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Innovations Impact on Efficiency of European Railway Companies

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The aim of this paper is the assessment of innovations impact on European railways efficiency. In order to achieve sustainable transportation development, the key challenge is modal shift from road to rail, and development of single European transport market. Innovations in the railway transport sector contribute to the higher efficiency of transport services and promoting a more competitive and resource-efficient transport system. In the first stage of this study, efficiency scores are obtained through the use of Data Envelopment Analysis (DEA), and the ranking of 23 railway companies for the time period from 2009 to 2013 is conducted. In the second stage, factors representing technological and organizational innovations are introduced. Using different statistical tests the impact of these factors on railways technical efficiency (TE) is analyzed. Results showed significant impact of innovations on efficiency level of railway companies. This paper considers most recent time period, thus enabling observation of current trends in European railway transport market. Innovations observed in this study represent key elements in the field of technological development and the structural organization of railways, with the aim of achieving sustainable European rail transport system.

Keywords: Railways, Innovations, Efficiency, Data Envelopment Analysis

1. Introduction

Transport plays an important role in the economic development of each country. All industries are largely dependent on the level of efficiency of the transport system. Ultimately, the development and efficiency of the transport system greatly influences the quality of people's lives. The European Union (EU) and the rest of the world are faced with serious problems such as constantly increasing in demand, pollution, climate changes and limited resources of conventional fuels.

In order to face and overcome aforementioned problems, the EU undertakes huge efforts in promoting and achieving sustainable development in transportation sector. Number of initiatives and measures are introducing in order to achieve a more competitive and resource-efficient transport system. The key challenge is modal shift from road to rail and the creation of Single European Railway Area (SERA). In that sense, one of initiatives in the EU is development of Trans-European Transport Network (TEN-T) through nine core network corridors. Shift2Rail[1] initiative involves major European railway actors and aims to increase competitiveness of the railway sector in mid-long term.

Since share of rail on European passenger and freight transportation markets is still very low compared to road transportation, it is necessary to constantly improve railway transportation service through implementation of different technological and organizational solutions. To achieve an efficient European railway transport market, it is necessary for every single national market to face the challenge of efficiency improvement. In that sense, this paper aims to investigate the impact of innovations on European railways technical efficiency.

The definition of *innovate* from the online Oxford Dictionaries is: *„Make changes in something established, especially by introducing new methods, ideas, or products"*. Following this definition, this study discusses the two types of innovation: (ii) technological innovation, and (ii) structural reform and railways industrial restructuring.

[1] http://www.shift2rail.org/

This paper is organized as follows. Efficiency assessment of European railway companies is conducted and presented after the Introduction, in the Section 2 of this paper. Analysis of innovations impact on European railways efficiency is presented in the Section 3. The conclusions of this study are given in the Section 4.

2. Efficiency assessment of European railway companies

This paper analyzes technical efficiency of European railway companies from larger Europe during the time period of five years, between 2009 and 2013. For this aim the Data Envelopment Analysis (DEA) is selected, as the most suitable and most widely used in transportation sector efficiency assessment. Literature surveys of Liu et al. (2013a & 2013b) as well as that of Liu et al. (2016) concluded that transportation and railways have important role in the discipline development of DEA applications.

2.1. Defining input data

Data set includes 23 national railway companies from larger Europe (Table 1). The data were obtained from the official UIC statistics[2]. Only companies which provide both, passenger and freight transportation, are selected. As infrastructure maintenance and all transportation activities have been performed as integrated for some firms, the values have been taken as they are when compiling the data; and as infrastructure maintenance and transportation activities have been separated for some firms, the respective values have been taken from different companies considering the relations among the companies (e.g. in case of Romania – companies CFR, CFR Calatori and CFR Marfa, which perform infrastructure maintenance, passenger and freight transportation service, respectively) and completed by processing for the firm which has been studied [11]. Companies from Denmark (DSB), Netherlands (NS), Norway (NSB) and Sweden (SJ AB) provide only passenger transportation service, thus they are omitted in the analysis. Also, due to the lack of data for the time period observed, companies from Estonia (EVR), Greece (OSE), Hungary (MAV), Ireland (CIE), Latvia (LDZ) and Ukraine (UZ) are excluded.

