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Analyzing Efficiency of Railway Freight Transportation in a Corridor: Case Study of Countries in One Belt One Road Initiative

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A B S T R A C T

Due to globalization, more and more freight are transported across the globe annually. The greater the modal share of railways the lesser would be the carbon footprint because of inherent sustainable characteristics of railway transportation. However, transporting freight by railways along corridors that span through continents is not easy and requires close coordination and collaboration between many countries. In these cases, overall performance of the corridor would be limited by bottlenecks. In this research two mathematical models are developed that are based on data envelopment analysis which can measure relative efficiency of railways in different countries along a corridor. The newly proposed One Belt One Road initiative is chosen as the case study. The models rank performance of railways in this route by considering the facilities they have including length of railway lines and number of freight wagons, main economic drive for transporting freight (GDP) and the quality of their logistic to transport railway freight (measured by tonne-km).

1. Introduction

Globalization has resulted in growing appeal of transportation around the globe. Due to advantages of railways such as lower fuel consumption, less carbon footprint, lower fare and ability to transport massive volumes of freight, it is superior over road in long distances. In many routes, it can also be a fierce competitor to marine transportation when total transportation time is considered. Currently there are various corridors to transport freight between Asia and Europe and there are some within the European continent. Belt and Road initiative (BRI) or One Belt, One Road was proposed by the president of China Xi Jinping in 2013 to revive the ancient Silk Road. It is comprised from land (belt) and marine corridors (road) as shown in Figure 1. It is a global strategy for the aim of improving "policy, trade, infrastructure and people-to-people exchanges" [1]. About 22% of 8.5 Billion US dollar loans by the Asian Infrastructure Investments Bank are meant for improving transportation infrastructure along these corridors [2].

While overall transportation infrastructures in this route are rather weak, improving infrastructure bottlenecks in even one country can improve the overall corridor performance hence it is very important to choose the right projects [3]. In a corridor that stretches over thousands of kilometers of railway lines and several countries, the key challenge is to pinpoint weaknesses and identify means to improve the overall throughput. The aim of this study is to analyze efficiency of railway transportation along BRI at the countries' level and develop quantitative models for this purpose for the first time. The structure of the paper is as follows. After reviewing recent research on this corridor, two models are proposed that can measure and rank relative performance of countries for transporting international rail

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freight. Data envelopment analysis (DEA), a widely used method to analyze efficiency of various units, is used in this regard. The results and potential underlying reasons for top performing and underperforming railways are also presented. The paper concludes with implications for policy makers and suggestions to develop models further by adding new variables and assess other aspects of this corridor.

2. Literature Review

Although BRI is a new initiative, due to its impact on global economy, many papers are published on different aspects of it in the past. The major work in this regard is presented in Table 1.

It can be seen that overall policy analysis, mode choices, forecasting transportation demand and appraisal of logistic facilities have been among the popular topics. Most of the existing works are qualitative studies that try to envisage the big picture and future of this corridor. However, the performance of the railway corridor and different measures that can help to improve it is understudied in the literature which is the main aim of this research. Most of the published articles are from China which is inevitable as this initiative was proposed by China, but other countries need to start doing research on how they can benefit from this international corridor and how they can improve their performance.

It is a well-known principle in system engineering that "a chain is as strong as its weakest link" [4]. Hence the overall performance of the railway corridor will be limited by the weakest performance and it is where investments and improvements should be focused.

In this regard the data envelopment analysis is chosen in this research which is widely used for efficiency evaluation. Several papers have reviewed its variations and applications: Stochastic DEA by Olesen and Petersen (2016) [6], network DEA by Kao (2014) [7], Imprecise DEA by Zhu (2003) [8] and 40 years of its applications by Emrouznejad and Yang (2017) [9]. The benefits of this method is that it does not use index numbers and does not need exact weights and relationship between variables like regression [10].

The underlying mathematical model of DEA is based on a fractional model that maximizes sum of weighted outputs divided by sum of weighted inputs.

