^{n} v_i\ x_{i0} = 1$, the problem can be reformulated as the following linear programming problem as shown in equation (3).

$$Max\ E_o = \sum_{r=1}^{m} u_r\ y_{r0}$$
$$s.t.\quad \sum_{i=1}^{n} v_i\ x_{i0} = 1,$$
$$\sum_{r=1}^{m} u_r\ y_{rj} \leq \sum_{i=1}^{n} v_i\ x_{ij},\quad j = 1,2 \dots, s$$
$$and\ u_r, v_i > 0, (r = 1,2, \dots, m)\ (i = 1,2, \dots, \mathrm{n}) \quad (3)$$

Where:

$DMUo$: $Decision\ Making\ Unit$,
$\boldsymbol{E_o}$: $\boldsymbol{Efficiency\ of\ DMUo}$,
$\boldsymbol{u_r}$: $\boldsymbol{weight\ for\ r^{th} output}$,
$\boldsymbol{v_i}$: $\boldsymbol{weight\ for\ i^{th}\ input}$,
$\boldsymbol{y_{rj}}$: $\boldsymbol{the\ amount\ of\ r^{th}\ output\ of\ DMUj}$,
$\boldsymbol{x_{ij}}$: $\boldsymbol{the\ amount\ of\ i^{th}\ input\ of\ DMUj}$,
$\boldsymbol{r}$: $\boldsymbol{number\ of\ outputs}$,
$\boldsymbol{i}$: $\boldsymbol{number\ of\ inputs}$,
s: number of DMUs to evaluate.

Hence, solutions can be derived through the iterative use of linear programming software.

The CCR model assumes constant returns to scale (CRS) in the productivity process and measures efficiency and overall technical efficiency (TE) [11].

3.2 CCR model for DMU-1(Mongolia)

Rail transportation is a public sector, so measuring the cost of input and output factors, the importance of services provided, and the resources used to depend on the evaluation target is difficult. Therefore, considering these characteristics, data envelopment analysis (DEA) models are widely used for evaluation, and this study uses an input-oriented model.

Regarding Mongolia's railways, it has been many years since the primary railway network was established, and it is challenging to completely repair and modernize it, mainly since all export, import, and transit cargoes are transported along a single main route. In this input-oriented model, one of the main objectives is to maintain the output level while enhancing the input level. Although it is difficult to carry out large-scale works such as expanding railway tracks in a short period, we selected this model because it is possible to improve the input factors such as the number of vehicles, personnel, and operating costs that can be enhanced to control the railway organization.

Mongolia's primary railway network has an average carrying capacity of 25 tons per axle (Axle Load). However, the load has increased in recent years, leading to overloading on some routes. This overloading has damaged the railway infrastructure, increased maintenance costs, affected the quality of the railway, and raised the probability of accidents, all of which directly impact performance. In the future, the volume of transportation and profitability will depend on the railway's capacity; therefore, there is a need to enhance the quality of the existing inputs to increase output. We have chosen this method because it is the most efficient way to carry out rail transport until the dual tracks and new transport corridors are created as part of the railway reform.

Accordingly, a basic model with a specific direction that can fix the output and reduce the input and a radial model that can obtain the same efficiency score regardless of unit change in input and output were assumed. The input-oriented envelope model is "a model that finds the $\boldsymbol{\theta}$ ratio that reduces the input level to the smallest by reducing all m input factors by a certain percentage while achieving at least the same output level as the current output level. " Let's calculate and interpret the efficiency of the railroad industry using the objective function and constraint formula of the linear planning method of the input-oriented envelope model. Assume there are 10 DMUs, and each DMU $(\boldsymbol{j = 1, 2, \dots, 10})$ produces $\boldsymbol{y_{rj}(r = 1, 2, \dots, m)}$ output variables by inputting $\boldsymbol{x_{ij}(i = 1, 2, \dots, n)}$ input variables. First, if the weight of input elements 1 to 4 are $\boldsymbol{v_1, v_2, v_3, v_4}$, and the weight of output elements 1 and 2 are $\boldsymbol{u_1, u_2}$, the CCR input-oriented model for calculating the DEA efficiency score of $\boldsymbol{DMUE_1}$ can be formulated as following equation (4).