Table 1: Railway companies included in the analysis

Country	Abbreviation	Name of the company (DMU)
Austria	OBB	Österreichische Bundesbahnen
Belarus	BC	Belarus Railways
Belgium	SNCB/NMBS	Société Nationale des Chemins de fer Belges
Bulgaria	BDZ	Bulgarian Railways
Croatia	HZ	Hrvatske Željeznice
Czech Republic	CD	České dráhy
Finland	VR	VR-Group Ltd
France	SNCF	Société Nationale des Chemins de fer Français
Germany	DBAG	Deutsche Bahn AG
Italy	FS	Ferrovie dello Stato SpA
Lithuania	LG	SPAB “Lietuvos Gelezinkeliai”
Luxembourg	CFL	Société Nationale des Chemins de Fer Luxembourgeois
Macedonia	MZ	Makedonski Železnici
Moldova	CFM	Calea Ferată din Moldova
Poland	PKP	Polskie Koleje Panstwowe S.A.
Portugal	CP	Caminhos de Ferro Portugueses
Romania	CFR	Căile Ferate Române
Serbia	ZS	Železnice Srbije
Slovak Republic	ZSSK ZSR	Slovak Rail Železnice Slovenskej Republiky
Slovenia	SZ	Slovenske Železnice d.d.
Spain	RENFE	Red Nacional de los Ferrocarriles Españoles
Switzerland	SBB CFF FFS	Schweizerische Bundesbahnen
Turkey	TCDD	Türkiye Cumhuriyeti Devlet Demiryollari Isletmesi

[2] UIC (International Union of Railways), Railisa Database, Available on: http://www.uic.org/statistics

Four input and two output variables that characterize railways transportation process are employed in this paper (Figure 1). Input variables include total length of lines, total number of employees, number of passenger cars and number of freight wagons. Two output variables which represent revenue measures are passenger-kilometers and freight ton-kilometers.

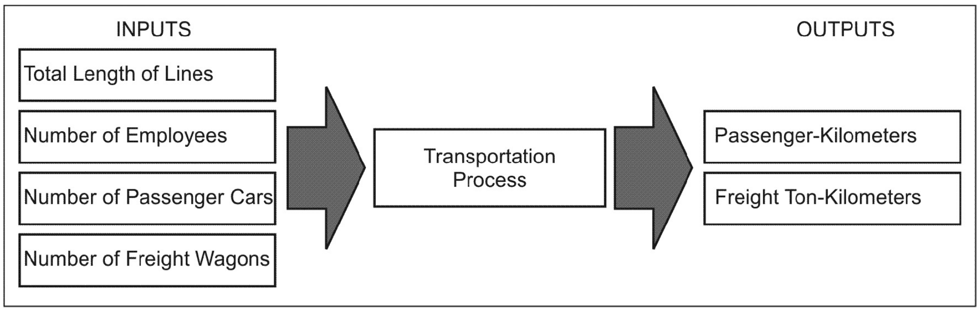


Figure 1: Inputs and outputs in DEA model

Although there are studies which analyze passenger and freight transportation efficiency separately (e.g. Hilmola, 2008; Yu & Lin, 2008), this paper aims to conduct overall efficiency assessment of European railways, thus all variables are integrated into a single model. Also, some authors included additional inputs and outputs, such as number of locomotives, number of passengers carried, freight tons transported (e.g. Hilmola, 2008; Kutlar et al., 2013), passenger and freight train-kilometers (Oum & Yu, 1994; Yu & Lin, 2008). These variables are not included in this study, since only factors which affect railway transportation process the most and which represent revenue measures are observed. Descriptive statistics of inputs and outputs selected for the time period observed are presented in Table 2.

