Measuring Global Logistics Efficiency Using PCA-DEA Approach

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Original scientific paper
UDC: 005.21:658.7
DOI: 10.5937/tehnika1605733A

In situation of increasing global trade, concentration of production and economic crisis cause the increasing importance of freight transport and logistics. In that manner, economic performances of a country are very affected by logistics performances. Measuring efficiency of logistics activities on global level is important for all participants in international trade. This paper proposes the new methodology for measuring global logistics efficiency that integrates international and domestic indicators into single measure. The Principal Component Analysis – Data Envelopment Analysis (PCA-DEA) approach is used in this paper. Proposed approach is tested on a numerical example which consists of eight countries. According obtained efficiency scores observed countries are ranked. The paper also identifies the most important factors affecting the global efficiency. Several hypotheses are tested in this paper. The results show that the proposed approach can be used for evaluation of logistics activities at the global level.

Key words: *Efficiency, Logistics Performance Index, PCA –DEA approach*

1. INTRODUCTION

High logistics performances can improve accessibility to international flows and increase trade volume. In recent years, logistics has increasing importance in the organization of international flows. Logistics performances of all sectors influence on the economic growth and prosperity of a country [10].

Some authors stated that the role of logistics is not only to move products and materials but also to create competitive advantage by providing services which meet customer demand [8]. Logistics influences market demand effectively by creating customer satisfaction, sales and market share [22].

Efficiency is a very important indicator of operations analysis, and it is one of the basic and the most frequently used performances. Measuring, monitoring and improving efficiency are the main tasks for companies in the 21st century.

The importance of efficiency measuring in logistics has been recognized in litera ture [18]. In the process of winning new markets, the company gives special importance to logistics activities of the countries. The efficient logistics activities decrease logistics costs in goods or services purchased by end customers and also improve a country's access to international markets and increase the trade volume.

Quality and efficient activities can further help country to gain a competitive advantage over other countries on regional and international markets. In the international supply chains effectiveness and efficiency of country logistics systems are key factors of country success.

This paper investigates possibilities of measuring efficiency logistics activities in countries on the global level. Measuring and monitoring efficiency of the country logistics activities is important for domestic and for international logistics operators, as well for other entities. Efficiency measurement process follows a number of problems.

There is lack of papers in literature that analysis mentioned problems. A new approach for measuring efficiency on the global level based on PCA-DEA approach is proposed in this paper. Proposed model is tested on numerical example. Numerical example is based on the study of the World Bank [5]. According obtained efficiency scores the observed countries are ranked. The ranking scores are compared with the existing LPI approach. There is difference in the

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Paper received: 09.02.2016.
Paper accepted: 20.09.2016.

ranking of proposed approach and World Bank approach.

Next section gives a review of indicators used for measuring efficiency in logistics from different perspectives. Methodology for measuring Global Logistics Efficiency Index (GLEI) is given in the third section. In the section four proposed methodology is tested on numerical example. Hypotheses are also tested in section four. At the end of the paper, the concluding remarks and directions of future research are presented.

2. LITERATURE REVIEW AND HYPOTHESIS DEFINITION

In literature there are not enough papers that deal with logistics efficiency on global level. The importance of logistics activities in globalization era is recognized in literature [17], [20]. The importance of logistics in international trade flows is emphasizes in emphasizes in [9]. O'Connor (2010) investigates the importance of regions on city logistics activities using Global Logistics Index (GLI). The author also shows the impact of infrastructure on global city functions. An overview of the emerging transport geography of logistics and freight distribution is given in [12]. They also provide an analysis the relationship between logistics and the core dimensions of transport geography (flows, nodes/locations and networks). Some authors linking improvements in transport and logistics with improvements in import/export performances. Hummels (1999) estimates that exporters with 1% lower shipping costs have a 5-8 % higher market share. Limao and Venables (2001) find that differences in infrastructure quality account for 40 % of the variation in transport costs for the coastal countries and up to 60 % for the landlocked countries.