$$\begin{aligned}
&\boldsymbol{Max\ E_1 = 19,989u_1 + 128,975u_2}\\
&\boldsymbol{s.t.\ 13364v_1 + 1810v_2 + 3319v_3 + 129,329v_4 = 1}\\
&\quad \boldsymbol{19,989u_1 + 128,975u_2 \leq 13364v_1 + 1810v_2 + 3319v_3 + 129,329v_4}\\
&\quad \boldsymbol{5,190u_1 + 213,284u_2 \leq 22886v_1 + 2066v_2 + 4193v_3 + 217,629v_4}\\
&\quad \boldsymbol{2,693,000u_1 + 89,259,332u_2 \leq 2,003,306v_1 + 111821v_2 + 764783v_3 + 82,236,988v_4}\\
&\quad \boldsymbol{339,000u_1 + 1,708,912u_2 \leq 76240v_1 + 15529v_2 + 56504v_3 + 1,367,884v_4}\\
&\quad \boldsymbol{10,000u_1 + 200,412u_2 \leq 12700v_1 + 1994v_2 + 4469v_3 + 135,202v_4}\\
&\quad \boldsymbol{1,742u_1 + 18,391u_2 \leq 326v_1 + 75v_2 + 17v_3 + 10,444v_4}\\
&\quad \boldsymbol{12,421u_1 + 71,936u_2 \leq 80054v_1 + 7791v_2 + 15164v_3 + 144,001v_4}\\
&\quad \boldsymbol{5,454u_1 + 51,8876u_2 \leq 5770v_1 + 597v_2 + 450v_3 + 49,358v_4}\\
&\quad \boldsymbol{67,600u_1 + 63,5326u_2 \leq 58239v_1 + 4593v_2 + 20448v_3 + 56,015v_4}\\
&\quad \boldsymbol{6,031u_1 + 56,903u_2 \leq 5131v_1 + 417v_2 + 1080v_3 + 38,603v_4}
\end{aligned} \quad (4)$$

$$and\ u_1, u_2, v_1, v_2, v_3, v_4 \geq 0$$

To obtain the optimal solution of the above linear programming model using MS Excel Solver, the Mongolian railway industry, which is the subject of evaluation, uses input and output variables such as 13,364 staff (v_1), 1,810 km of railway line extension (v_2), 3,319 freight vehicles (v_3), and operating expenses of USD 12.9 billion (v_4), resulting in railway freight performance of 19,989 tons of freight (u_1) and USD 12.8 billion in revenue (u_2) to obtain the DEA efficiency score.

3.3 Data collection

Since there is no precise definition of input and output factors, it is essential to define which factors are used as inputs and outputs together with the evaluation criteria. Considering the characteristics of railway transport and the availability of reliable information, input and output factors must be finalized, so factors relevant to the railway industry were selected from previous research. The data used in this study is based on the 2016-2018 Railway Sector Report of Member States published by the ADB. Also, the homepages, statistical websites, and press releases of the country's railway organizations were analyzed, and missing and additional information not included in the report was found. The data set consists of 10 countries in CAREC that do not have Turkmenistan. Because it does not provide data as simultaneously as other countries. The inputs and outputs used in this paper focus on the ten CAREC countries and review previous studies on railway efficiency using the DEA method. The available data from the cost-effectiveness analysis (Table 2) are summarized.

