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Efficiency Evaluation of Railway Freight Stations by Using DEA Approach

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Abstract

Railway freight stations roles as junctures in which traffic processes can converge and diverge are of paramount importance. Numerous activities such as train formation, alighting and interchanging, technical checks are also done at these points. Due to the great importance of using railway infrastructures and rolling stocks facilities efficiently, the efficiency studies in this area are considered as a demanding task more than ever. Therefore, we implement a methodology based on data envelopment analysis to address this issue. The suggested methodology in this research can be used for measuring the efficiency of railway freight stations and ranking them by using DEA and Anderson & Peterson methods. This methodology can be used for analyzing the relative 'technical efficiency' of railway freight stations to manage train stops regarding the current station capacity. We applied these models in a case study of the 12 busiest train stations in Isfahan railway to measure and rank their efficiency and assess the effect of traffic type on the results by using robust regression.

Keywords:
Railway freight stations
technical efficiency
Data envelopment analysis (DEA)
Robust regression

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INTRODUCTION

The railway industry plays an important role in logistic freight loads. Having the capacity to carry a variety of products and volumes over long distances at a lower cost makes a relative advantage for railway transportation rather than other ways of transportation. By and large, developing this industry comes into the investment agenda of many countries, since it provides many opportunities such as regional integration, decreasing the costs of transportation, and CO_2 emissions. According to UIC[1] (2019), the length of railway lines in the world is 1.1 million kilometers, almost 7.1 million people are working in this industry and 10600 billion ton-kilometers were carried in this part of the shipping industry. Table 1 indicates the freight performance of railways in different regions of the world.

Since the industry of transportation is extremely sensitive to the economic conditions of different countries, these statistics can be changed according to world economic growth. Accordingly, many studies have been done to measure the efficiency of railway transportation. For instance, Marchetti and Wanke (2020) evaluate the efficiency of the Brazilian railway system by using TOPSIS and genetic algorithm methods. Sameni et al. (2016) worked on the efficiency of railway passenger stations based on the data envelopment analysis approach. Oum and Yu (1994) evaluate the efficiency of 19 OECD [2]countries rail companies over ten years by applying the data envelopment analysis (DEA) method. Cowie (1994) compared the efficiency of Switzerland's public and private railways by applying DEA method to evaluate technical and managerial efficiency. The role of railway freight stations in managing traffic of the railway network and enhancing its overall efficiency is significant. Due to the lack of efficiency, they usually are considered the main bottlenecks of railway networks. In other words, proper management of these points can have a significant impact on the productivity of the railway network. Despite the importance of railway freight stations in the success of this industry, a few pieces of research have been done to study railway freight stations' efficiency and rank them. Most of the studies on this field have been concentrated on traffic management of stations through optimizing the routes of trains such as the works by Qu et al. (2015), Sama et al. (2018), Pellegrini et al. (2015); Carey and Crawford (2007); Wenzheng et al. (2009) have studied on declining delays of trains movement through robust timetabling and train scheduling. Burkolter (2005) and Carey and Carville (2003) have focused on train routing and scheduling. Armstrong et al. (2011); Landex (2011) and Lindfeldt (2007) have presented analytical methods for measuring station's capacity. Razmi et al. (2018) have presented an innovative knowledge-based method for conflict identification in order to enhance the efficiency of logistic networks. Regarding the importance of freight stations in the efficiency of this industry, developing a proper method for measuring, analyzing, and ranking the efficiency of these critical points is an issue of paramount importance. Isfahan railway located in the central area of the Iran railway network as a hub and the main lines of the Isfahan railway network include more than 700 kilometers. According to the Iran railway organization statistic (RAI.ir, 2019), Isfahan railway contribution in annually ton-kilometers of carried freights is more than 20% of total carried freights. The number of ton-kilometers is the weight in tons of material transported multiplied by the distance of kilometers driven.

In this paper, we have applied the standard model of data envelopment analysis (DEA) to measure the efficiency of railway freight stations and robust regression for analyzing the effect of having mixed traffic (passenger and freight) on the efficiency of freight stations. Also, the Anderson and Peterson method is used for ranking the technical efficiency of efficient units. The model is then applied to a case study in Isfahan railway. The body of this paper is structured as follows: In the next section the related literature is reviewed. The DEA method is presented in section 3. The studied case and its application is presented in section 4. Section 5 concludes the paper.