Table 2: Descriptive statistics of inputs and outputs in DEA model

Var.	Description	Unit	Obs.	Mean	Min	Max	Std.Dev.
x_1	Total length of lines	km	115	8218.09	275	33708	8932.64
x_2	No. of employees	Person ($\times 10^3$)	115	43.13	1.1	294	60.94
x_3	No. of passenger cars	Cars	115	4484.21	77	29470	6501.19
x_4	No. of freight wagons	Wagons	115	20568.10	1007	113657	23258.22
y_1	Passenger-Kilometers	Person$\times$km ($\times 10^6$)	115	13926.96	99	86094	23084.12
y_2	Freight Ton-Kilometers	Ton$\times$km ($\times 10^6$)	115	14608.66	189	111980	22324.52

2.2. Mathematical formulation of DEA model

In order to obtain consistent technical efficiency scores, appropriate DEA model must be defined. Regarding the orientation of model, form of identified technical efficiency and the assumption of return to scale, this paper employs input oriented DEA model with constant return to scale (see Oum and Yu, 1994; Hilmola, 2008), and considers Pareto-Koopmans technical efficiency. Although Coelli & Perelman (2000) stated that the choice of orientation of the distance function is not as important in case of railway companies as for other industries, this paper employs input orientated model, assuming that the railway companies have a higher influence on the inputs than on the outputs (Merkert et al., 2009).

Based on work of Farell (1957), who introduced basic idea and definition of DEA, Charnes et al. (1978) developed linear programming (CCR DEA) model. Input oriented CCR DEA model employed in this paper has the following form:

$$(\max)\ h_k = \sum_{r=1}^{s} u_r y_{rk} \tag{1}$$

With constraints:

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{2}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,\dots,n \tag{3}$$

$$u_r > 0, \quad r = 1,\dots,s \tag{4}$$

$$v_i > 0, \quad i = 1,\dots,m \tag{5}$$

One of the main drawbacks of previous DEA model is that it is not able to make a difference in efficiency level of efficient units, since all efficient units have efficiency score equal 1. To rectify this shortcoming, Andersen & Petersen (1993) introduced super-efficiency grade and showed that the CCR model can be modified for the purpose of ranking units. The modification is leaving out the unit for which the efficiency is measured in the constraints set (3), so it becomes (8). The DEA model in this case has the following form:

$$(\max)\ h_k = \sum_{r=1}^{s} u_r y_{rk} \tag{6}$$

With constraints:

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{7}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,\dots,n; \quad j \ne k \tag{8}$$

$$u_r > 0, \quad r = 1,\dots,s \tag{9}$$

$$v_i > 0, \quad i = 1,\dots,m \tag{10}$$

2.3. Efficiency scores of European railway companies

Using data defined above, models (1)-(5) and (6)-(10) are solved for each year of the time period observed, and the technical efficiency (TE) and super efficiency (SE) scores are obtained. Models (1)-(5) and (6)-(10) are solved using EMS[3] software. TE and SE scores are presented in Table 3.

Best performance during the period observed showed companies from Spain, Switzerland, Lithuania, France and Belarus, and they represent benchmarks for other railway companies. Also, high efficiency level (above 80% efficiency level in average) showed companies from Austria, Finland, Germany, Italy and Portugal. Lowest performance (below 30% efficiency level in average) showed railway companies from Moldova and Serbia.

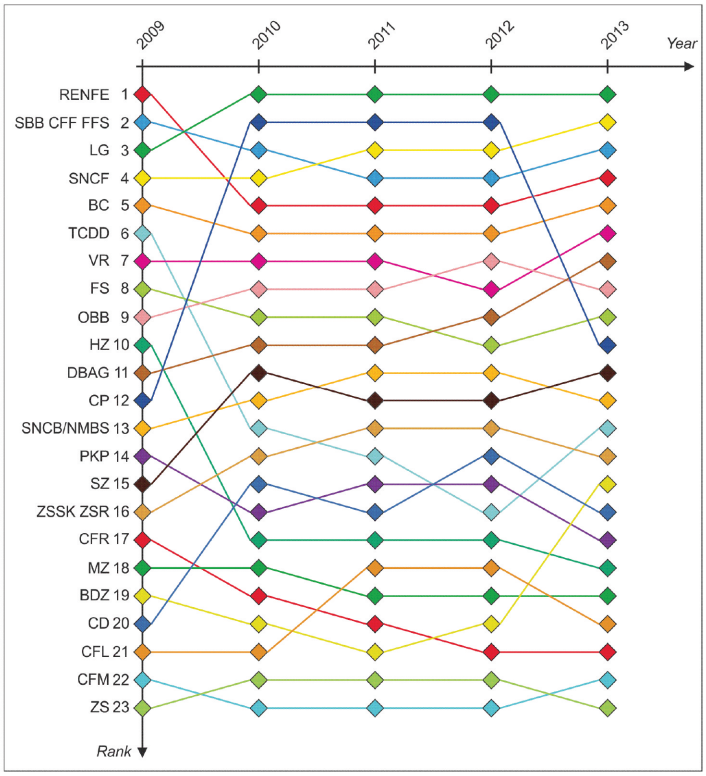
[3] EMS – Efficiency Measurement System, Available on: http://www.holger-scheel.de/ems/