One of the most frequently used indicators of global logistics activities is Logistics Performance Index (LPI). This index was introduced in 2007 through the cooperation between the World Bank and academic partners. This is useful tool for estimation logistics friendliness of a particular country. The LPI measures trade logistics performance in the 155 countries. This index can help national leaders, key policymakers, and private sector traders understand the challenges in reducing logistical barriers to international commerce [5]. Trade logistics is an important element of country competitiveness. Freight transport and logistics industry represent one of the most dynamic and important sectors of the European economy, accounting for at least 10 percent of GDP. The international supply chains are strong only as its weakest link. The LPI survey is organized as questionnaire with two parts: international and domestic [5]. The international parts relate to six key areas of logistics performances and respondents foreign logistics professionals. In the domestic LPI respondents in more detail estimate the logistics environment in the countries where they work. The LPI is used in the literature as the basis of different approaches. Kim and Min (2011) measure the efficiency of the supply chain of a country from a green perspective by proposing the *Green Logistics* Performance Index (GLPI) combining the LPI and the Environmental Performance Index (EPI). Authors suggested GLPI as a good indicator of a country's green logistics efficiency, showing what impact the country's logistics competitiveness has on its environment. Lau (2011) defined composite index for measuring green logistics performances.

This approach is also based on the LPI. Global Logistics Efficiency Index is a new indicator that combines a number of partial indicators into a single measure. This indicator also integrates domestic and international LPI indicators in order to give better measure of logistics operations in particular country [3].

Logistics activity in particular country describes a large number of different indicators, and the problem is how to select relevant indicators which describe logistics activity in the best way. This is the basic problem in application the Data Envelopment Analysis (DEA) method, as one of the most frequently used methods for efficiency measuring [7]. In that manner, it is necessary to examine influence of various factors on the country logistics activity and to select the most important.

Depending on the perspective there are two groups of indicators: domestic (national) and international. Domestic indicators provide information describe logistics activities from the perspective of the local (domestic) entities.

On the other side international indicators come from foreign logistics and trade entities. To the best of our knowledge, there are no papers in the literature that integrate domestic and international indicators in single measure. In order to obtain the most relevant efficiency score it is necessary to include internal (domestic) and external (international) indicators.

As mentioned before one of the most frequently used methods for efficiency evaluation is DEA method. In situation of large number of different indicators and relatively small number of the Decision Making Units (DMUs) discriminatory power of the DEA models is low. In order to solve mentioned problems we proposed methodology based on the Principal Component Analysis – Data Envelopment Analysis (PCA-DEA) approach.

On the basis of the previously described three basic hypotheses are set in this paper:

H1: There is difference in ranking between proposed model and LPI scores

H2: Quality indicators have the greatest influence on the efficiency scores

H3: There is the difference in the efficiency scores between countries of EU and other countries

Efficiency scores of the proposed model are used for hypotheses confirmation.

3. MODEL DEVELOPMENT - GLOBAL LOGISTICS EFFICIENCY INDEX

The development of appropriate models for estimating DC efficiency is an iterative process. For each iteration it is necessary to analyze the obtained results. The model development methodology and its application for measuring the DC efficiency are shown in Figure 1.