[1] . The International Union of Railways (UIC, French: Union internationale des chemins de fer) is an international rail transport industry body.

[2] . The Organization for Economic Co-operation and Development

Table 1: Freight performance of railways in different regions of the world (UIC, 2019).

Region	Ton-kilometer in 2018 (Billion)	Ton-Kilometer in 2017 (Billion)
Asia/Oceania/Middle east	3338.03	3238.39
Russian federation	2596.88	2491.88
America	2445.13	2314.69
Europe	530.32	539.2
Africa	156.97	131.9

LITERATURE REVIEW

The railway industry is a capital-intensive industry, so being efficient in different parts of this industry would be vital for its prosperity. A great number of researches have been done in this field, but these studies mainly focus on either international comparisons of railways or the overall performance of this industry and they do not pay attention to the efficiency of stations as the main part of this industry. Because of some similarities between the operations and processes of railway freight stations with containership ports and seaports, so we propose to review a plethora of research on performance analysis in the railway industry to develop a proper model for measuring and ranking the efficiency of railway freight stations. In this section, for evaluating and measuring the efficiency of railway freight stations, we are going to review other studies in this field to choose the best inputs and outputs indexes. By doing surveys involving cargo and passenger railways, the analysis of the efficiency of the railway using DEA method combined with other methods has been addressed. Table 2 presents the literature review.

To develop a holistic model for measuring the efficiency of railway freight stations, inputs and outputs used for evaluating operational efficiency in a wide variety of researches have been studied. Typical inputs include the number of workers, number of lines, and operating costs. Outputs range from ton-kilometer, passenger-kilometer, stopped trains, and revenues. Despite the importance of railway freight stations, non-parametric methods do not study under a meticulous lens in railway freight efficiency measurement.

Data envelopment analysis (DEA) methodology

DEA model presented by Charnes et al. (1978) was used for measuring the efficiency of decision-making units (DMU's). DEA models measure the efficiency of DMUs considering their inputs and outputs. According to the DEA approach for measuring the efficiency of decision-making units, we can apply two different models: CCR (Charnes et al. 1978) and BCC (Banker et al. 1984). Traditionally, for measuring the efficiency of DMU's we have two directions: using an input-oriented model or an output-oriented model. The DEA model is going to measure the efficiency of DMU's through maximizing the ratio of weighted outputs to weighted inputs when the weights are positive. In this research, we have used the output-oriented CCR and BCC models of DEA for measuring the efficiency of the railway freight stations. By taking into account *n* DMUs (stations), *m* inputs and *s* outputs, x_{ij} as the input *i* for DMU *j*, y_{rj} as the output *r* for DMU *j*, u_r and v_i as the weights for outputs and inputs, the formulation of the output-oriented CCR model for each DMU is as follows (Charnes et al., 1978):

$$\begin{aligned} & MinZ = \sum_{i=1}^{m} v_i x_{i0} \\ & \sum_{r=1}^{s} u_r y_{r0} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{n} v_i x_{ij} \le 0 \quad j = 1,2,\ldots,n \\ & u_r, v_i \ge 0 \quad \forall i, r \end{aligned} \qquad (1)$$

The output-oriented BCC (Banker, Charnes, Cooper) model is as follows:

$$MinZ = \sum_{i=1}^{m} v_i x_{i0} - w$$

$$\sum_{r=1}^{s} u_r y_{r0} = 1$$

Table2: literature review

Paper	Purpose of the study	Inputs	Outputs
George and Rangaraj (2008)	Measuring the performance of the railway industry	Operating costs, rolling stock	Ton.km, passenger.km
Hilmola (2007)	The productivity in the European cargo ship industry	Employees, locomotives, wagons, line length	Tons
Yu (2008)	Measuring and comparing the efficiency of 40 railways	Employees, wagons, line length, passenger cars, passenger trains.km, cargo trains. km	Ton.km, pass.km, passenger trains.km, cargo trains.km
Yu and Lin (2008)	Measuring technical and services efficiency of 20 railways	Employees, wagons, line length, passenger cars, passenger trains.km, cargo trains. km	Ton.km, passenger.km, passenger trains.km, cargo trains.km
Shi et al. (2010)	The matter of productivity and technical efficiency in the railway industry	Employees, locomotives, wagons, fuel consumption, line, length, materials, consumed	Revenues/ton.km
Guzmán and Montoya (2011)	Calculating the efficiency of Spanish railway between 1910 and 1922	seats available, available cargo capacity, distance traveled	Revenues
Hilmola (2011)	Measuring and Assessment types of public transport in major cities (railways and others)	Population and population density; and proportion of jobs in downtown area, GDP/urbanpopulation jobs density(large DEA)	Bus.km/tramway.km/VLT.km/ metro vehicle.km/train.km/
Bhanot and Singh(2012)	The efficiency of containership in the railway industry	Employees, wagons, cargo terminals, transshipment equipment, containers	ton. km, net profits
Kutlar et al. (2012)	Measuring the efficiency of freight and passenger companies in the railway	Employees, locomotives, wagons, operating cost, line length, and passenger cars	Revenues, passengers, passengers/km, tons, ton/ km
Bil (2013)	The efficiency of the railway in the passenger section	Employees, wagons, line length, passenger cars	Ton.km, passenger.km
Kabakasal et al. (2013)	The efficiency of railway companies	Employees, locomotives, wagons, operating cost, line length, and passenger cars	passengers/km, tons, ton/ km
Oum et al. (2013)	The social efficiency of public transportation (railways and airlines)	Employees, operating cost, physical capital cost, time travel	Passenger. km, life-cycle CO2
Doomernick (2014)	Measuring the service efficiency of HST systems and production efficiency of these systems	Line length, seats available, seats.km	Seats available, passenger. Km, passengers
Barros and Wanke (2015)	The key player in the railway industry efficiency	Employees, locomotives, wagons, fuel	Investment, revenues, ton. km,
Bogart and Chaudary (2013)	Measuring the TFP of Indian railwaysbetween 1874 and 1912.	Employees, fuel consumption, line length, physical	Ton.km, passengers.km
Chen (2014)	The effect of the arrival of the Taiwan high-speed rail system on the efficiency of the bus industry	Number of buses, number of drivers, fuel consumption	Passengers. km
Crafts et al. (2007)	Measuring the productivity of British railways between 1852 and 1912	Physical capital, employees, fuel consumed	Passenger trains. Miles, ton-miles
Couto and Graham (2008)	The relationship between technical and allocated efficiency	Mean wages costs, costs of materials and energy/trains.km, types of equipment	Passenger.km, ton.km (or pass train.km, cargo train.km)
Crafts et al. (2008)	The Performance of the British railway industry at the beginning of the nineties century	Capital, employees, fuel consumed	Passenger trains. Miles, ton-miles
Graham (2008)	Comparing non-parametric and parametric efficiency of companies	Employees, fleet capacity (seats), and line length (km)	Passenger cars.km/year
Kumbakar et al.(2007)	Measuring the efficiency of 17 European railways	Energy consumption, employees and physical capital and passenger cars	Tons/km, passenger/km
Loizides and Tsionas (2002)	Measuring and Assessment of the efficiency of 10 European railways during 1970 e1992.	Employees, fuel, capital includes: physical assets, wagons, and equipment	Passenger.km, tons.km
Jitsuzumi and Nakamura (2010)	Enhancing the efficiency of Japanese railways	Physical assets, employees, operating costs	Passenger.km, tons.km
Mallikarjun (2014)	Relationship between governments supports and the efficiency of US urban railways between over a ten-years course of time	Operating costs, vehicle. Miles, revenue. Miles, passenger. Miles	Vehicle. Miles (1 stage), revenue. Miles (2 stages), passenger. Miles (3 stages) fare revenue (4 stages)
Khadem et al. (2016)	Measuring the efficiency of railway passenger stations	Number of platforms, percentage of through lines, length of platforms	Number of trains stop, number of passengers entries and exist.

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{n} v_i x_{ij} + w \leq 0 \quad j = 1, 2, \ldots, n$$
$$u_r, v_i \geq 0 \quad \forall r, i \quad w \text{ free in sign} \tag{2}$$

Data envelopment analysis modes have been used in many fields such as measuring the efficiency of railway systems. (Mahmoudi et al, 2019). According to Emrouznejad and Yang (2017), applying DEA models for evaluating the transportation systems efficiency and in the particular railway industry is in the high rank. In this research, we have used CCR and BCC output-oriented models for measuring the efficiency of railway freight stations.