Table 2 Numerical value of input and output data (2016~2018)

DMU	Nation	Year	Employee	Rail length (km)	Freight car	Expenses (million)	Freight volume (million)	Revenue (million)
1	Mongolia	2016	13,364	1,810	3,319	129,329,438	19,989,000	128,975,110
		2017	15,800	1,815	6,500	131,396,347	22,765,000	156,494,526
		2018	16,482	1,920	7,130	135,234,892	25,763,000	181,887,977
2	Azerbaijan	2016	22,886	2,066	4,193	217,629,533	5,190,000	213,284,345
		2017	19,000	2,944	4,193	251,214,852	4,630,000	225,982,681
		2018	19,000	4,285	4,193	287,268,868	4,490,000	222,192,685
3	China	2016	2,003,306	111,821	764,783	82,236,988,290	2,693,000,000	89,259,332,909
		2017	1,848,032	131,000	808,736	88,298,554,192	3,689,000,000	97,145,983,456
		2018	1,841,500	132,000	839,213	94,318,371,635	4,026,000,000	104,425,165,720
4	Kazakhstan	2016	76,240	15,529	56,504	1,367,884,179	339,000,000	1,708,912,128
		2017	119,071	16,040	54,925	1,497,596,421	387,000,000	1,895,768,595
		2018	130,400	16,040	55,000	1,699,228,918	387,000,000	2,167,872,187
5	Georgia	2016	12,700	1,994	4,469	135,202,727	10,000,000	200,412,171
		2017	10,765	1,443	5,001	284,672,249	10,600,000	175,951,569
		2018	13,000	1,443	5,001	404,665,087	9,900,000	165,032,421
6	Afghanistan	2016	326	75	17	10,444,413	1,742,000	18,391,248
		2017	326	75	17	11,366,813	1,968,000	19,540,701
		2018	326	75	17	10,458,603	3,298,000	29,871,588
7	Pakistan	2016	80,054	7,791	15,164	144,001,414	12,421,000	71,936,068
		2017	72,078	7,791	16,085	143,283,202	20,884,000	71,939,659
		2018	72,078	7,791	16,159	153,542,854	20,849,000	89,004,365
8	Tajikstan	2016	5,770	597	450	49,358,470	5,454,000	51,887,272
		2017	5,700	680	450	30,813,922	4,647,000	33,623,702
		2018	5,400	682	450	33,998,339	5,348,000	37,744,712
9	Uzbekistan	2016	58,239	4,593	20,448	56,015,791	67,600,000	63,532,616
		2017	64,100	4,669	20,448	36,831,650	67,900,000	76,728,643
		2018	70,000	4,718	20,448	81,615,768	68,400,000	83,461,310
10	Kyrgyz	2016	5,131	417	1,080	38,603,219	6,031,000	56,903,831
		2017	4,700	424	1,080	54,984,268	7,157,000	61,720,401
		2018	4,817	424	1,080	48,365,901	7,526,000	56,020,596

*Data was collected from the report of Railway Sector Assessment CAREC countries, ADB (2022) [14].

4 Results and discussion

This study conducted a DEA efficiency analysis on ten national railway industries from 2016 to 2018, spanning three years. Turkmenistan was excluded from the analysis due to insufficient information on its profits and operating costs among the 11 national railway institutions of CAREC member countries. MS Excel Solver was used as the analysis tool. The DEA model evaluates a DMU with an efficiency value of 1 as the most efficient; if the value is less than 1, the DMU is considered relatively inefficient. The trend of efficiency changes for each national railway operating industry is shown in (Figure 1).