Table 3: Efficiency scores of European railway companies for period 2009-2013

Comp.	2009		2010		2011		2012		2013	
	TE	SE	TE	SE	TE	SE	TE	SE	TE	SE
OBB	0.853		0.850		0.923		1.000	1.063	0.993	
BC	1.000	1.279	1.000	1.453	1.000	1.242	1.000	1.293	1.000	1.236
SNCB	0.654		0.562		0.716		0.741		0.706	
BDZ	0.386		0.274		0.307		0.304		0.543	
HZ	0.764		0.407		0.375		0.452		0.421	
CD	0.380		0.431		0.464		0.515		0.528	
VR	0.948		0.896		0.923		0.971		1.000	1.165
SNCF	1.000	1.615	1.000	1.746	1.000	2.045	1.000	2.245	1.000	2.068
DBAG	0.758		0.767		0.776		0.818		1.000	1.042
FS	0.934		0.773		0.839		0.807		0.852	
LG	1.000	1.922	1.000	3.021	1.000	3.906	1.000	3.836	1.000	3.900
CFL	0.365		0.246		0.347		0.381		0.370	
MZ	0.390		0.317		0.338		0.338		0.389	
CFM	0.238		0.173		0.223		0.199		0.236	
PKP	0.551		0.410		0.474		0.475		0.496	
CP	0.716		1.000	2.775	1.000	3.530	1.000	3.183	0.848	
CFR	0.440		0.302		0.330		0.299		0.351	
ZS	0.233		0.229		0.247		0.212		0.236	
ZSSK	0.485		0.500		0.502		0.531		0.553	
SZ	0.548		0.624		0.632		0.655		0.758	
RENFE	1.000	2.064	1.000	1.616	1.000	1.630	1.000	1.755	1.000	1.817
SBB	1.000	1.934	1.000	1.866	1.000	1.838	1.000	1.801	1.000	1.866
TCDD	0.989		0.522		0.489		0.466		0.642	

Using TE and SE scores obtained, ranking of railway companies is conducted (Figure 2). The highest year-to-year rank difference during the period observed showed companies from Portugal, Turkey and Croatia. Except companies from Lithuania, France, Croatia, Germany, Romania and Macedonia, there are no clear trends in ranking of railways, in terms of constant rank improvement or worsening during the period observed.

Figure 2: Ranking of European railway companies for period 2009-2013



3. Analysis of innovations impact on European railway companies efficiency

This paper investigates impact of two types of innovations on railways efficiency level – technological innovations and innovations in terms of structural and regulatory reforms. Using technical efficiency scores obtained in the previous stage, this stage introduces additional innovation indicators and conducts different statistical tests.

3.1. Impact of technological innovations on railways efficiency level

In order to obtain a unique European railway transport market, one of the main goals is to provide railway interoperability across Europe. Increased cross-border traffic is faced with different signaling and control systems from country to country, as a consequence of different manufacturers. In order to respond this challenge, European Commission (EC) initiated development of new signaling and control system. Directive 96/48/EC enforces *"the ability of the Trans-European high-speed rail system to allow the safe and uninterrupted movement of high-speed trains which accomplish the specified levels of performance"* (Council Directive, 1996). As a consequence, project called European Rail Traffic Management System (ERTMS) has been established. The ERTMS system is composed of two main components: European Train Control System (ETCS), implemented, in part, onboard trains and partly as a fixed infrastructure, and GSM-R, which is the communication system between the ETCS onboard subsystem and the ETCS trackside subsystem (Ghazel, 2014). The ERTMS is constantly evolving and many countries are gradually introducing this system.