Ranking efficient units procedure

Data Envelopment Analysis (DEA) evaluates the relative efficiency of decision-making units (DMUs) but does not provide explanation for ranking of them. Anderson and Peterson suggested a method for ranking the efficient units which is a modified version of DEA method based upon comparison of efficient DMUs relative to an efficient unit. The process provides a framework for ranking efficient units and facilitates comparison with rankings based on parametric methods. The basic idea of this method is to compare the units which are evaluating with a linear combination of all other units in the sample, i.e., the DMU itself is excluded. In this process an efficient DMU may increase its input vector proportionally while preserving efficiency. The efficiency score of the unit in this model can be above one. The score shows the radial distance from the DMU which is under evaluation to the production frontier estimated with that DMU excluded from the sample. This method gives an efficiency rating of efficient units similar to the rating of inefficient units above one (Andersen & Petersen 1993). In this study, for getting a better insight into the relative efficiency of efficient as well as inefficient units, we have used Anderson& Peterson method for ranking the stations in terms of efficiency.

CASE STUDY DESCRIPTION AND APPLICATION

The main roles of freight stations include: technical duties such as reception, sending and letting the trains to pass through, shunting and combining trains, technical and trade inspection of wagons, loading, and unloading of wagons, and other tasks related to train's traffic and maneuvering.

At first, the efficiency of railway freight stations utilizing the existing capacity of the infrastructure at stations is measured. Hence, according to Mahmoudi et al. (2019), technical efficiency for railway companies can be defined as how infrastructure resources can be utilized, efficiently. The main infrastructure resource at freight stations is the number of operational lines. Another input for assessing the technical efficiency of railway freight stations is the number of operational employees in the stations. In this study, we take the number of freight trains stopped in the stations for giving services as an output. It can be extracted from working timetables. Fig. 1. illustrates schematic representation of the technical efficiency model for freight stations.

Fig.1. Schematic representation of the technical efficiency model for frights stations

The 12 freight stations in Isfahan railway organization were chosen in terms of the operational volume according to Iran railway organization reports (RAI, 2020). Freight trains stopped in the stations of the case study was extracted from timetable files released by the department of planning of Iran railway organization (RAI, 2020). The statistical data of the case study is presented in Table 3.

According to the result of measuring the technical efficiency of Isfahan Railway Freight Stations, four stations are efficient in the technical efficiency (output-oriented) model. The efficient stations for technical efficiency are Sistan station (busiest train station in Isfahan railway), Hassan Abad, Dizecheh, and Firozeh stations. By managing traffic control of freight trains and increasing the market contribution of carrying freights, the efficiency score of other stations can be improved. Details of station efficiency scores for BCC and CCR models are summarized in Fig. 2.

Table 3: Descriptive statistics of the case study data

	Number of lines	Number of employees	Number of stopped trains
Average	8.5	27	4603
SD	5.6	30.7	4527.9
Min	3	1	195
Max	18	100	12516

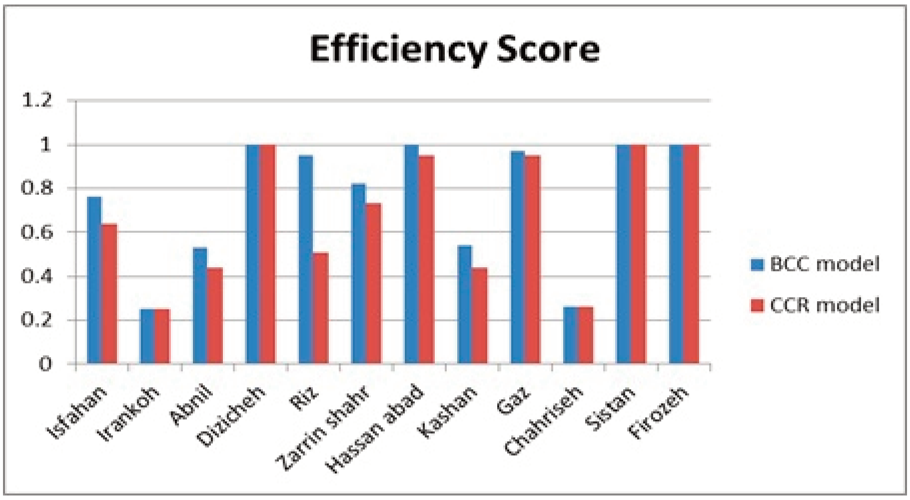

Fig.2. Efficiency score of stations for technical efficiency (CCR and BCC model)

To have a better understanding of the relative efficiency of efficient and non-efficient units and comparing them, we have used Anderson and Peterson method and Table 4 summarizes our investigation. Taking this matter into the issue is of great importance that measuring the efficiency of decision-making units by DEA approach is relative to the group of decision-making units (i.e., freight stations). In other words, when we call a DMU a completely (100%) efficient DMU, in case that the performances of other DMUs do not change significantly (Cooper et al., 2011). Therefore, with a different group of stations, the efficiency frontier will be changed, if the rations between outputs and inputs have changed and so the efficient units can be changed.