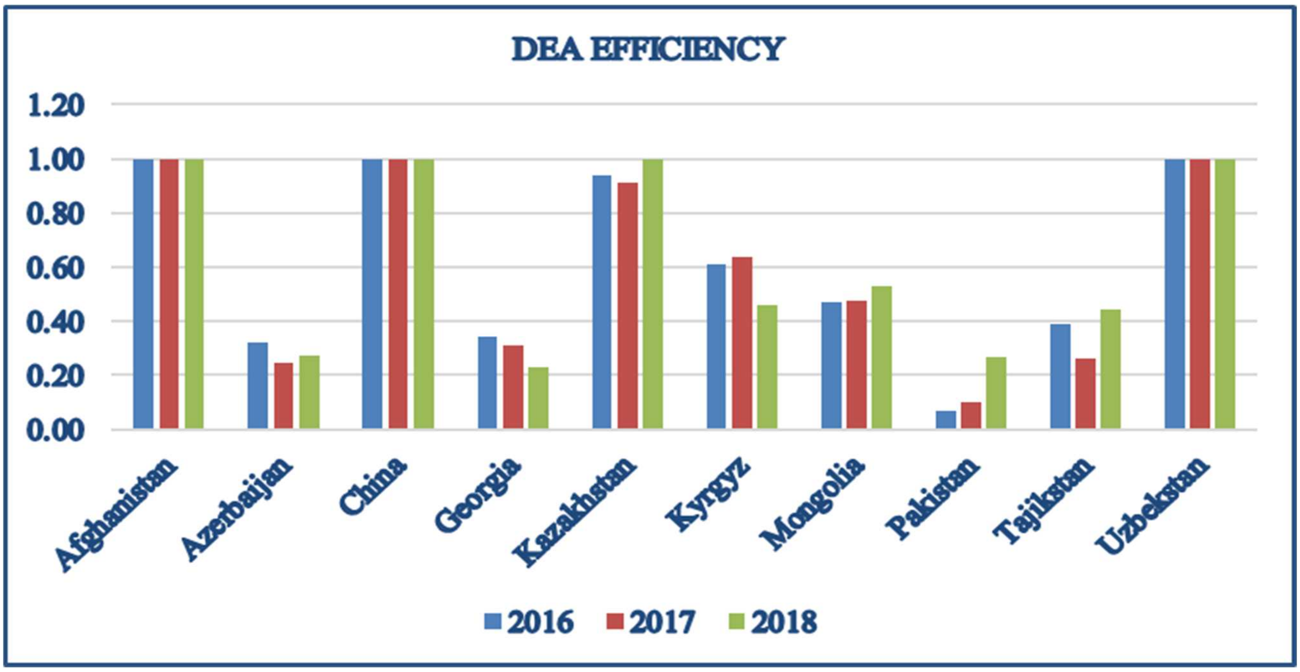

Figure 1 Efficiency of the 10 DMUs

The analysis results using the CCR model are shown in (Table 3). When measuring the operational performance of the countries operating the railways, the total performance of the operating income and the total amount of transported freight were selected to measure the efficiency. As a result, four of the railway organizations were efficient, and six were analyzed as inefficient. The institutions operating at 100% efficiency are China Railway Corporation (DMU-3), Afghanistan Railway Authority (DMU-6), Kazakhstan Railways (DMU-4), and Uzbekistan Railways (DMU-9) have worked efficiently for one year each. Afghanistan Railway Authority (DMU-6) was the most efficient DMU analyzed 22 times for the DMU with the most significant reference group. After that, China Railway Corporation (DMU-3) had many references, 15, and finally, Uzbekistan Railways (DMU-9) was analyzed as the subject of efficiency evaluation four times.

It has been concluded that the Mongolian railway sector (DMU-1) did not operate at 100% efficiency during the specified years. The Mongolian railway fleet suffers from significant wear and tear, with approximately 60% of logistics elements, such as wagons and locomotives, being at least 26 years old. These vehicles operate under harsh conditions and often receive minimal maintenance, rendering them prone to increased deterioration. According to data from the International Union of Railways (UIC), UBTZ ranks third lowest in the number of wagons among comparator countries and fourth in the number of diesel locomotives (2017). However, from 2016 to 2018, the efficiency rate gradually improved, rising from 47.4% in 2016 to 47.5% in 2017, reaching 51% in 2018. This improvement can be attributed to a continuous increase in freight performance, operating income, and output factors. Specifically, cargo flow throughput increased from 19.989 million tons in 2016 to 25.763 million tons in 2018, reflecting an annual growth rate of approximately 13%. Simultaneously, operating profit rose by 26%, from 156.494 million to 181.887 million. Additionally, the growth rate of operating expenses remained low and was effectively managed. If activities such as the comprehensive renovation of the existing railway fleet, technical logistics, the acquisition of new equipment, and timely maintenance are undertaken, the productivity of railway operations could reach 100%. Furthermore, the Mongolian government has recently initiated a new railway project aimed at expanding the railway network and enhancing mining operations, which are critical factors influencing the development of the railway industry. As part of this project, the railway network will be expanded, leading to increased cargo volume and enhanced efficiency within the Mongolian railway sector.