In order to analyze the impact of ERTMS implementation on technical efficiency of railway companies, Tobit regression (Tobin, 1958) is used in this stage. When the efficiency scores calculated by DEA are used as dependent variables in regression, we find a good example of censoring, which means that the values of the dependent variable (TE in our case) are limited to a range of values (between 0 and 1). More precisely, censoring occurs when the dependent variable is observed as a subsample, while information about independent variables for the entire sample is available. This is why the Tobit regression (also known as the censored regression) has been widely used to determine the efficiency drivers of railway companies (e.g. Oum & Yu, 1994; Merkert et al., 2009; Nashand & Nash, 2010; Kutar et al., 2013).

Using TE scores as dependent variable, two different explanatory variables, representing ERTMS implementation are defined – percentage of lines equipped with ERTMS, and percentage of vehicles equipped with ERTMS. Considering large differences in absolute values (length of lines and number of vehicles) from country to country, these ratio indicators are used as most adequate. Only projects implemented before or during the time period observed are taken into account. Data are obtained from the official ERTMS deployment statistics[4]. In addition, three additional explanatory variables, representing infrastructure development are introduced. These variables include network density, percentage of double-track lines and percentage of electrified lines. Descriptive statistics of variables used in Tobit regression are presented in Table 4.

Table 4: Descriptive statistics of variables in Tobit regression

Var.	Description	Unit	Obs.	Mean	Min	Max	Std.Dev.
TE	Technical efficiency	-	115	0.660052	0.173	1	0.285763
z_1	Network density	km/km^2	115	0.055621	0.011286	0.123482	0.030833
z_2	Percentage of double-track lines	%	115	49.64953	0	100	25.1595
z_3	Percentage of electrified lines	%	115	29.4834	0	77.75294	19.18845
z_4	Percentage of lines equipped with ERTMS	%	115	2.225403	0	38.79262	7.276728
z_5	Percentage of vehicles equipped with ERTMS	%	115	3.316203	0	82.81853	12.69245

[4] ERTMS deployment statistics, Available on: http://www.ertms.net/

Results of Tobit regression are presented in Table 5. Tobit regression, as well all other statistical tests in this paper are conducted using Stata software[5]. Regarding network density, results showed statistically significant negative impact on technical efficiency of railway companies. It could be explained as a consequence of excessive engagement of input variable (length of lines) by railway companies. Variable regarding percentage of double-track lines showed negative impact on efficiency, although it has no statistical significance. Variables which represent percentage of electrified lines and percentage of lines equipped with ERTMS showed statistically significant and positive impact on efficiency, as expected. Variable which represents percentage of vehicles equipped with ERTMS showed statistically significant and negative impact on railways efficiency, which could be explained with reduced sample of railway companies in this study, considering that some omitted companies are large ERTMS users.

Table 5: Results of Tobit analysis

Variable	Coefficient	t-ratio
z_1	-7.810897**	-6.49
z_2	-0.002507	-1.49
z_3	0.016739**	6.64
z_4	0.025803**	3.44
z_5	-0.010601*	-2.51
Constant	0.760149**	10.52
Sigma	0.282205	
Pseudo R2	0.4440	
Log Likelihood	-37.032108	
Number of observations	115	
Uncensored observations	84	
Censored observations	31	

*Denotes statistical significance at level α=5%
**Denotes statistical significance at level α=1%

The implementation of ERTMS contributes to uninterrupted cross-border traffic, by overcoming above-mentioned problems of different signaling and control systems between countries. This allows increased volume of transit traffic, which in most countries has a significant share in the total traffic volume. Also, the implementation of ERTMS contributes to removing bottlenecks and improving trains performance, thus enabling railways to meet increased transport demand.

In order to analyze difference in efficiency level of railway companies which implemented ERTMS and those which did not, next hypothesis is set:

Hypothesis 1: There is a difference in efficiency scores of railway companies which implemented ERTMS and those which did not, and companies which implemented ERTMS have higher efficiency level, as a consequence of increased traffic flow.

The previous hypothesis was tested using non-parametric Man-Whitney and Kolmogorov-Smirnof tests. Results of Mann-Whitney test (Table 6) showed that there are statistically significant differences between these two groups, and that the companies which implemented ERTMS have higher efficiency scores. Thus the null hypothesis is rejected, and Hypothesis 1 is accepted. Results of Kolmogorov-Smirnof test (Table 7) confirmed this conclusion.