Table 4: Ranking of railway freight stations by Anderson and Peterson method

Name of station	Score	Efficiency	Rank
Sistan	1.62	Efficient	1
Dizicheh	1.18	Efficient	2
Hassan Abad	1.17	Efficient	3
Firozeh	1.03	Efficient	4
Gaz	0.97	Non-efficient	5
Riz	0.95	Non-efficient	6
Zarrin shahr	0.82	Non-efficient	7
Isfahan	0.76	Non-efficient	8
Kashan	0.54	Non-efficient	9
Abnil	0.53	Non-efficient	10
Chahriceh	0.26	Non-efficient	11
Irankoh	0.26	Non-efficient	12

Robust regression analysis

Although the DEA model determines the efficient freight stations, it does not provide any reasons as to why some of the stations are efficient. Regarding this weakness, we can use statistical methods such as robust regression model to evaluate the relationship between exogenous factors and DEA efficiency scores in the final stage of our study (Hoff, 2007). Although in this paper the focus is on freight operations, stations' facilities and tracks can be used for passenger purposes as well. Such dual purpose stations may affect the results of model as the number of freight train stops may be constrained by passenger train operations. To study this, a robust regression is estimated with technical efficiency to consider that the mixed traffic can affect the efficiency of freight stations or not. To define robust regression, it has been said that it is a form of regression analysis that can be used for finding the relationship between one or more independent variables and a dependent variable. Typical regression methods, such as the least-squares, work well if their hypotheses are true, but they may not work well for data that violates their assumptions. In particular, the least-squares method is sensitive to outliers' data. As a method, the lowest absolute value is the most stable equivalent for the least-squares and instead of the second power of the regression error, the absolute amount of the error is used (Eq. 3):

$$S = \sum_{i=1}^{n} \left| y_i - f(x_i) \right| \tag{3}$$

Outlier data has less effect on the absolute amount of the error than the square of the error (Wilcox, 2010). Though in this paper the concentration is on measuring the efficiency of freight stations, we should consider this matter that station's infrastructures such as lines and human resources can be used for passenger operational purposes as well. Such dual-purpose can affect the output of the stations and as a ramification, in the second step of our model, a robust regression analysis is used with technical efficiency as the dependent variable and an dummy variable for station dividing (0 if freight only and 1 otherwise) as the independent variable. Table 5 presents the result of estimation.

Table 5: Analysis of results

Criteria	Number of stations	Average of Results	SD
Freight -only	4	0.56	0.24
Mixed traffic	8	0.48	0.18

Table 6. Result of Robust regression analysis

Efficiency	Coef	Std. Err.	T	P N |t|	[95% conf interval]
freight-only	- 0.07	0.06	- 1.26	- 0.18	0.041
_cons	0.54	0.064	8.41	0.41	0.67

According to the Table 6, the coefficient value of freight-only operations in the robust regression model is -0.07 which can be considered as, if we switch from a dual function station to a freight-only station, the technical efficiency does not change.

CONCLUSION

Although railway freight stations' role in the success of railway transportation is undeniable, there is no comprehensive study to measure the efficiency of railway freight stations. In this study, we have applied a DEA method based on the studying of other DEA applications in the railway industry, to present a practical model for analyzing relative capacity utilization at freight stations. The analysis of capacity utilization or technical efficiency of railway freight stations can be used for managing trains stop or traffic management in railway stations to use railway infrastructures and human resources efficiently. In this study, we have used the number of station lines and station's employees as inputs and the number of train stops as an output of stations. The DEA model was used in a case study of the 12 busiest train stations in Isfahan railway for measuring the efficiency of stations and then they are ranked by the help of Anderson and Peterson method. Follow up, the result of robust regression shows that freight-only stations do not have higher technical efficiency than the other stations and as a result it can be concluded that having both types of operation (passenger or freight operations) cannot affect the efficiency of stations. Based on the main idea presented model, future studies in this field can concentrate on the optimization of the target value of scheduling of trains stop at stations.

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