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Performance Evaluation in Railway Transport: The Case of Europe and Türkiye

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ABSTRACT
Purpose: The purpose of the current study is to investigate the efficiency of ten European countries and Türkiye according to their GNP ratios in railway transportation. The study also aims to identify significant productivity differences between countries and determine which countries are most affected by the 2020 COVID-19 outbreak in terms of rail transport.
Methodology: Since it is performance research, secondary data was used. Data from the years 2011 to 2020 were utilized for the study. Data Envelopment Analysis (DEA)-Malmquist Index method was employed to reveal the efficiency changes over the years. The analysis of the data was conducted using the DEA-based Windows Analysis Program (DEAP).
Findings: According to the total factor productivity change rates in the Malmquist Index; while there is a 1% increase in productivity in Lithuania, 0.3% in Romania and 0.2% in the UK, a slight decrease is observed in the productivity of other countries. The decreases in the productivity of the countries are mostly experienced during the COVID-19 epidemic period in 2011-2020.
Originality: In the current literature, studies on railway performance have been made using historical data from four countries in the European Union. However, in recent years, there is a lack of productivity studies focusing on input and output variables according to the GNP ratio of European countries. Therefore, it is thought that this study will make an important contribution to the existing literature.
Keywords: International Logistics, Rail Performance, Malmquist Productivity Index, Supply Chain Management, Data Envelopment Analysis.
JEL Codes: L90, L91, L92.

Demiryolu Taşımacılığında Performans Değerlendirmesi: Avrupa ve Türkiye Örneği

ÖZET
Amaç: Bu çalışmanın amacı, GNP oranına göre belirlenmiş 10 Avrupa ülkesi ile Türkiye'nin demiryolu taşımacılığındaki etkinliklerini araştırmaktır. Bunun yanında ülkeler arasında önemli etkinlik farklılıklarını ortaya koymaktır. Ayrıca, 2020 yılı COVID-19 salgınından hangi ülkelerin demiryolu taşımacılığında daha fazla etkilendiğini ortaya çıkarmaktır.
Yöntem: Performans araştırması olduğu için ikincil verilerden yararlanılmıştır. Araştırma için 2011 ve 2020 yılları arsındaki veriler kullanılmıştır. Yıllara bağlı etkinlik değişimlerini ortaya çıkarmak için, Veri Zarflama Analizi (DEA)- Malmquist Index yöntemi kullanılmıştır. Verilerin analizi için DEA tabanlı Windows Analysis Programı (DEAP)'ndan yararlanılmıştır.
Bulgular: Malmquist Index değerlerindeki toplam faktör verimlilik değişimi değerine göre, Litvanya'da %1, Romanya'da %0,3 ve İngiltere'de %0,2 oranlarında üretkenlik artışının olduğu anlaşılırken diğer ülkelerde bir miktar gerileme görülmektedir. Ülkelerdeki gerilemelerin en fazla 2011-2020 yılarındaki COVID -19 salgını zamanında yaşandığı söylenebilmektedir.
Özgünlük: Literatürde demiryolu performansı ile ilgili Avrupa Birliği'ndeki 4 ülkeye yönelik geçmiş yıllardaki verilerin kullanıldığı çalışma bulunmaktadır. Fakat, GNP oranına bağlı Avrupa ülkelerinin son yıllara ait girdi ve çıktı değişkenlerine yönelik verimlik çalışmasına rastlanmamıştır. Bu açıdan çalışma literatüre katkı sağlayacaktır.
Anahtar Kelimeler: Uluslararası Lojistik, Demiryolu Performansı, Malmquist Verimlilik Endeksi, Tedarik Zinciri Yönetimi, Veri Zarflama Analizi.
JEL Kodları: L90, L91, L92.

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1. INTRODUCTION

Given the costly of resources used in railway operations and the involvement of multiple personnel in the shipping process, operational efficiency becomes a critical concern for businesses. The measurement of railway operations'; is crucial, as it aids in identifying factors leading to decreased efficiency and enables the implementation of necessary measures to enhance it. In addition, the calculation of railway transport (RT) efficiency enables to reveal idle capacity rates and to take appropriate actions to optimize this capacity. Unused capacity could potentially escalate enterprise costs, including factors such as depreciation and labor expenses (Yu and Lin, 2008). Efficient and effective RT significantly contributes to the enhanced economic productivity of enterprises, thereby increasing their chances of survival in a fiercely competitive environment (Sharma et al., 2016).

According to the European Union Commission Report (EUCR,2021), RT stands out as an environmentally friendly mode of transport, holding a significant place in the future objectives of the European Union. In particular, the fact that 81% of the trains operating in the European Union (EU) run on electricity is one of the important steps to mitigate climate change. The potential of cross-border rail transport remains largely untapped, accounting for only 10% of cross-border passenger transportation. However, with the projected expansion of high-speed train infrastructure by 2030, this rate is anticipated to double or even triple. For the advancement of rail freight and passenger transport within the EU, over 400 projects have been supported with a contribution of 16.5 billion Euros between 2014 and 2020. These initiatives have spurred the acceleration of digitalization and electrification within RT systems. Nevertheless, the years 2020-2021 saw a substantial impact on RT due to the COVID-19 outbreak (EUCR, 2021).