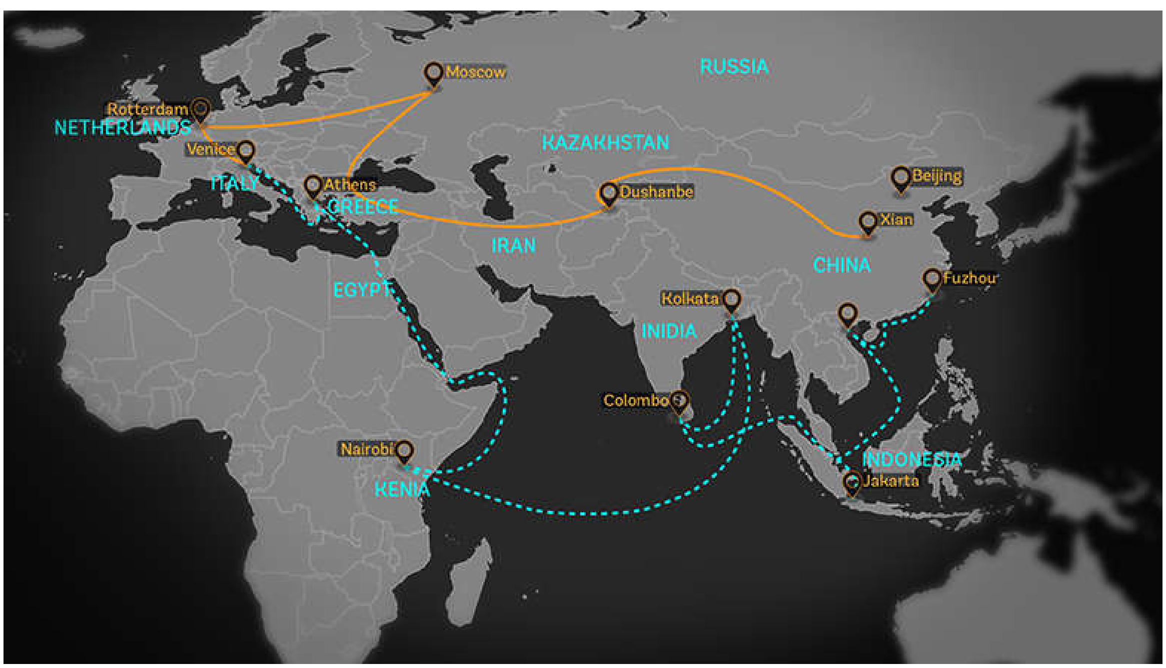

Figure 1. Map of Belt and Road Initiative [5]

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Table 1. Summary of major research on One Belt One Road Initiative

Author(s), year	Topic	Methodology
(Cheng, 2016), [11]	Major objective and investments needed for BRI-Priorities for China's mutual collaboration	Policy analysis
(Wei et al., 2018), [12]	Importance of dry ports in linking BRI (land transportation and marine transportation)	Logistic gravity model
(Chhetri et al., 2018), [13]	Evaluating position of "global logistic cities" in BRI	Policy analysis
(Zhang et al., 2018), [14]	Analyzing the pros and cons of free trade zones in BRI	Computable general equilibrium model
(Yu and Sun, 2019), [15]	Change in service trade of China as the result of BRI	vector-error correction model and impulse response functions
(Liu et al., 2018), [16]	Comparing four different models for logistic contracts	Game theory
(Sheu and Kundu, 2018), [17]	Oil supplies distribution flows in BRI	Spatial-temporal interaction-Markov chain
(Jiang et al., 2018), [18]	Shipping mode choice between sea and railway in BRI	Logit model
(Zhai, 2018),[19]	Estimated economic gains for different countries in BRI	Computable general equilibrium model
(Wen et al., 2019), [20]	Calculating route utility function for different routes in BRI	Utility function
(Herrero and Xu, 2017), [21]	Predicting export changes for countries in BRI	Regression
(Vinokurov and Tsukarev, 2018), [22]	Estimating capacity of container transportation in different corridors of BRI	Capacity analysis

Its linear form is:

$$\max \theta = \mu_1 y_{1o} + \cdots + \mu_s y_{so}$$

Subject to $\quad v_1 x_{1o} + \cdots + v_m x_{mo} = 1$

$\mu_1 y_{1j} + \cdots + \mu_s y_{sj} \leq v_1 x_{1j} + \cdots + v_m x_{mj}$ (j= 1,…,n)

$v_1, v_2, \ldots, v_m \geq 0$

$\mu_1, \mu_2, \ldots, \mu_s \geq 0$

where there are n DMUs to be optimized and μ_r is the weight of output yr and vi is weight of input xi for the DMU j.

3. Models

Two DEA models are developed in this research. In the first model it is analyzed that how well the railway of a country in BRI can attract freight in comparison with other modes of transportation in the country. There are three inputs for this model: GDP is one of the best proxies to measure the size and scale of economic activities in a country and the higher the GDP, the higher would be the potential and demand for transportation of freight. Length of lines and freight wagons are used as proxy variables to reflect the available infrastructure and rolling stock in the countries. Staff is not used as one of the inputs as the authors found out that caution must be taken when using available statistics on the staff of world railways otherwise it would lead to misleading results. Structure of railways in different countries varies (in terms of

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vertical/ horizontal integration /separation). For some countries such as Iran, the number of staff only reflects the staff of the company that is the member of International Union of Railways (which is usually the infrastructure manager and not the freight train operators). Low staff input will result in high efficiency scores. Hence this variable is not used for the modeling purposes in this research.