Azerbaijan Railways (DMU-2) 's efficiency decreased year over year from 2016 to 2018, directly related to higher operating income than expenses. The main reason is that during this period, Azerbaijan Railways invested a lot of finance in the project, investing in the infrastructure works to connect the Baku-Tbilisi-Kars BTK railway line. Once the project is fully implemented, it will cover expenses, increase income, and be profitable. The Baku-Tbilisi-Kars (BTK) railway connects Baku, Azerbaijan, with Tbilisi, Georgia, and Kars, Turkey. The line is an important transit corridor from the Caspian Sea to Europe and has developed into one of the main routes connecting China, Central Asia, the Caucasus, and Europe. In 2016-2018, the efficiency of China's railways (DMU-3) improved due to the expansion of high-speed rail and the growth of passenger flow and freight revenue. During this period, China expanded its domestic and international rail network and increased shipments to Europe under the Belt and Road Initiative, contributing significantly to revenue. Profitability has also been boosted by introducing technologies to control costs, reduce excessive workforces, and improve operational efficiency. Although the liabilities of the railway sector have increased, long-term profitable investments have stabilized profitability. China's railway network remained generally financially stable and profitable during this period.

The efficiency of Kazakhstan's railways has steadily increased year after year, and research has confirmed that it was 100% efficient in 2018. During this period, the increase in freight revenue, especially in China-Europe transit traffic, was a key factor supporting profitability. The volume of transport flow is growing every year, and Kazakhstan has developed into one of the leading trade routes of Eurasia. Also, infrastructure improvements and technological innovations have reduced costs and increased efficiency. Kazakhstan Railways has expanded its international connections with countries such as Russia and China, further increasing its operating financial income. As a result, the country's railway industry has reached a financially stable and profitable state.