RT is considered one of the essential modes of transportation, exerting both economic and social impacts on countries. When compared to other forms of transportation such as air, road, sea, and waterway transportation, railway transportation presents both advantages and disadvantages. Among the notable benefits of RT are its cost-effectiveness in comparison to road and air transport, its capacity to carry substantial amounts of cargo, and its resilience to adverse weather conditions. However, it is some of its drawbacks, including lower transportation speeds, higher infrastructure expenses, and its limitation to areas with established railway networks. Furthermore, railway transport can be integrated with other modes of transportation through concepts like combined, intermodal, and multimodal transportation. This ability to collaborate with other transportation modes confers a significant advantage to the overall transportation system. Additionally, railways play a pivotal role in facilitating the movement of cargo to and from ports, aiding in the loading and unloading of ships (Sevinç, 2022:19-20).

According to data from the World Bank Open Source, the volume of goods transported by railways in certain European Union countries (measured in million tons-km) tended to decrease between 1995 and 2019. Despite a notable decline in rail freight transport across the European Union during the 2009 economic crisis, the years from 1995 to 2019 witnessed an overall upward trajectory (WBDO, 2022).

RT companies have tended to reduce their costs and increase their profitability in an intensely competitive environment. To reduce their costs, they need to use the resources they have (machinery, equipment, raw materials, materials, equipment, personnel, etc.) effectively and efficiently. When resources cannot be used efficiently and effectively, idle capacity arises depreciation costs increase, and production costs per product increase. Therefore, businesses measure their activities and observe how efficient they are, and take necessary precautions regarding inefficient areas.

Within the existing body of literature, numerous national and international studies delve into the efficiency of railway transportation. Among the pioneering research in measuring the efficiency of RT, Doomernik (2015) investigated the performance and efficiency of high-speed rail systems across four Asian and four European countries. The study unveiled notable disparities between Asian and European nations, concluding that the productivity improvements in rural European countries exceeded those in Asian counterparts. Kutlar et al. (2015) embarked on efficiency analyses for 31 prominent global railway enterprises. Utilizing the Malmquist productivity index, their analysis revealed certain enterprises witnessing a three per thousand increase in total vector productivity. Sharma et al. (2016) conducted a comparative analysis of service performance across 16 regions in rail transport within India. Inputs, encompassed employee expenses, employee count, and rail length, while outputs encompassed punctuality, passenger traffic mileage, accident statistics, and public complaints. The study successfully identified both productive and inefficient regions. Cowie (2018) employed the Malmquist efficiency index to assess the efficiency of privatized railways in the UK. The research incorporated labor force, wagon count, and line length as input variables, while passenger numbers were utilized as output variables. The findings highlighted a diminishing trend in productivity increases over time. Bhatia and Sharma (2021) undertook an evaluation of the efficiency of railway zones within India. Rail vehicle and equipment expenditures constituted expenses, whereas cargo volume and passenger counts were regarded as output factors. While certain regions exhibited a decline in productivity, the study noted an uptick in productivity for other regions. Academic studies on the efficiency of rail transport mainly cover a particular country. However, there is no academic study covering most of the European countries and Türkiye. In order to fill this gap in the literature, the railway efficiency of 10 European countries and Türkiye has been calculated. Also, the input and output parameter sequences used in productivity measurement are different from other academic studies. In addition, the data used in the research includes the values in recent years. For these reasons, this study is of original value.

Since the investments in the railway are increasing and diversifying day by day among the countries, the works in the past will not reflect the present. Additionally, with the developing technology, the diversification and renewal of the vehicles and equipment used in the railway can also change the efficiency rates. In the literature, there are studies on railway efficiency for 4 countries in the European Union. However, there was no productivity study based on the input and output variables of the European countries with the highest GNP ratio in recent years. Therefore, in this study, the railway efficiency of 10 European countries and Türkiye, determined according to the GNP ratio, is calculated between the years 2011-2020. The annual productivity change rates of each country are determined in the calculation. In addition, which countries were affected at the time of the COVID-19 outbreak were highlighted.

In the second part of the study, there is a literature study on the efficiency of railway transportation. In the third part, the data set used in the research, Malmquist productivity index and research method are mentioned. In the fourth chapter, the findings of the research are given. In the last part, there is the conclusion and evaluation part of the research.

2. LITERATURE REVIEW

Due to the high infrastructure and superstructure costs and operating costs used in railway transportation, it is important to measure efficiencies and reveal idle capacity. Although DEA is widely used in the literature on the efficiency of rail transport, many regulations such as Frontier Function are used.

The choice of input and output variables used in research conducted with the DEA method is left to the researchers. Therefore, DEA input and output variables need to be determined very well (Akdamar and Eren, 2021). The information on the input and output variables most used in the productivity measurements on railway transportation in the literature is given in Table 1. The purpose of the research, the country where it was conducted, and the analysis methods used are also given.

In Table 1, the author(s) who conducted the research, the research's purpose, the country where the research was conducted, input and output variables, as well as the research methods, are mentioned. As seen in the table, efficiency studies have been carried out in many parts of the world. In these studies, the Malmquist Index method was mainly used. Many input variables (e.g., railway length, personnel numbers, cost, etc.) and output variables (e.g., passenger-km, tonne-km, etc.) were used for the analysis. In the field of railway efficiency research, most studies have focused on specific regions or a limited number of countries. Surprisingly, no studies have been found that examine the railway efficiencies of Turkey and ten European countries with high GNP ratios. This study was conducted to address this notable gap in the existing literature. What further distinguishes this study from others is the variation in input and output variables, as well as the inclusion of historical data for these variables.