In order to evaluate how well railways perform, two outputs are used. Modal share of railway for freight that shows the competitiveness and actual performance in comparison with other modes of transportation. Tonne-km of freight carried annually indicates the performance of railways in absolute terms. The schematic of the first model is presented in Figure 2.

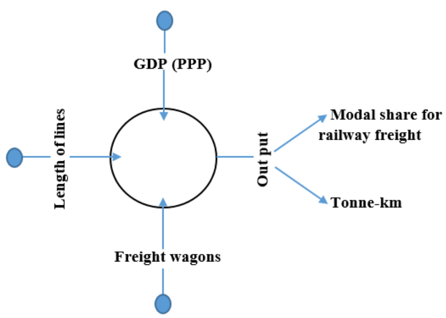

Figure 2. Schematic representation of model 1

To do the case study, data is collected from various sources. For 11 countries in BRI all the necessary data can be found. For others some variables such as modal share of railways was not available. Hence the countries that are included in the case study are: Belarus, Bulgaria, China, Germany, Iran, Kazakhstan, Poland, Romania, Russia, Turkey, and Ukraine.

The second DEA model that is developed in this research has two stages. In the first stage it is intended to analyze technical efficiency of railway freight sector. The model uses 3 inputs of GDP, length of lines and number of freight wagons as inputs and the output of this stage of the model is freight train-km. The output of the first stage of model 2 is chosen as train-km to evaluate the macro ability of railway to move freight trains on its network. So based on this model, a railway would be more efficient relative to the economic situation of the country (GDP). Hence the resulting demand, can have a denser traffic of freight trains with the available rolling stock and infrastructure by appropriate marketing, train timetabling, capacity allocation and network management.

In the second stage of the model it is intended to analyze the effectiveness of railway freight services and how effectively railway can turn freight train-km into tonne-km carried. Obviously if freight traffic is dense but trains are running on the network mostly empty or with low loads it won't be efficient. Hence the first input of the second stage is the output of the first stage. As logistic capabilities immensely affect the performance of different transportation modes including railway, the Logistic Performance Index (LPI) that is published by the World Bank is chosen as the second input. The output of the model is the freight tonne-km. Schematic presentation of the model 2 is presented in Figure 3. The countries that are included in the case study for the second model are the same as the first model.

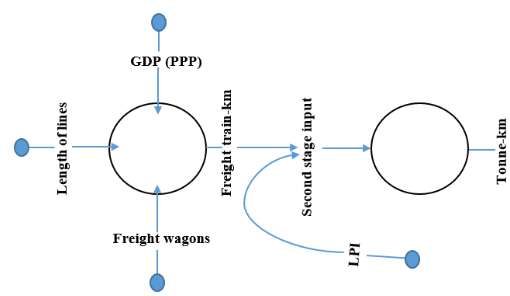

Figure 3. Schematic of model 2

4. Results

Descriptive statistics of the data for model 1 and 2 for the countries of the case study are presented in Table 2 and Table 3, respectively. It can be deduced that Russia has the highest length of lines, modal share of freight and tonne-km while the highest GDP and number of freight wagons belong to China. Germany has the best logistic performance. DEA models can be solved with the purpose of maximizing outputs (output orientation) or minimizing inputs (input orientation). As the aim of railways are to maximize throughputs, the former is chosen and models are solved by output orientation and constant return to scale.

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The results of the first model (Table 4) demonstrate that China, Ukraine and Russia have the most efficient railways in terms of railway freight modal share and tonne-km by the available railway infrastructure and rolling stock that they have and also GDP of the country that is the engine behind economic activities. Romania, Turkey and Bulgaria have the lowest efficiency in this regard meaning that in order to have a better flow of railway freight at BRI, these countries are the "weakest links of the chain" and need to improve their railway performance. In other words and by relative comparison, these countries have higher potential for transporting railway freight which can be fulfilled by taking necessary steps.

Countries that have underperformed according to this model, should work on better marketing railway freight transportation to be able to increase total tonne-km and overall modal share. In this regard, UNSCAP [25] suggests railways to improve their marketing procedures by focusing on most profitable commodities and routes, "demarketing" routes or commodities that make a loss or seeking financial help from government for them and finally improve efficiency of their operations.