Table 3 Estimation result of railway industries efficiency

DMU	Nation	Year	V1	V2	V3	V4	U1	U2	Efficiency (%)	Reference point
1	Mongolia	2016	0.00E+00	2.37E-08	0.00E+00	5.50E-04	0.00E+00	2.79E-11	47.4	DMU 3, 6
		2017	0.00E+00	2.09E-08	0.00E+00	5.47E-04	0.00E+00	6.08E-11	47.5	DMU 3, 6
		2018	2.69E-09	5.92E-11	0.00E+00	0.00E+00	0.00E+00	7.71E-09	51.4	DMU 6, 9
2	Azerbaijan	2016	1.51E-09	0.00E+00	0.00E+00	3.63E-04	0.00E+00	1.15E-09	32.3	DMU 3, 6
		2017	1.09E-09	0.00E+00	0.00E+00	2.72E-04	0.00E+00	7.96E-10	24.6	DMU 3, 6
		2018	1.22E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.48E-09	27.1	DMU 6
3	China	2016	0.00E+00	2.09E-08	0.00E+00	5.47E-04	0.00E+00	8.50E-12	100.0	-
		2017	2.69E-09	5.92E-11	0.00E+00	0.00E+00	0.00E+00	7.52E-12	100.0	-
		2018	9.58E-12	0.00E+00	0.00E+00	2.90E-06	0.00E+00	6.54E-12	100.0	-
4	Kazakhstan	2016	0.00E+00	2.77E-09	1.75E-07	6.35E-05	0.00E+00	0.00E+00	93.8	DMU 3, 6
		2017	0.00E+00	2.36E-09	0.00E+00	6.17E-05	0.00E+00	6.87E-12	91.2	DMU 3, 6
		2018	9.58E-12	0.00E+00	5.68E-07	0.00E+00	0.00E+00	9.64E-12	100.0	-
5	Georgia	2016	1.72E-09	0.00E+00	0.00E+00	4.13E-04	0.00E+00	1.31E-09	34.5	DMU 3, 6
		2017	1.76E-09	0.00E+00	0.00E+00	4.39E-04	0.00E+00	1.29E-09	31.0	DMU 3, 6
		2018	1.40E-09	0.00E+00	0.00E+00	4.25E-04	0.00E+00	9.57E-10	23.1	DMU 3, 6
6	Afghanistan	2016	5.44E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.96E-06	100.0	-
		2017	5.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.70E-07	100.0	-
		2018	3.35E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-08	100.0	-
7	Pakistan	2016	0.00E+00	5.52E-09	0.00E+00	1.28E-04	0.00E+00	6.49E-12	6.9	DMU 6
		2017	0.00E+00	4.89E-09	0.00E+00	1.28E-04	0.00E+00	1.43E-11	10.2	DMU 3, 6
		2018	0.00E+00	9.86E-09	0.00E+00	0.00E+00	3.29E-05	3.06E-09	26.7	DMU 6, 9
8	Tajikistan	2016	0.00E+00	7.19E-08	0.00E+00	1.67E-03	9.31E-06	0.00E+00	39.2	DMU 3, 6
		2017	0.00E+00	5.59E-08	0.00E+00	1.46E-03	0.00E+00	1.63E-10	26.0	DMU 3, 6
		2018	0.00E+00	8.31E-08	0.00E+00	0.00E+00	2.77E-04	2.57E-08	44.4	DMU 6, 9
9	Uzbekistan	2016	0.00E+00	1.48E-08	0.00E+00	0.00E+00	4.76E-05	4.89E-08	63.3	DMU 3, 6
		2017	0.00E+00	1.47E-08	0.00E+00	0.00E+00	4.85E-05	2.45E-08	57.6	DMU 6
		2018	0.00E+00	1.46E-08	0.00E+00	0.00E+00	4.87E-05	4.53E-09	100.0	-
10	Kyrgyz	2016	0.00E+00	1.03E-07	0.00E+00	2.39E-03	0.00E+00	1.21E-10	61.2	DMU 3, 6
		2017	0.00E+00	8.88E-08	0.00E+00	2.32E-03	0.00E+00	2.59E-10	63.5	DMU 3, 6
		2018	0.00E+00	6.11E-08	0.00E+00	8.84E-04	0.00E+00	1.29E-08	46.9	DMU 6, 9

Georgian Railways (DMU-5) operated at a loss because expenses exceeded income in 2016-2018. During this period, the organization made significant investments, such as the Baku-Tbilisi-Kars (BTK) railway project, which may have adversely affected profitability. Higher operating costs, maintenance, and employee costs that exceeded revenue were the main reasons for the loss. Also, transit demand volatility and transport revenue dependence have increased economic risks. In addition, the burden of loans and liabilities may also hurt income. Therefore, it can be assumed that short-term financial difficulties cause the loss of Georgian Railways. As a result, operating costs also increased sharply from 284 million to 404 million, and operating profit and freight transport performance did not increase that much, which is believed to have continuously decreased efficiency.

The main reasons for Afghanistan Railways' (DMU-6) showed an efficiency of 100% every year in its efficiency measurement value. Afghanistan's crucial strategic location connects Central and South Asia and the Middle East, creating favorable transportation and logistics conditions. Afghanistan's railway network is relatively short; as of 2018, its total length was about 75 km. At that time, the main route was the line connecting the ports of Khairaton and Uzbekistan. Although the length of the railway was limited, the use of freight cars and increased transit traffic to the Middle East and Central Asia significantly impacted growing revenues. Although the number of freight cars may be low, higher international freight demand has increased the volume of freight transiting Afghanistan, which has positively impacted the profitability of the country's railways.