Table 1. Studies on the efficiency of rail transport in the literature

Study	*Purpose*	*Country*	*Methods*	*Input Variables*	*Output Variables*
Estache et al. (2007)	To determine the efficiency of rail freight transport	Brazil	Malmquist Index	Staff, energy	Ton-km
Shi et al. (2010)	Productivity and technical efficiency of 1st class railways	America	Malmquist Index	Personnel, locomotives, wagons, fuel consumption, line length, materials used	Income-ton/km
Guzmán and Montoya (2011)	The efficiency of Spanish railways	Spain	Malmquist Index	Locomotive traction, passenger seats, load capacity, mileage	Income
Li and Hu (2011)	Investigation of production, consumption, and earnings efficiency of railway enterprises	China	Malmquist Index	Number of personnel, length of the railway, fixed costs, number of locomotives, capital measurement, and number of passenger trains	Passenger-train/km, freight-train/km, outputs produced, locomotive-km
Perçin and Çakır (2012),	TCDD efficiency measurement	Türkiye	DEA	Passenger and cargo capacity, personnel	Passenger-km, Netton-km
Kazancıoğlu (2012)	To investigate the situation of Türkiye in railway transportation according to EU countries.	Türkiye	Malmquist Index	Railway length, number of passengers, passenger-km, Subsidy	Travel frequency and operating expenses
Sarıkaya et al. (2012)	Regional performances of rail transport	Türkiye	Malmquist Index	Number of personnel, electrical main line length, non-powered main line length, and annual total locomotive operating hours	Passenger-km, Ton-km
Kutlar et al. (2013)	Identifying rail passenger and freight transport activities worldwide	World	DEA	Cost, Personnel, mainline length, freight wagon, number of vehicles	Revenue, number of passengers, passenger-km, cargo amount, ton-km
Erturan and Uysal (2013)	Efficiency analysis of railways in Türkiye	Türkiye	Network DEA	Number of personnel, line length, number of passenger and freight wagons, GDP per capita, population density	Passenger-km, ton-km
Sharma et al. (2015)	Evaluate rail service performance	India	Malmquist Index	Personnel expenses, number of personnel, equal distance km	Revenue, passenger-km, complaints
Doomernik (2015)	Determination of production and service efficiency of high-speed railways.	4 countries from the Asian and European continents	Malmquist Index	Expenses (Personnel, operation, maintenance, repair, traffic, fuel)	Passenger-km and Net ton-km
Cowie (2018)	Assessing long-term efficiency in the rail industry.	England	Malmquist Index	Staff, tow cars, line length	Train-km
Bayat and Özdemir (2019)	To determine the effectiveness of regions in rail transport	Türkiye	DEA	Road-railway lengths, number of ships calling at ports, number of aircraft landing and departure, GDP, and number of vehicles	Turnover of enterprises operating in the logistics sector
Bhatia and Sharma (2021)	To achieve efficient performance and cost savings in different railway zones.	India	Malmquist Index	Operating and working expenses	Passenger-km and Net ton-km

3. DATA SET and METHOD

This section encompasses the research's datasets along with reports detailing descriptive statistics for these data. Furthermore, correlation analyses were conducted to assess the relationships between the datasets, thus ascertaining their suitability for subsequent analyses. Alongside the literature concerning the Malmquist method, which serves as the analytical framework, the formulas integral to this method have been explicated.

3.1. Data Set

European countries have been investing in many areas and allocating great resources to this area to further develop railway transportation from past to present. Therefore, a study has been carried out to determine the variability of European countries in railway transportation depending on the years. The population of the research consists of European Countries. Since the data of Spain, Netherlands, and Switzerland among the top 10 countries according to the GNP ratio were not available, other European countries were preferred. Thus, Austria, Czech, France, Germany, Italy Lithuania, Poland Romania, Sweden, United Kingdom, and Türkiye were preferred. The data of the research were compiled from Eurostat Database (E.D. 2022), Statista Statistics (S.S. 2022), and World Bank Open Data (WBOD, 2022). To better reflect the results of the research, the data obtained in recent years (2011-2020) were used. Data belonging to some years that could not be obtained were completed with data preprocessing methods and scaling was made. The Malmquist method was preferred to determine the railway efficiency variables of each country depending on the years separately. DEA-based Windows Analysis Program (DEAP) was used for data analysis. In the study, The Constant Return Method (CRS) was preferred because the decision makers could have an effect on the input and output variables, and the input-weighted method was preferred to determine how the input variables affect the output. Considering the literature sources, the number of passengers and freight transported by rail constitutes the output variables, while the rail lengths, wagon volumes, and train movements constitute the input variables. Descriptive statistics values of input and output variables are given in Table 2. According to the minimum, maximum, average, and standard stub data of the data to be used in the research, the standard deviation is at the highest wagon volumes (1691555).

Table 2. Descriptive statistics of inputs and outputs (N = 110)

Variable	*Inputs1_NL*	*Inputs2_WV*	*Inputs3_TM*	*Outputs1_ PT*	*Outputs2_ GT*
Indicator	Network Length (Total route-km)	Wagon Volume (m^3)	Train movements (Thousand train kilometers)	Passengers Transported (Millions of passenger kilometers)	Goods Transported (Thousand tonnes)
mean	14.683	1.606.431	297.199	32.020	115.677
SD	9.272	1.691.555	293.430	33.479	94.527
min	1.767	54.329	13.926	237	24.286
max	33.575	7.138.556	1.095.781	100.252	396.326

Table 3. Correlation coefficient (2011–2020).