More investment on railway infrastructure is also needed in these countries, otherwise the vicious cycle of Figure 4 will be inevitable. Underinvestment will lead to lower quality of

Table 2. Descriptive statistics for the case study by model 1 – Basic data was extracted from [23] and [24]

	GDP(PPP) Billions of current $	Length of lines/km	Freight wagons	%Modal share freight	Tonne-km
Standard.dev	5.16	26307.97	204402	23.37	873470.94
Median	0.89	16040	52669.00	11.00	48538.20
MAX	18.70 China	89281 Russia	754143 China	88.40 Russia	2491875.90 Russia
MIN	0.12 Bulgaria	4030 Bulgaria	6072 Bulgaria	1.35 Ukraine	3172.68 Bulgaria
Average	2.74	25973.545	112920.73	20.81	478309.16

Table 3. Descriptive statistics for the case study by model 2- Basic data was extracted from [23] and [24]

	GDP(PPP) Billions of current $	Length of lines/km	Freight wagons	Freight train-km	LPI	Tonne-km
Standard.dev	5.16	26307.97	204402	293125.43	0.45	873470.94
Median	0.89	16040	52669.00	27512.00	2.57	48538.20
MAX	18.70 China	89281 Russia	754143 China	1058148.0 Russia	4.20 Germany	2491875.90 Russia
MIN	0.12 Bulgaria	4030 Bulgaria	6072 Bulgaria	7738.42 Bulgaria	2.57 Belarus	3172.68 Bulgaria
Average	2.74	25973.545	112920.73	145599.47	3.13	478309.16

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services and ultimately decreasing revenue and freight modal share.

Table 4. Results of the first model

Country	Efficiency Scores
China	1.00
Ukraine	1.00
Russia	1.00
Kazakhstan	0.81
Belarus	0.56
Germany	0.44
Iran	0.25
Poland	0.19
Bulgaria	0.19
Turkey	0.18
Romania	0.13

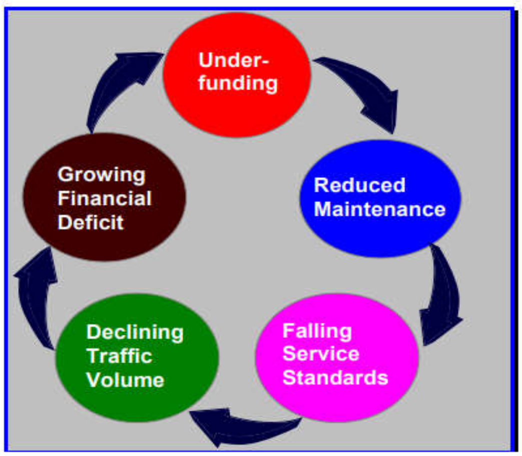

Figure 4. Vicious cycle of railways [25]

In Iran, Poland, Bulgaria, Turkey and Romania, investments should especially be directed to improve Trans Asian Railway (TAR) routes that are also in line with BRI [26]. One section that seriously needs attention is the only missing railway link along BRI, at Van Lake, that ferries are used between Van and Tatvan. This hinders the flow of traffic considerably.

It is also known that the capacity of double track railway lines can be up to four times more than single track ones. Hence investing on double tracking the single lines can also be beneficial. The countries that had lower performance in the first model had considerably lower percentage of double track (or more) lines as it can be detected in Table 5. In the top four performing countries the average of 45% of lines is double track or more whereas in bottom four performing countries this number is 28%.

The results of the second model show that Ukraine and Russia have the highest efficiency scores for the first stage and Romania and China have the lowest. Higher efficiency scores in the first stage of the model mean that the railway has been efficient at the macro level in generating freight train-km. Hence China and Romania had relatively higher potential to transport freight trains on their network by the available rolling stock they had. In other words, the railway network of top performing countries according to this model is more saturated with freight trains and the available capacity of infrastructure is utilized more efficiently. The countries that have obtained lower scores have either a bigger share of passenger trains passing on their network (such as the case of China with extensive high speed railway network) or still have spare capacity of infrastructure that has the potential to be utilized more efficiently (by either passenger or freight trains).

According to the results of the second stage (Table 6), it can be concluded that China and Russia have obtained the highest scores. Therefore, they have been very efficient in transforming freight train-km to freight ton-km or micro capacity utilization. Bulgaria, Romania and Turkey have the lowest efficiency scores in the second stage meaning that there are a lot of freight train-km transported on their network but the resulting tone-km is relatively low. Hence they should improve their freight train routing, increase average load wagons and length of trains as far as possible, take appropriate marketing measures. More details on the results are presented in Table 7.