[5] Stata software, Available on: http://www.stata.com/

Table 6: Results of Mann-Whitney test - ERTMS implementation

ERTMS implemented	Observations	Rank sum	Expected
No	77	3929.5	4466
Yes	38	2740.5	2204
Combined	115	6670	6670
Unadjusted variance	28284.67		
Adjustment for ties	-554.07		
Adjusted variance	27730.60		
Z	-3.222		
p-value (α=0.05)	0.0013		

Table 7: Results of Kolmogorov-Smirnof test - ERTMS implementation

Smaller group	D	P-value
No	0.4012	0.0000
Yes	0.0000	1.0000
Combined	0.4012	0.0001
Observations	115	
Unique values	80	

3.2. Impact of structural and regulatory reforms on railways efficiency level

Railway reform in EU began in 1991 with the EC directive 91/440/EEC aiming to facilitate the creation of Single Market and to increase railways efficiency. The four main objectives are related to: (i) insuring the independent management of railway undertakings (operators); (ii) separating the management of railway operations and infrastructure from the provision of transport services; (iii) improving the financial structure of the undertakings; (iv) ensure international access to the networks of Member states for international combined transport of goods (Council Directive, 1991). Licencing issues were subject of the following Directive 95/18/EC (Council Directive, 1995). After that, a set of four "railway packages" and complementary initiatives were brought by EC in the early 2000s. An essential goal of the rail reforms in the EU was to improve the efficiency and competitiveness of the European railway system and in the end to increase its market share in the modal split (Grushevska et al., 2016).

Two different indicators regarding structural and regulatory reforms implementation are considered in this paper – the implementation of vertical separation and the implementation of horizontal separation. Following the UIC classification, there are five categories of railway organizations: (1) integrated company, (2) railway undertaking (i.e. passenger and freight operators), (3) passenger operator, (4) freight operator, and (5) infrastructure manager. Based on this classification, the vertically integrated company represents a company providing rail operations while holding its own infrastructure, while the vertically separated company is a company comprised of a railway undertaking and an infrastructure manager (Mizutani & Uranishi, 2013). Horizontally separated company is a company (railway undertaking) which separated its passenger and freight operations.

Although there are different types of vertical separation (Vešović & Bojović, 2002), in this study, only vertical separation at the institutional level is considered, meaning that two different organizations held by the same holding company are not observed as separated organizations. Therefore, in this paper, vertical separation means that the rail operations and infrastructure management activities are performed by completely separated companies. The same principle goes for horizontal separation. Data related to the implementation of vertical and horizontal separation of railway companies are gathered from different studies (Sanchez et al., 2008; Wolff, 2011; Mizutani & Uranishi, 2013; Mizutani et al., 2014), and also from respective companies annual reports. The implementation of vertical and horizontal separation during the period observed is presented in Table 8.

Table 8: The implementation of vertical and horizontal separation during the period 2009-2013

Country	Abbreviation	Vertical separation	Horizontal separation
Austria	OBB	No	No
Belarus	BC	No	No
Belgium	SNCB/NMBS	No	No
Bulgaria	BDZ	Yes	No
Croatia	HZ	No	No
Czech Republic	CD	Yes	No
Finland	VR	Yes	No
France	SNCF	Yes	No
Germany	DBAG	No	No
Italy	FS	No	No
Lithuania	LG	No	No
Luxembourg	CFL	No	Yes
Macedonia	MZ	No	No
Moldova	CFM	No	No
Poland	PKP	No	No
Portugal	CP	Yes	No
Romania	CFR	No	No
Serbia	ZS	No	No
Slovak Republic	ZSSK ZSR	Yes	Yes
Slovenia	SZ	No	No
Spain	RENFE	Yes	No
Switzerland	SBB CFF FFS	No	No
Turkey	TCDD	No	No

In order to analyze difference in efficiency level of railway companies which conducted vertical separation and those which did not, next hypothesis is set:

Hypothesis 2: There is a difference in efficiency scores of railway companies which conducted vertical separation and those which did not, and companies which conducted vertical separation have higher efficiency level, as a consequence of different business environment.