		Inputs1_NL	*Inputs2_WV*	*Inputs3_TM*	*Outputs1_ PT*	*Outputs2_ GT*
Inputs1_NL	Pearson Correlation	1				
	p-value					
	Sample size	110				
Inputs2_WV	Pearson Correlation	0.692**	1			
	p-value	0.000				
	Sample size	110	110			
Inputs3_TM	Pearson Correlation	0.63**	0.74**	1		
	p-value	0.000	0.000			
	Sample size	110	110	110		
Outputs1_ PT	Pearson Correlation	0.879**	0.624**	0.75**	1	
	p-value	0.000	0.000	0.000		
	Sample size	110	110	110	110	
Outputs2_ GT	Pearson Correlation	0.703**	0.836**	0.65**	0.533**	1
	p-value	0.000	0.000	0.000	0.000	
	Sample size	110	110	110	110	110

Note: ** represents the correlation coefficient that is significant at the 0.01 level (2-tailed).

To determine whether the data to be used in the research are suitable according to the Malmquist method, the correlation values between the variables were examined. According to the results of the correlation analysis in Table 3, the p-value of each variable among the other variables is less than 0.05. In this case, there is a strong positive correlation between the variables with a 5% margin of error in the (95% confidence interval). The presence of a significant and positive relationship between the variables means that the input and output variables to be used are suitable for analysis.

3.2. Malmquist Productivity Index

Malmquist Efficiency Index is a DEA-based method and is one of the methods that investigate the change in production (Malmquist, 1953). In the DEA study, linear programming was used to measure efficiency, and then the use of technical efficiency measures or distance functions in productivity measures were developed. Färe, Grosskopf, and Lovell (1994:3-29) developed DEA-based Malmquist productivity measures. With these studies, today, the changes in total factor productivity between two points can be measured with an input or output focus. Malmquist calculations are based on the lowest point where the input amount can be kept or the highest output amount that can be produced (Özal, 2019:45-53).

One of the interesting features of the Malmquist Productivity Index (MPI) is that it captures the variable dynamics in the productivity measure, and it can determine the ratio of the total input to total output in any time interval. It is a widely used approach to evaluate dynamic efficiency based on DEA, utilizing fixed return scale (CRS) technology. The important feature of the DEA Malmquist Index is that it can divide into two components, one measuring productivity Change (EC) and the other measuring Technical Change (TC) (Doomernik, 2015).

MPI is divided into two main groups: technological change and changes in technical efficiency (Figure 1). MPI is obtained by multiplying the two groups of variables mentioned. The change in technical efficiency consists of the change in pure efficiency and the change in scale efficiency and is obtained by multiplying two variables. Technical efficiency is expressed as the degree to catch the limit in production. Accordingly, it expresses the ability of the minimum amount of input that can be used to reach an output amount. If the result is less than one, the resources are not used properly or there is idle capacity (Tutkavul, 2017; Deliktaş, 2002).

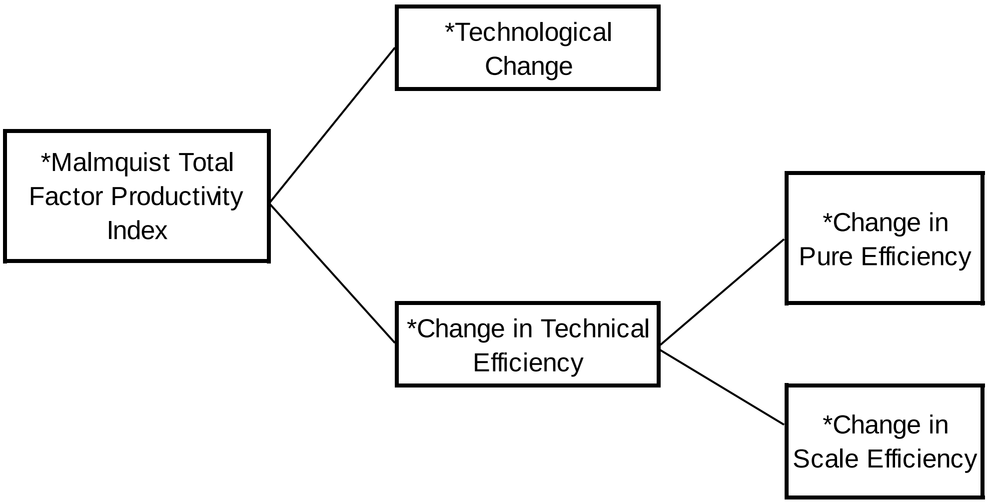

Figure 1. Malmquist total factor productivity analysis (Li ve Chunlu, 2010).

Technological change means a shift or displacement of the frontier curve in production. The shift or displacement shows the change in the upper bound curve of production over time. If the result is equal to one, it shows that there is no technological change, if it is less than one, there is a regression, and if it is greater than one, it shows that there is technological progress. The concept of technology refers not only to machinery or equipment but also to policies, regulations, and the environment that have an impact on productivity (Rezitis, 2006).