Despite its economic importance, Pakistan's railway (DMU-7) faced several challenges in 2018. The railway network is 7,791 km long and suffers from aging infrastructure. Technological innovation and automated systems are essential to improve the delivery of freight and passenger services. Lack of finance and harmful deficits are stabilizing the development of the industry, and the lack of political protection from the outside is used to eliminate the negative impact of strategic decisions. Improving sub-operations, attracting international investment, and developing cooperation with other countries are essential. Therefore, there is potential to transform energy, develop strategies for developing Pakistan's railway sector, and significantly impact economic growth.

Table 4 Average Efficiency of DMUs (2016~2018)

DMU	Nation	Year	Dea Efficiency	Average Efficiency
1	Mongolia	2016	47.4%	48.8%
		2017	47.5%	
		2018	51.4%	
2	Azerbaijan	2016	32.3%	28.0%
		2017	24.6%	
		2018	27.1%	
3	China	2016	100%	100%
		2017	100%	
		2018	100%	
4	Kazakhstan	2016	93.8%	95.0%
		2017	91.2%	
		2018	100%	
5	Georgia	2016	34.5%	29.5%
		2017	31.0%	
		2018	23.1%	
6	Afghanistan	2016	100%	100%
		2017	100%	
		2018	100%	
7	Pakistan	2016	6.9%	14.6%
		2017	10.2%	
		2018	26.7%	
8	Tajikistan	2016	39.2%	36.5%
		2017	26.0%	
		2018	44.4%	
9	Uzbekistan	2016	63.3%	73.7%
		2017	57.7%	
		2018	100%	
10	Kyrgyz	2016	61.2%	56.9%
		2017	63.5%	
		2018	46.9%	

Due to several factors, the Tajikistan Railway (DMU-8) was moderately efficient in 2016-2018. The overall length of the railway network was relatively short, limiting domestic transport capacity. The unstable demand for transit cargo is believed to have led to the risk of lower income. Profitability was adversely affected by the high operational and maintenance costs of railways. These factors are believed to have contributed to Tajikistan Railways' moderate profitability and the fact that there was too much labor force compared to the length of the railway extension and cargo vehicles.

During this period, the cargo transportation capacity of the Uzbekistan Railway (DMU-9) increased due to significant investments in infrastructure improvement and the construction of new lines. In 2018, the increase in demand for transit transportation supported the growth of freight traffic to the Middle East and Central Asia. The tariff policy made transport prices more flexible and increased competitiveness. In 2018, the efficiency measure was measured as 1, showing 100% efficiency, because Uzbekistan expanded its high-speed rail network, strengthened connections between major cities, and also applied eco-friendly technologies such as replacing existing diesel locomotives with electric locomotives or introducing hybrid technologies to reduce the energy consumption of railway vehicles.

In 2016-2018, the efficiency of the Kyrgyz Railways (DMU-10) was moderate due to the limited capacity of domestic transportation and the lack of opportunities for transit freight. The length of the railway network and the relatively low level of infrastructure development negatively affected profitability. Although specific projects and investments have been made, economic difficulties and political instability have limited investment. Freight revenues were volatile, and competitiveness could have been better. The inflexibility of the tariff policy also contributed to lower profitability. Therefore, the Kyrgyz railway sector has not achieved sustainable growth and requires significant reforms and investments for further development.

The average efficiency is shown in (Table 4). The average efficiency of each national railway industry was 0.4878 for DMU-1, 0.2799 for DMU-2, 1 for DMU-3, 0.9500 for DMU-4, 0.2953 for DMU-5, 1 for DMU-6, 0.1457 for DMU-7, 0.3654 for DMU-8, 0.7367 for DMU-9, and 0.5691 for DMU-10.

Examining the efficiency trends of each operating institution reveals a general increase over time. This improvement reflects the continuous efforts made by these institutions to enhance efficiency. However, inefficiencies persist, primarily due to rising operating costs. To reduce these costs and further boost efficiency, it is crucial to introduce digital technologies, improve energy efficiency, optimize operation management, utilize eco-friendly technologies, and enhance infrastructure. By implementing these measures, the railroad industry can operate more competitively and sustainably, leading to increased profitability in the long run.

