

# A DEA BASED APPROACH FOR CROSS-COUNTRY EVALUATION OF RAIL FREIGHT TRANSPORT: Possibilities and Limitations

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**Abstract:** Data Envelopment Analysis (DEA) is recognized as a method of great potential for measuring the efficiency of different economic sectors. However, in order to obtain meaningful and relevant results, the proper DEA models have to be chosen. In this paper, we demonstrate the potentials of Data Envelopment Analyses for cross-country performance evaluation in the field of transport. Three alternative DEA models have been applied to measure relative efficiency of rail freight transport in selected European countries during five years period (2005-2009).

**Keywords:** DATA ENVELOPMENT ANALYSIS, EFFICIENCY, TRANSPORT, CROSS-COUNTRY COMPARISONS, RAIL FREIGHT

## 1. Introduction

Efficiency evaluation is important for staying competitive and prospering in a business environment facing global competition. Efficiency has been analyzed under many points of view, using different techniques and investigating its main determinants. One of these techniques is the non-parametric method called Data Envelopment analysis (DEA). DEA became very popular in evaluating the performances of many different kinds of entities engaged in many different activities in many different contexts [1]. It has been extensively used to compare the efficiencies of non-profit and profit organizations such as schools, hospitals, shops, bank branches and other environments in which there are relatively homogeneous units [2].

DEA has also found its implementation in the field of transport. It has been applied to ports [3,4], railways [5], airlines [6,7], urban transit [8]. It is used both for calculating efficiency of transport companies and in cross-country comparisons. Sanchez [8] took a comparative efficiency analysis of public bus transport in Spain using Data Envelopment Analysis. A procedure for efficiency evaluation was established with a view to estimate its technical and scale efficiency. Su and Rogers [9] examined multi-year transportation efficiency of OECD countries using data envelopment analysis to determine efficiency scores. Their analysis provides year-by-year efficiency scores for each country, suggestions for improving individual country efficiency, and a discussion on factors that "drive" efficiency. Savolainen [10] estimated relative technical efficiency of European transportation systems. His study uses DEA as a method to individually evaluate the current relative technical efficiencies of three European transportation systems: rail, maritime and air.

In our study we focus on cross-country efficiency evaluation in the rail freight transport domain. For efficiency calculations we deployed three DEA models. Empirical example is given for rail freight sector in 14 European countries. European railway system is one of the key areas of development towards sustainable transport. Therefore, it is important to perform cross-country efficiency evaluations and help decision makers to see how they stand relative to each other and who the best performing ones are. In this paper we demonstrate how DEA can help in this kind of analysis.

The paper is organized in following manner. Section two describes DEA models used in our study and the research sample. Results and discussion are presented in the section three. The final section gives concluding remarks and future research directions.

## 2. Methodology

### 2.1. CRS and VRS DEA models

Data Envelopment Analysis (DEA) is a linear programming technique that evaluates the relative efficiency of homogeneous units (called Decision Making Units – DMUs) by considering multiple inputs and outputs. DEA calculates the efficiency as a ratio of the weighted sum of outputs to the weighted sum of inputs. Efficiency in the DEA model is the concept of technical efficiency, which is the concept of relative efficiency that is determined through comparison with the units that form so called frontier. In other words, since it is impossible to measure absolute efficiency that is evaluated according to ideational datum point, it measures the degree of efficiency through comparison with reference set that has similar input and output structure.

For a given set of input and output variables, DEA produces a single comprehensive measure of performance (efficiency score) for each DMU. This is done by constructing an empirically based "best-practice" or efficient frontier as a result of identified set of efficient DMUs (on the frontier) and inefficient DMUs (not on the frontier). Inputs are resources used by a DMU while outputs can be products produced and/or performance measures of the DMU.

Depending on the type of frontier (i.e. envelopment surface) there are two types of DEA models - CRS model and VRS model. CRS model was proposed by Charnes, Cooper and Rhodes [11] and the basic idea of this model is to assume constant returns to scale (hence the name CRS, or alternatively CCR by the authors). CRS DEA model assumes that change in any product combinations is scaled up or down proportionally. The CRS assumption is only appropriate when all DMU's are operating at an optimal scale. Imperfect competition, constraints of finance, etc. may cause a DMU to be not operating at optimal scale. Banker, Charnes and Cooper [12] suggested an extension of the CRS DEA model to account for variable returns to scale situations (hence the name VRS, or alternatively BCC by the authors).

The use of the CRS specifications when not all DMU's are operating at the optimal scale will result in measures of technical efficiency (TE) which are confounded by *scale efficiency* (SE). The use of the VRS specification will permit the calculation of TE devoid of these SE effects.