Distance functions define multi-input and multi-output production technology. Here, maximum profit is aimed with minimum input, and it characterizes the production technology depending on the minimum proportional contraction of the input vector, given the input-dependent output vector. The output distance function expresses the maximum expansion of the output vector depending on the input vector. Li and Liu (2010) used the following formulas while defining an output distance function under production technology in the “t” period.

Equation 1-6 has been used to calculate the values obtained from the input and output variables in the study Li and Liu (2010).

$D_0^t\ (x^t, y^t)$ = inf {θ: ($x^t, y^t / \theta$)) € s^t} (1)

The variable representing an output-oriented offset function is the '0' subscript. $x^t,\ y^t$ represents the input and output vector, respectively, in the period t. Similarly, the input and output vectors ($x^t,\ y^t$) of the $t+1$ period, belonging to the t period in the S^{t+1} production technology are defined in Equation 2.

$D_0^{t+1}\ (x^t, y^t)$ = inf {θ: ($x^t, y^t / \theta$)) € $s^t + 1$} (2)

The input and output vector (x^{t+1}, y^{t+1}) of the $t+1$ period in the S^t production technology of the t period is given in Equation 3.

$D_0^t\ (x^{t+1}, y^{t+1})$ = inf {θ: ($x^{t+1}, y^{t+1} / \theta$)) € s^t} (3)

According to the above formula, a production technology represents the set of all output vectors y that can be produced using the input vector x. The formula created accordingly is given in Equation 4.

S^t= {(x^t, y^t) : x^t can generate y^t at time t } (4)

When calculating based on the conditions of $-\theta y_i^t + Y^t\lambda \geq 0$, $X_i^t - X^t\lambda \geq 0$ and $\lambda \geq 0$, Equation 5 (objective function) is obtained for constant return to scale (CRS) technologies by adding the extra constraint condition, the convexity constraint N1, $\lambda = 1$.

$[D_0^t(x^t, y^t)) \mid CRS]^{-1} = max_{\theta,\lambda}$ (5)

In Equation 6 Malmquist's formula, which is formed by separating the change in total factor productivity (M), neutral and biased technical changes, pure technical productivity change, and technological change consisting of economies of scale are presented.

$$M= \left[\frac{D_0^t(x^{t+1}, y^{t+1} \mid CRS)}{D_0^t(x^t, y^t \mid CRS)} \times \frac{D_0^t(x^{t+1}, y^{t+1} \mid CRS)}{D_0^{t+1}(x^t, y^t \mid CRS)} \right]^{1/2} \quad (6)$$

4. EMPIRICAL FINDINGS

In this part of the study, the Malmquist Total Factor Efficiency Index evaluation results of 10 European countries and Türkiye's rail transport are given. The productivity of any country can be transformed into more output with the same or lower level of inputs.

The technical efficiency change values in 11 countries by year are given in Table 4. The technical efficiency changes of Austria, Italy, Lithuania, Poland, and England remained stable. While the technical efficiency changes of Czech decreased by 7,7% between 2019-2020, the biggest increase (6.9%) was between 2014-2015. Although the technical efficiency values of France have remained stable for many years, a decrease of 3.5% was observed between 2019-2020. While the biggest decrease in Germany's technical efficiency (4.2%) was between 2019-2020, the biggest increase (1.9%) was between 2018-2019. While Romania's technical efficiency decreased by 11.3% in 2014-2015, it increased by 33.6% between 2011-2012. While the biggest decrease in Sweden's technical efficiency (6.1%) was between 2017-2018, the biggest increase (12.2%) was between 2015-2016. While the greatest decrease in Türkiye's technical efficiency (31.2%) was between 2019-2020, the biggest increase (58.5%) was between 2018-2019. Looking at the technical efficiency change average of the countries over the years, the average of France and Germany remains below 1, while the average of other countries is above 1.

Table 4. Catch-up index (efficiency change)

Countries	*2011-2012*	*2012-2013*	*2013-2014*	*2014-2015*	*2015-2016*	*2016-2017*	*2017-2018*	*2018-2019*	*2019-2020*	*Average*
Austria	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Czech	0.978	**1.026**	**1.046**	**1.069**	**1.013**	0.972	**1.001**	**1.022**	0.923	**1.006**
France	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.965	0.996
Germany	0.999	0.984	**1.015**	**1.002**	1.000	1.000	0.982	**1.019**	0.958	0.995
Italy	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Lithuania	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Poland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Romania	**1.336**	**1.116**	0.959	0.887	**1.114**	0.961	**1.017**	**1.174**	1.000	**1.063**
Sweden	**1.006**	**1.012**	**1.054**	0.991	**1.122**	**1.009**	0.939	**1.081**	**1.080**	**1.033**
Türkiye	0.799	0.879	**1.076**	**1.020**	0.964	**1.038**	**1.062**	**1.585**	0.688	**1.012**
United K.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average	1.011	1.002	1.014	0.997	1.019	0.998	1.000	1.080	0.965	1.010
Max.	1.336	1.116	1.076	1.069	1.122	1.038	1.062	1.585	1.080	1.063
Min.	0.799	0.879	0.959	0.887	0.964	0.961	0.939	1.000	0.688	0.995