5 Conclusions

In the previous studies of the Mongolian railway industry, many studies were conducted on the current status of Mongolian railways and railway construction plans, and studies on efficiency were rare. This study was conducted to measure the Mongolian railway transportation industry's efficiency and derive improvement points. Using the DEA method, this study analyzed the efficiency of railway institutions in 10 CAREC countries from 2016 to 2018. As a result of the efficiency analysis, 4 DMUs were interpreted as the most efficient operating institutions and 6 DMUs were analyzed as inefficient operating institutions.

Between 2016 and 2018, the operating efficiency of the railway sectors within the Central Asian Economic Cooperation varied significantly. The average efficiency of each operating agency was analyzed to be higher overall in agencies that operate large-scale urban railways or railways with small input elements. For three years, the China Railway Corporation and Afghanistan Railway Authority were analyzed as the most efficient operating institutions.

Also, China, Kazakhstan, and Uzbekistan achieved efficiency through effective policies promoting transit cargo transportation, infrastructure development, and substantial investment. In contrast, while Afghanistan's railway network is limited in length, it generated profits through the effective use of freight wagons and increased transportation to the Middle East and Central Asia. Conversely, Tajikistan and Kyrgyzstan experienced moderate profitability, hampered by infrastructure constraints, political instability, and insufficient investment. Georgia's railway network, characterized by exceptionally high expenditures, contributed to its poor performance. Research in Pakistan and Mongolia indicated that the railway infrastructure, rolling stock, and equipment were only partially profitable due to their outdated condition.

Therefore, it is concluded that future measures to enhance the operations of the Central Asian Economic Cooperation railway countries should include expanding the railway network, building new lines, and strengthening cooperation among regional countries. Additionally, improving the transit transport and logistics systems will be essential. These measures have the potential to support the growth of the Central Asian railway industry by reducing operating costs while enhancing safety and service quality.

According to the DEA analysis results, Mongolia would benefit from selecting appropriate benchmarking targets to reduce operating costs and optimize operations to improve railway efficiency. Railway infrastructure expenses, train operating costs, and corporate overhead costs are the three primary categories of expenditures associated with railways. The capital and maintenance expenses for the track, engineering structures (such as bridges and tunnels), signaling, communications systems, power supply, and terminal facilities are all included in the railway infrastructure costs. The costs of fuel or power, rolling stock and locomotive depreciation or leasing, crews, terminal operations, rolling stock maintenance, and commercial expenses (such as freight booking) are all included in train operating costs. Findings reveal that the Mongolian railway sector faces significant challenges due to outdated infrastructure, rolling stock, and equipment, which hinders profitability. It is necessary to invest in railway modernization. Investing in extensive or one-time upgrades to the railway network will improve efficiency while encouraging the modernization of critical components to overcome systemic issues. Expansions in the handling facilities and transshipment activities, yard areas, and railway infrastructure to optimize operations and transit times and enhance service quality. It also reduces maintenance over the years, increases safety, and increases capacity for the rail sector, resulting in more dependable and competitive services. This investment strengthens the railway system and, subsequently, the economy by ensuring the seamless and faster movement of goods and individuals. Moreover, Mongolia's railway sector's sustainable development is expected to significantly influence rolling stock improvements and technological innovation, attract international funding, and facilitate investment in new railway projects.

A limitation of this study is that the data used in the study was not the most recent, but data from 5 years ago, so recent efficiency analysis was not possible. This is because the open data of the CAREC railway sector released by the Asian Development Bank was published in 2021, but the data is from the previous year. In addition, there has yet to be a recent report from ADB. Another expected research topic in the future is a study on specific strategies for Mongolia to reduce operating costs and improve operating efficiency, and among the CAREC countries that were compared and analyzed in this study, benchmarking the efficient frontier or analyzing alternatives through AHP analysis would be effective.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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