Many studies have decomposed the TE scores obtained by CRS DEA into two components, one due to scale inefficiency and one to "pure" technical inefficiency [9]. This may be done by applying both CRS and VRS DEA using same data. If there is a difference in the two efficiency scores for a particular DMU, then this indicates that the DMU shows scale inefficiency, and that the scale inefficiency can be calculated from the difference between the VRS TE score and the CRS TE score as in (1). In other words, the CRS

technical efficiency measure is decomposed into "pure" technical efficiency (VRS efficiency) and scale efficiency.

$$\text{Scale efficiency (SE)} = \frac{\text{CRS eff.}}{\text{VRS eff.}} \quad (1)$$

DEA models can be applied in input or output orientation. Input-oriented technical efficiency measures keep output fixed and explore the proportion of the possible reduction in input usage, while output-oriented technical efficiency measures keep inputs constant and explore the possible proportional expansion in output quantities. Under CRS, the DEA results are the same whether an input orientation or an output orientation is specified. However, under VRS the two are not in general equivalent.

In our study we used both CRS and VRS model because it is hard to capture and be assured about stability of rail market conditions. European rail transportation is characterised by a high level of economic and territorial control since most rail companies are operating in a monopoly (as mostly in Europe, although deregulation is somewhat progressing) and not operating at optimal scale. We used the output-oriented model for evaluation of CRS and VRS efficiency because the idea was to analyze the possibility of increasing the outputs while keeping the current level of the inputs.

## 2.2. Strengths and limitations of DEA method

DEA can be a powerful tool when used wisely. A few of the characteristics that make it useful are: [2]

- DEA can handle multiple input and multiple output models.
- It doesn't require an assumption of a functional form relating inputs to outputs.
- DMUs are directly compared against a peer or combination of peers.
- Inputs and outputs can have very different units.
- DEA allows efficiency evaluation through the time

However, DEA has some limitations too, like:

- DEA is deterministic rather than statistical technique, and produces results that are particularly sensitive to measurement error (input and output specification and the size of the sample).
- DEA only measures efficiency relative to best practice within the particular sample. Thus, it is not meaningful to compare the scores between two different studies.
- DEA is good at estimating "relative" efficiency of a DMU but it converges very slowly to "absolute" efficiency. It reveals how well a DMU is doing compared to its peers but not compared to a "theoretical maximum".
- Since DEA is a nonparametric technique, statistical hypothesis tests are difficult and are the focus of ongoing research.
- Standard formulation of DEA creates a separate linear program for each DMU and can be computationally intensive.
- All efficient units are assigned with the same score (1.00) thus their further ranking is not possible.

To minimize the impact of DEA limitations we avoided unnecessary imputations of missing data which influenced the size of our country sample. To provide information on best performing unit i.e. rank the efficient ones, we relied on modified DEA model proposed by Petersen and Andersen [13]. This model enables the ranking of efficient units, by calculating the so called super-efficiency score. In order to rank the efficient units, Anderson and Peterson [13] suggested allowing the efficient units to receive a score greater than 1.000 by dropping the constraint that bounds the score of the evaluated unit k; namely the primary problem of unit k will be formulated as in (2-6):

$$(\max) h_k(\mu, \nu) = \sum_{r=1}^s \mu_r y_{rk} \quad (2)$$

subject to:

$$\sum_{i=1}^m \nu_i x_{ik} = 1 \quad (3)$$

$$\sum_{r=1}^s \mu_r y_{rj} - \sum_{i=1}^m \nu_i x_{ij} \leq 0, \text{ for } j = 1, \dots, n, j \neq k \quad (4)$$

$$\mu_r \geq \varepsilon, \quad r=1, 2, \dots, s \quad (5)$$

$$\nu_i \geq \varepsilon, \quad i=1, 2, \dots, m \quad (6)$$

where

- $y_{rj}$  is the amount of output r from unit j
- $x_{ij}$  is the amount of input i to unit j
- $h_k$  - the relative efficiency of the unit k;
- $n$  - number of DMU under analysis;
- $m$  - number of inputs;
- $s$  - number of outputs;
- $\mu_r$  - weight coefficient of output r;
- $\nu_i$  - weight coefficient of input i.

Super-efficiency model described above was used in our study to rank the efficient countries and identify best performing one. For DEA VRS, CRS and super-efficiency calculations we used EMS software.<sup>1</sup> Research sample of our study is described in the following section.

## 2.3. Data sample

We used three inputs and one output for DEA efficiency calculations. All the inputs and outputs are technical by nature, so possible effects of currency fluctuations are avoided. For inputs we decided on: length of lines in use (total route – km), number of wagons for goods transportation, number of employees. For output we used transport activity measured by freight ton – kilometres. Our selection of input and outputs is in line with the study done by Hilmola [5]. Electrification of rail network was also considered as an input but we excluded this indicator based on preliminary statistical analysis.