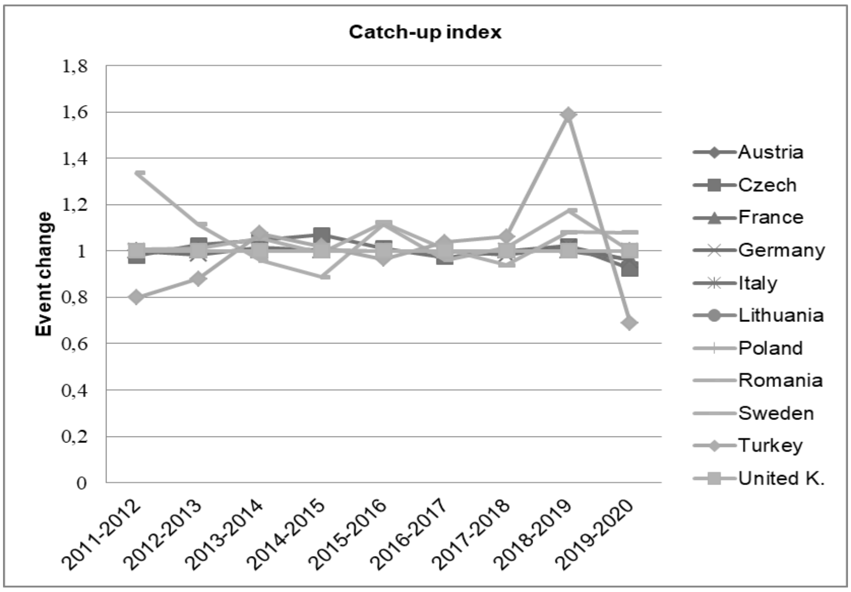

Figure 2. Technical efficiency change

Information on the technological change indices of countries over the years is given in Table 5. While the biggest decrease in technological change efficiency (12,7%) in Austria was between 2019-2020, the biggest increase (4.1%) was between 2013-2014. While the greatest decrease in Czech's technological change efficiency (13.5%) was between 2019-2020, the biggest increase (5.6%) was between 2016-2017. While the biggest decrease in France's technological change efficiency (35.4%) was between 2019-2020, the biggest increase (17%) was between 2011-2012. While the biggest decrease in Italy's technological change efficiency (33.4%) was between 2019-2020, the biggest increase (13.5%) was between 2014-2015. While the biggest decrease in Lithuania's technological change efficiency (8.4%) was between 2011 and 2012, the biggest increase (31.6%) was between 2016-2017. While the biggest decrease in the technological change efficiency of Poland (16.9%) was between 2011-2012, the biggest increase (4.8%) was between 2017-2018. The biggest decrease in Romania's technological change efficiency (22.3%) was between 2011-2012, while the biggest increase (0.7%) was between 2014-2015. While the biggest decrease in Sweden's technological change efficiency (8.7%) was between 2018-2019, the biggest increase (1.4%) was between 2012-2013. While the biggest decrease in Türkiye's technological change efficiency (5.7%) was between the years 2019-2020, the biggest increase (4.8%) was between the years 2016-2017. While the greatest decrease in England's technological change efficiency (16.5%) was between 2013 and 2014, the biggest increase (17.8%) was between 2019-2020.

Table 5. Frontier-shift index (technological change)

Countries	*2011-2012*	*2012-2013*	*2013-2014*	*2014-2015*	*2015-2016*	*2016-2017*	*2017-2018*	*2018-2019*	*2019-2020*	*Average*
Austria	**1.016**	0.975	**1.041**	0.997	**1.026**	**1.036**	0.982	0.995	0.873	0.993
Czech	**1.013**	0.991	**1.015**	0.980	**1.006**	**1.056**	**1.018**	**1.002**	0.865	0.994
France	**1.170**	0.982	0.993	**1.070**	0.982	**1.032**	0.992	**1.024**	0.646	0.988
Germany	**1.011**	**1.019**	0.967	0.997	**1.060**	0.950	0.988	0.992	0.936	0.991
Italy	0.954	**1.052**	**1.019**	**1.135**	0.722	**1.112**	**1.003**	**1.017**	0.666	0.964
Lithuania	0.916	**1.036**	**1.015**	**1.122**	0.936	**1.316**	0.995	0.949	0.992	**1.031**
Poland	0.831	1.000	**1.002**	0.980	0.896	0.986	**1.048**	0.898	0.867	0.945
Romania	0.777	0.980	0.998	**1.007**	0.853	0.943	**1.005**	0.951	0.939	0.939
Sweden	1.000	**1.014**	0.966	0.992	0.941	0.983	**1.001**	0.913	0.971	0.976
Türkiye	**1.022**	**1.012**	0.992	0.995	0.979	**1.048**	**1.024**	**1.009**	0.943	**1.003**
United K.	**1.110**	**1.099**	0.835	**1.035**	0.905	0.982	0.972	0.972	**1.178**	**1.010**
Average	0.984	1.015	0.986	1.028	0.937	1.040	1.003	0.975	0.898	0,985
Max.	1.17	1.099	1.041	1.135	1.06	1.316	1.048	1.024	1.178	1,031
Min.	0.777	0.975	0.835	0.98	0.722	0.943	0.972	0.898	0.646	0,939

The technological change index of countries over the years is shown in Figure 3. Although there are sudden ups and downs in the technological change values of Romania, Lithuania, Italy, France, and England depending on the years, the rate of change in other countries is at a certain level.