Both, Man-Whitney (Table 9) and Kolmogorov-Smirnof test (Table 10) showed that there is statistically significant difference in efficiency scores between these two groups, and that railway companies which conducted vertical separation have higher efficiency level. Thus, null hypothesis is rejected, and Hypothesis 1 is accepted.

Table 9: Results of Mann-Whitney test - Vertical separation

Vertical separation	Observations	Rank sum	Expected
No	80	4273	4640
Yes	35	2397	2030
Combined	115	6670	6670
Unadjusted variance	27066.67		
Adjusted for ties	-530.21		
Adjusted variance	26536.46		
Z	-2.253		
p-value (α=0.05)	0.0243		

Table 10: Results of Kolmogorov-Smirnof test - Vertical separation

Smaller group	D	P-value
No	0.2518	0.046
Yes	0.0000	1.000
Combined	0.2518	0.091
Observations	115	
Unique values	80	

In addition, in order to analyze difference in efficiency level of railway companies which conducted horizontal separation and those which did not, next hypothesis is set:

Hypothesis 3: There is a difference in efficiency scores of railway companies which conducted horizontal separation and those which did not, and companies which conducted horizontal separation have higher efficiency level, as a consequence of different business environment.

Results of Man-Whitney test (Table 11), as well as of Kolmogorov-Smirnof test (Table 12) showed that there is statistically significant difference in efficiency scores between these two groups, and that railway companies which conducted horizontal separation have lower efficiency scores. Thus, both null hypothesis and Hypothesis 3 are rejected. This could be explained with the fact that many companies have conducted vertical separation, but are still operating as a single passenger and freight operator, or they have conducted horizontal separation at the accounting level. Also, some of companies omitted in the analysis represent best practice in reforms implementation.

Table 11: Results of Mann-Whitney test - Horizontal separation

Vertical separation	Observations	Rank sum	Expected
No	105	6333	6090
Yes	10	337	580
Combined	115	6670	6670
Unadjusted variance	10150.00		
Adjustment for ties	-198.83		
Adjusted variance	9951.17		
Z	2.436		
p-value (α=0.05)	0.0149		

Table 12: Results of Kolmogorov-Smirnof test - Horizontal separation

Smaller group	D	P-value
No	0.0857	0.874
Yes	-0.5905	0.002
Combined	0.5905	0.003
Observations	115	
Unique values	80	

Conclusion

This paper analyzes impact of innovations on technical efficiency of European railway companies. The evaluation of efficiency and ranking of 23 national railway companies was conducted using DEA method, observing time period from 2009 to 2013. Using four input and two output variables which characterize railway transportation process, technical efficiency scores are obtained by solving input oriented CCR DEA model. The ranking of railway companies is successfully conducted using modified DEA model, which enables ranking of efficient companies by introducing super efficiency scores. This approach provided the observation of efficiency and ranking trends of railway companies during the period observed.

In the second stage of the study, different factors representing technological and organizational innovations in railway sector are introduced. Variables representing technological innovations consider implementation of European Rail Traffic Management System (ERTMS), and include percentage of lines and vehicles equipped with ERTMS. Also three additional variables, which represent infrastructure development are introduced. These include network density, and percentage of double-track and electrified lines. The impact of these explanatory variables on railways efficiency was analyzed using Tobit regression. In addition, the hypothesis testing was conducted aiming to observe the difference between railway companies which implemented ERTMS, and those which did not. Results showed that railway companies which implemented ERTMS have higher efficiency level. Considering structural reform and railways industrial restructuring, hypothesis testing was conducted with the aim to analyze the difference in efficiency level between companies which conducted vertical and horizontal separation, and those which did not. Results showed that companies which separated infrastructure management and transport operations have higher efficiency level. Regarding horizontal separation, it has been shown that companies which conducted horizontal separation have lower efficiency scores.

Overcome of the problem of lack of data for some companies would enable larger sample analysis. Also, future research directions are including some private railway operators in the analysis, as well as observing differences in passenger and freight transportation service. In addition, inefficiency aspect of companies will be analyzed in DEA, in terms of efficiency improvement possibility by reduction of some inputs.

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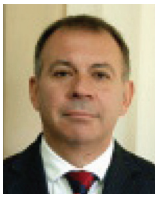

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