Efficiency was calculated for 14 European countries for the period 2005-2009. Data were obtained from EUROSTAT, International Transport Forum - ITF, International Union of Railways - UIC, and for Serbia from National Statistics Office.

Our first intention was to evaluate all European countries but many were excluded from the analysis because of the absence data, and (as we already mentioned) because of DEA's sensitivity to measurement errors. The results and the following discussion are presented in the next section.

## 3. Results and discussion

Results obtained by DEA CRS and VRS models are presented in Table 1. The table contains results for "pure" technical efficiency, scale and technical efficiency scores denoted by  $E_{VRS}$ ,  $E_{SE}$  and  $E_{CRS}$  respectively. Results of DEA super-efficiency model are presented in Table 2.

The results on DEA CRS efficiency showed that only Latvia was found to be technical efficient in all observed years. However, a number of countries were found to be efficient in case of DEA with VRS. Estonia, Latvia, Poland and Slovenia are the countries that were found to be efficient by VRS model in all observed years. Also, average index of VRS efficiency are better than average score on the CRS model.

<sup>1</sup> <http://www.holger-scheel.de/ems/#down>

Table 1: Efficiency scores ("pure" technical -  $E_{vrs}$ , scale -  $E_{se}$  and technical -  $E_{crs}$ ) for 14 European countries for 2005 - 2009

DMU	2005			2006			2007			2008			2009		
	$E_{crs}$	$E_{vrs}$	$E_{se}$	$E_{crs}$	$E_{vrs}$	$E_{se}$	$E_{crs}$	$E_{vrs}$	$E_{se}$	$E_{crs}$	$E_{vrs}$	$E_{se}$	$E_{crs}$	$E_{vrs}$	$E_{se}$
BE	3,87	2,70	1,43	3,11	2,27	1,37	3,12	2,26	1,38	3,41	2,45	1,39	4,99	3,24	1,54
HR	5,76	4,94	1,17	3,92	3,18	1,23	3,91	3,15	1,24	4,46	3,48	1,28	4,96	3,74	1,33
CZ	5,75	2,15	2,67	4,60	2,02	2,27	4,74	2,02	2,35	5,37	2,13	2,53	5,46	2,05	2,67
EE	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	1,74	<b>1,00</b>	1,74	1,18	<b>1,00</b>	1,18
FI	1,56	1,44	1,09	1,30	1,17	1,11	1,39	1,21	1,15	2,51	1,95	1,28	2,34	2,14	1,09
LV	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>
LT	1,33	1,32	1,01	1,08	1,07	1,01	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	1,04	<b>1,00</b>	1,04	1,48	1,39	1,06
PL	3,51	<b>1,00</b>	3,51	2,85	<b>1,00</b>	2,85	3,00	<b>1,00</b>	3,00	3,36	<b>1,00</b>	3,36	4,33	<b>1,00</b>	4,33
RS	6,76	5,84	1,16	4,05	4,01	1,01	3,78	3,63	1,04	4,18	3,96	1,06	5,97	5,77	1,03
SK	3,58	2,34	1,53	2,87	1,97	1,46	3,06	2,18	1,40	3,37	2,37	1,42	4,12	2,90	1,42
SI	3,07	<b>1,00</b>	3,07	2,54	<b>1,00</b>	2,54	2,57	<b>1,00</b>	2,57	2,83	<b>1,00</b>	2,83	3,06	<b>1,00</b>	3,06
ES	2,12	1,85	1,15	2,28	1,77	1,29	2,65	1,99	1,33	2,92	2,11	1,38	3,59	2,64	1,36
SE	1,04	<b>1,00</b>	1,04	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	<b>1,00</b>	1,52	<b>1,00</b>	1,52	1,51	1,05	1,44
TR	4,00	2,48	1,61	3,31	2,31	1,43	3,82	2,42	1,58	4,12	2,27	1,81	3,42	2,07	1,65
AVERAGE	<b>3,17</b>	<b>2,15</b>	<b>1,60</b>	<b>2,49</b>	<b>1,77</b>	<b>1,47</b>	<b>2,57</b>	<b>1,8</b>	<b>1,50</b>	<b>2,99</b>	<b>1,91</b>	<b>1,69</b>	<b>3,39</b>	<b>2,21</b>	<b>1,73</b>