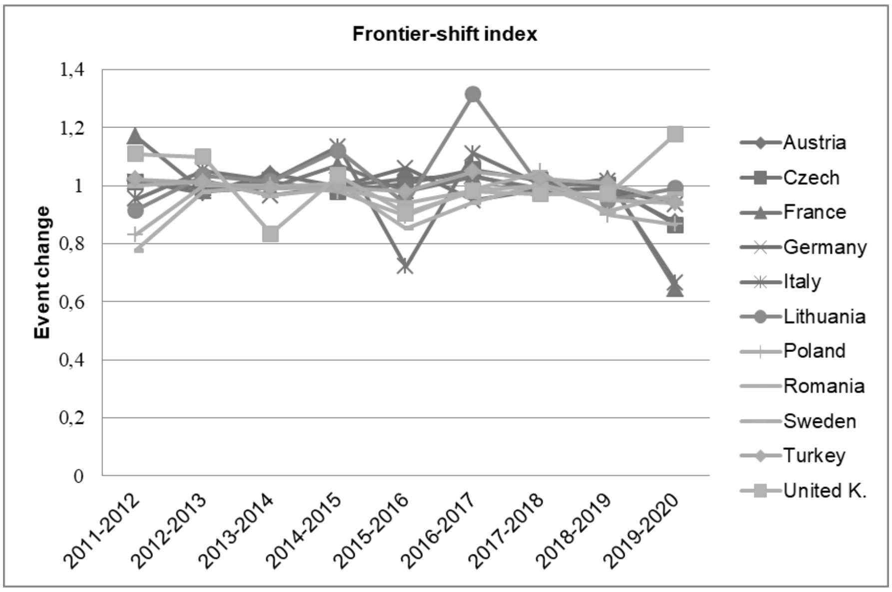

Figure 3. Technological efficiency frontiers

The summary values of the Malmquist Index calculated between 2011-2020 are given in Table 6. Malmquist Index subvalues are shown as technical efficiency (effch), technological change (techch), pure productivity change (pech), scale efficiency change (sech) and total factor productivity change (tfpch). While Austria's effch, pech, and sech values remained constant, techch value and tfpch values decreased by 0,8%. While an increase was observed in Czech's effch and pech values, there was 0,8% decrease in techch value and 0,3% decrease in sech and tfpch values. While a decrease was observed in all values of France, the biggest decrease was observed in the tfpch value (2,7%). While the pech value of Germany remains constant, the greatest decrease is seen in the tfpch value (1,4%). While Italy's effch, pech, and sech values remained stable, there was 5% decrease in techch value and tfpch value. While no decrease was observed in any of the variables of Lithuania, an increase of 2,5% was observed in techch and tfpch values, and there was no change in other values. While a 5,7% decrease was observed in Poland's techch and tfpch values, other values remained stable. While Romania's effch and sech values increased by 5,5%, techch value decreased by 6,4% and tfpch value by 1,2%. While a decrease of 2,5% is observed in Sweden's techch value, there is an increase of 0,6% in tfpch value. Türkiye's techch value increased by

0,2% and sech value increased by 1%, while effch value decreased by 1,2%, pech value by 2,2%, and tfpch value by 1%. Finally, England's effch, pech, and sech values remained stable, while techch and tfpch values increased by 0,5%.

Information on the Malmquist Index results of the countries is shown in Figure 4. The effch values of Czech, Romania, and Sweden were above 1, while other countries remained stable or decreased. While there is an increase in the techch values of Lithuania, Türkiye, and the UK, a decrease is observed in other countries. While pech values of Czech and Sweden have increased, other countries have seen a decrease or remained stable. While the sech values of Romania, Sweden, and Türkiye increased, they remained stable or decreased in other countries. While there was an increase in the tfpch values of Lithuania, Sweden, and England, there was a decrease in other countries.

Table 6. Malmquist index (Malmquist index summary of country means)

Countries	*effch*	*techch*	*pech*	*sech*	*tfpch*	*Average*
Austria	1.000	0.992	1.000	1.000	0.992	0.997
Czech	**1.005**	0.992	**1.008**	0.997	0.997	1.000
France	0.996	0.977	0.997	0.999	0.973	0.988
Germany	0.995	0.990	1.000	0.995	0.986	0.993
Italy	1.000	0.950	1.000	1.000	0.950	0.980
Lithuania	1.000	**1.025**	1.000	1.000	**1.025**	**1.010**
Poland	1.000	0.943	1.000	1.000	0.943	0.977
Romania	**1.055**	0.936	1.000	**1.055**	0.988	**1.007**
Sweden	**1.031**	0.975	**1.006**	**1.026**	**1.006**	**1.009**
Türkiye	0.988	**1.002**	0.978	**1.010**	0.990	0.994
United K.	1.000	**1.005**	1.000	1.000	**1.005**	**1.002**
Average	1.006	0.981	0.999	1.007	0.987	0,996
Max.	1.055	1.025	1.008	1.055	1.025	1,010
Min.	0.988	0.936	0.978	0.995	0.943	0,977