At this stage in the research it is intended to analyze what exogenous factors affect the efficiency scores and this is what Tobit regression is suggested for [27].

Table 5. Percentage of double track lines in the countries of the case study

Country	Total [23]	Double Tracks [23]	Percentage of double tracks
China	67515	35349	0.52
Ukraine	21626	11358	0.53
Russia	85626	38442	0.45
Kazakhstan	16061	4945	0.31
Belarus	5459	1634	0.30
Germany	33440	18542	0.55
Iran	9306	2134	0.23
Poland	18536	8618	0.46
Bulgaria	4030	990	0.25
Turkey	10417	1385	0.13
Romania	10765	2917	0.27

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Table 6. Efficiency scores of countries for stage 1 and 2 of model 2

Stage 1		Stage 2	
Country	**Efficiency scores**	**Country**	**Efficiency scores**
Ukraine	1.000	China	1.000
Russia	1.000	Russia	1.000
Kazakhstan	0.809	Kazakhstan	0.087
Belarus	0.556	Ukraine	0.076
Germany	0.443	Germany	0.032
Iran	0.246	Belarus	0.024
Poland	0.191	Iran	0.016
Bulgaria	0.186	Poland	0.012
Turkey	0.180	Turkey	0.006
Romania	0.131	Romania	0.005
China	0.010	Bulgaria	0.002

Table 7. Descriptive statistics of the results of model 2

	Stage 1 efficiency	Stage 2 efficiency
Standard deviation	0.34	0.38
Median	0.25	0.02
MAX	1.00	1.00
MIN	0.01	0.002
Average	0.43	0.21

Table 8.Tobit Regression for the second model & first stage with petrol

Variable	Coefficient	Std. Error	z-Statistic	Probability
SERIES03	-0.526	0.212	-2.475	0.013
C	0.969	0.232	4.173	0.000

After trying various variables, it is found that petrol price is negatively correlated with the efficiency scores of the first stage of the second model and it is statistically significant at 5 percent level (Table 8). Therefore, countries that have low petrol prices have challenge in attracting freight transportation to railway resulting in lower efficiency scores.

5. Conclusions

BRI is a huge multinational collaboration and in order to improve transportation in this route it is important to consider different countries as links in a chain. Overall transportation cannot be increased along this route unless weakest links are improved. This study focused on the railways of BRI and proposed two models based on DEA that analyze efficiency of freight railway transportation of different countries in this route.

In the first model, overall relative efficiency of railways is measured by considering length of lines, GDP and number of wagons as inputs and modal share for railway freight and tonne-km as outputs. China, Ukraine and Russia have the most efficient railways according to the results. Poland, Bulgaria, Turkey and Romania have much higher potential to increase their railway freight modal share and tonne-km carried.

The second model has two stages in the first of which the inputs are the same as the first model but the output is freight train-km. The output of the first stage together with logistic performance index are the inputs of the second stage, the output of which is tonne-km. China, Ukraine, Russia and Kazakhstan have the highest overall scores in both models while Poland, Turkey, Romania, Bulgaria and Iran the least scored implying that railway infrastructure and logistics in these countries should be upgraded in order to improve overall throughput of the BRI. The results of these models can help policy makers to identify the best investment options and compare their performance

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relatively with other countries that exist in this corridor.

Although in this research the corridor is broken down to the level of countries, there are other issues such as the interaction between railways of different countries that need to be considered to have a better view of the system. One of these major issues is track gauge change (or as it is called "break of gauge") that happens at the borders of China- Kazakhstan (1435 mm to 1520 mm), Turkmenistan- Iran (1520 mm to 1435 mm), Bulgaria- Ukraine (1435 mm to 1520) and Belarus-Poland (1520 mm to 1435 mm). Efficiency of operations at these points (such as change of bogies) are crucial and should be assessed and improved as far as possible to avoid bottlenecks.

Future research is suggested in several fields: Conducting a time-series analysis and analyzing how the efficiency of BRI countries has changed in the past years according to the proposed models and whether the efficiencies are improving over time or not. Competition of railways with road transportation can provide useful insights in these countries. New models can also be developed or new variables (such as transited freight) can be added to model. The proposed models of this study can also be applied to other Eurasian railway corridors and the results can be compared with BRI. Finally, price and travel time along this corridor are important factors that should be considered in future works. Although accurate data in this regard are not officially published and are difficult to obtain.

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