Table 2: DEA super-efficiency scores in VRS terms for 2005 - 2009

2005			2006			2007			2008			2009		
RANK	Zemlja	VRS	RANK	Zemlja	VRS	RANK	Zemlja	VRS	RANK	Zemlja	VRS	RANK	Zemlja	VRS
1	LV	<b>0,42</b>	1	PL	<b>0,42</b>	1	PL	<b>0,43</b>	1	PL	<b>0,44</b>	1	PL	<b>0,44</b>
2	PL	<b>0,43</b>	2	LV	<b>0,51</b>	2	LV	<b>0,51</b>	2	LT	<b>0,90</b>	2	LV	<b>big</b>
3	SE	<b>0,91</b>	3	SE	<b>0,77</b>	3	SE	<b>0,82</b>	3	SE	<b>0,95</b>	3	SI	<b>big</b>
4	EE	<b>big</b>	4	EE	<b>big</b>	4	LT	<b>0,94</b>	4	LV	<b>big</b>	4	EE	<b>big</b>
5	SI	<b>big</b>	5	SI	<b>big</b>	5	SI	<b>big</b>	5	SI	<b>big</b>	5	SE	1,05
6	LT	1,32	6	LT	1,07	6	EE	<b>big</b>	6	EE	<b>big</b>	6	LT	1,39
7	FI	1,44	7	FI	1,17	7	FI	1,21	7	FI	1,95	7	CZ	2,05
8	ES	1,85	8	ES	1,77	8	ES	1,99	8	ES	2,11	8	TR	2,07
9	CZ	2,15	9	SK	1,97	9	CZ	2,02	9	CZ	2,13	9	FI	2,14
10	SK	2,34	10	CZ	2,02	10	SK	2,18	10	TR	2,27	10	ES	2,64
11	TR	2,48	11	BE	2,27	11	BE	2,26	11	SK	2,37	11	SK	2,90
12	BE	2,70	12	TR	2,31	12	TR	2,42	12	BE	2,45	12	BE	3,24
13	HR	4,94	13	HR	3,18	13	HR	3,15	13	HR	3,48	13	HR	3,74
14	RS	5,84	14	RS	4,01	14	RS	3,63	14	RS	3,96	14	RS	5,77

A country may be found to be efficient in terms of VRS while inefficient in CRS terms. This is due to the scale inefficiency. Poland is an example for this. It is found to be VRS efficient in all observed years but also inefficient in CRS and scale terms.

Average efficiency scores are lowest for the two last observed years (2008 and 2009). This may be seen as a consequence of some general economic conditions in this period.

One of the questions is to determine which country can be seen as the best performing one. The results on CRS efficiency highlight Latvia as the most successful one, but in terms of VRS more than one country showed efficiency (five countries in 2005 and 2006, six in 2007 and 2008, and four in 2009). To determine which one can be seen as the best practice exemplar in the sample, we decided to apply super-efficiency model in VRS terms. The results are summarized in Table 2.

Super-efficiency DEA allows the efficiency scores greater than 1.00 (i.e. less than 1.00 in case of output-oriented model) and it is also possible to rank countries by level of efficiency. Further discussion of ranks is related to the results of applied super-efficiency model.

Poland is a country with rank 1 in all observed years, except for 2005. Serbia is the last positioned in the observed populations through monitored years. The result of "big" in Table 2 means that the DMU remains efficient under arbitrary large decreased outputs.

However if we apply the same procedure (DEA super-efficiency) in CRS terms, Estonia (2005, 2006) and Latvia (2007-2009) stand out as best practice exemplars. This is due to scale efficiency included in CRS efficiency estimation.

General observation is that there is no significant difference in the estimation of the super-efficiency over the observed years. The first five and the last five countries are the same throughout the time. This suggests that the surveyed countries are to some extent stable in their performance. The reasons can be found in "fixed" nature of inputs and in the fact that rail sector requires great financial investments along with longer period for their activation. Results also indicate that there is a difference in the obtained efficiency scores between the EU member states and non-members.

Beside information on efficiency scores, DEA provides each inefficient unit (here seen as a country) with its corresponding benchmark (within so called efficiency reference set). This is an efficient country that is the closest to the projection of the inefficient one on the frontier. For example, DEA VRS highlights Latvia as a corresponding benchmark country for Serbia. However, the final decision on country 'to look up to' requires further and broader analysis. This means that some other criteria like sociology-demographic as well as geographical conditions must be taken into account. In the case of Serbia, the second suggested benchmark - Slovenia may be seen as better choice. However, it is up to policy maker to combine DEA results with some other indicators/criteria and decide which country can serve as a suitable benchmark.

#### 4. Conclusion

Efficiency is an important performance measure in rail freight transport. DEA methodology can help and support efficiency estimation in cross-country comparisons of rail freight transport. DEA super-efficiency model enables ranking efficient countries and determining the best performing one. Here we want to remind that

the estimated efficiencies are relative and depend on the selection of countries. We also want to emphasize that some additional inputs and outputs can improve the findings, like indicators on sector investments (for input) and revenues (output). This can be the subject of future research.

### Acknowledgment

This paper is part of the project "Critical infrastructure management for sustainable development in postal, communication and railway sector of Republic of Serbia", funded by the Ministry of Education and Science of the Republic of Serbia, Project number: TR36022.

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