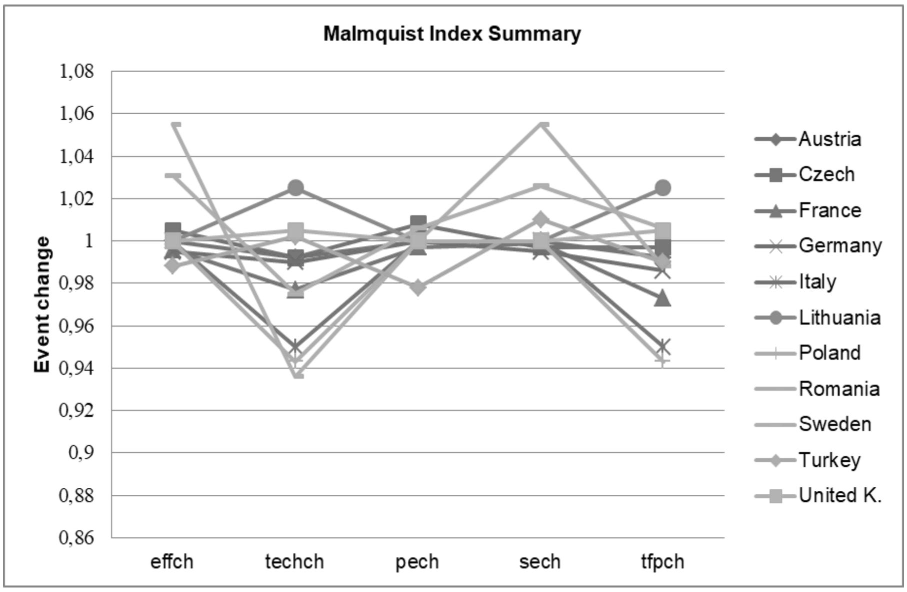

Figure 4. Malmquist index summary of the country means

4. CONCLUSION and EVALUATION

European countries increased their investments in railways in order to reduce environmental pollution and logistics costs. Thanks to the efficiency measurement, how effectively the activities are carried out, the degree of use of the available resources, and the idle capacity ratios are determined. Thanks to measurements, it contributes to taking the right steps toward inactive areas. In this study, using the DEA Malmquist Index model, the railway efficiency values of 10 European countries and Türkiye between the years 2011-2020 were investigated. Using the literature sources, the number of passengers and freight transported by rail was used as output variables, while rail lengths, wagon volumes, and train movements were used as input variables. The research has revealed what kind of changes have occurred in the railway efficiency of which country over the years. European countries are increasing the importance given to railway transportation day by day and there is a change in productivity between countries.

The average technical efficiency changes values of countries between the years 2011-2020 show an increase of 0,6% for Czech, 6,3% for Romania, 3,3% for Sweden, and 1,2% for Türkiye. In addition, while the average technical efficiency of France decreased by 0,4% and Germany by 0,5%, it followed a stable course in Austria, Italy, Lithuania, and England.

According to the average technological change indices of the countries, an increase was observed in Lithuania by 3,1%, Türkiye by 0,3%, and the UK by 1%. While there was a decrease in other countries, the biggest decrease was in Romania with 6.1 percent. According to the total factor productivity change value in the Malmquist Index values, it is understood that there is a productivity increase of 1% in Lithuania, 0,3% in Romania, and 0,2% in the UK. Besides, in total factor productivity change, rates have decreased Austria at 0,8%, Czech at 0,3%, France at 2.7%, Germany at 1.4%, Italy at 5%, Poland at 5.7%, Romania at 1.2% and Türkiye at 1%.

Doomernik (2015) studied the rail transport efficiency of 4 Asian and 4 European countries between 2007 and 2012 and showed that while the average Malmquist Productivity Index value of France decreased by 1,4%, Germany's 2.8% and Italy increased by 0.6. In this study, similar to the other study, the Malmquist Productivity Index value of France decreased by 2,7%. However, this study unlike other studies, there is a decrease, not an increase, in the Malmquist Productivity Index values of Germany and Italy. These differences may arise from different date ranges of the study, as well as from the variety of input and output variables used.

The data used in the research covers the years 2011-2020 constitutes the first limitation of the research. The number of input and output variables used for the research is another constraint. Future studies can be conducted on product loading and unloading efficiencies in railway transportation in terms of countries or businesses. In addition, railway efficiencies can be calculated by using different input or output variables.

According to the results of the research in terms of European countries and Türkiye, there is an increase in the production efficiency of railway transportation in Lithuania, Sweden, and England, while a slight decline is observed in other countries. According to the results, these regressions were mostly experienced during the epidemic in 2019-2020. While the COVID-19 epidemic did not affect UK railway transportation between 2019-2020, it mostly affected Türkiye, France, and Italy, among other countries. Due to the high value of the resources used in rail transport, the effect of a small improvement in efficiency can greatly affect the profitability of the enterprises. Furthermore, significant shifts in productivity have been observed in Romania, Poland, and Italy across different years. These changes in inefficiencies are likely attributed to the substantial investments these countries have channeled into their railway systems. Additionally, it can be inferred that the emphasis placed on Europe's east-west railway corridor is steadily growing with each passing day.

The following conclusions are also drawn from the research. There is no continuity in the railway efficiency of the countries that are the subject of the research. While productivity increases in some years, there is a decrease in some years. The productivity of other countries increased more than the European countries (Germany, France, Italy) with the highest GNP ratio (except the UK). In some countries such as Türkiye and Italy, there are sudden decreases and increases in productivity. These situations show that there are sufficient resources related to the railway, but that sufficient demands cannot be collected. In addition, countries with high productivity show that they invest in the right places and manage their resources and demands more accurately.

Conflict of Interest

No potential conflict of interest was declared by the author.

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Compliance with Ethical Standards

It was declared by the author that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement

It was declared by the author that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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