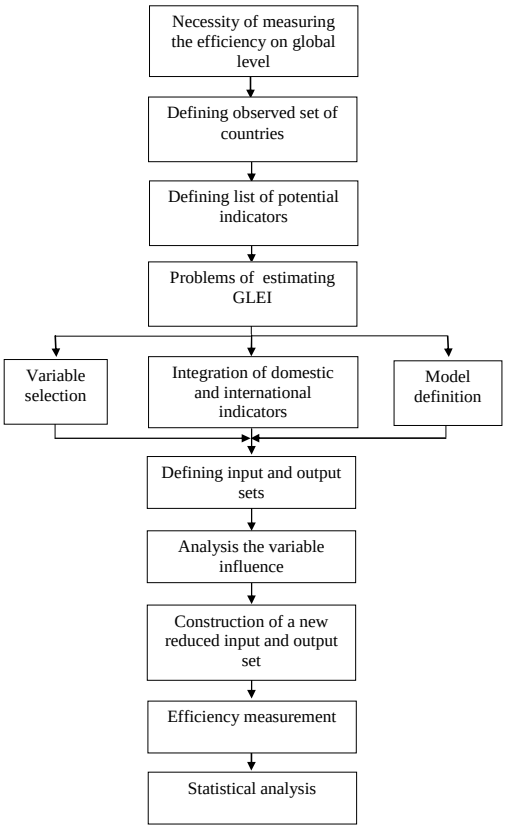

Figure 1 - Model development methodology

The figure shows the basic steps for the model development and solving the aforementioned problems. After recognizing the necessity of measuring the efficiency on the global level the set of observed countries is defined. The next step relates to defining the list of relevant indicators. In that sense we define fifteen indicators. Six of them are international while nine are domestics. All indicators are separated in two groups. The first international indicator relates to transport infrastructure. Roads, ports and railroads are very important for efficient logistics activities. The costs of arranging international shipments also have influence on logistics activities in particular country. The next international indicator is the speed, simplicity and predictability of customs procedures. Three mentioned international indicators are used as inputs in proposed approach. Quality of logistics services provided by logistics providers, transport operators, freight forwarding agencies, etc. are crucial for international trade flows. Timeless relates to shipments that reach the consignees within the scheduled or expected time. As timeless, ability track and trace shipments are also used as outputs in the proposed approach.

The group of domestic indicators has nine indicators. Eight of them are input, while one is output indicator. The only output indicator is the percent of quality correct shipments. Numerous factors affect quality of shipments in the international transport (theft, damage in transport, deterioration due inappropriate transport conditions, etc.). Lead time and export costs may greatly affect the efficiency of logistics activities. Number of import and export agencies and number of import and export forms influence the ease and speed of international goods flows. The physical inspection and multiple inspections significantly slow the customs clearance.

For overcoming the problem of variable selection PCA approach is used. The PCA is data reduction technique of multivariate data. The PCA explains the variance structure of a matrix of data through linear combinations of variables, consequently reducing the data to a few principal components (PCs), which generally describe 80-90% of the variance in the data [21]. If most of the population variance can be attributed to the first few components (dummy variables), then they can replace the original variables with minimum loss of information. After defining input and output variables the PCA was separately applied to eleven inputs and four outputs. In the reduced data set the influence is on the most influential variables

As mentioned, in the PCA the most of the population variance can be attributed to the first few components, so they can replace the original variables with minimum loss of information ([1], [2]). According to [11] a random vector $X=[X_1, X_2,\ldots, X_p]$ (the p is the number of original inputs/outputs chosen to be aggregated) has the correlation matrix C with eigenvalues $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_p \geq 0$ and normalized eigenvectors $l_1, l_2, \ldots, l_p$.

Consider the linear combinations, where the superscript t represents the transpose operator:

$$X_{PC_i} = l_i^t = l_{1i}X_1 + l_{2i}X_2 + \ldots + l_{pi}X_p, i = 1,2,\ldots, p \quad (1)$$

$$Var(X_{PC_i}) = l_i^t C l_i, i = 1,2,\ldots, p \quad (2)$$

$$Correlation(X_{PC_i}, X_{PC_k}) = l_i^t Cl_k,$$
$$for\ i = 1,2,...,p, k = 1,2,...,p, i \neq k \quad (3)$$

As mentioned before, the PCA ranks PCs in a descending order of importance. Alder and Golany (2002) set additional constraints that require the weight of PC_1 to be at least that of PC_2, the weight of PC_2 to be at least that of PC_3 and so on. The PCA–DEA model for DMU_a used in this paper has the following form [4]:

$$\max_{U_{PC}, V_{PC}} U_{PC} Y_{PC}^a \quad (4)$$

Subject to:

$$V_{PC} X_{PC}^a = 1 \quad (5)$$

$$V_{PC} X_{PC} - U_{PC} Y_{PC} \geq 0 \quad (6)$$

$$V_{PC}^t L_x \geq 0 \quad (7)$$

$$U_{PC}^t L_y \geq 0 \quad (8)$$

$$V_{PC}, U_{PC}, free \quad (9)$$

V_{PC} and U_{PC} represents vector of weights assigned to inputs and outputs PCs, while X_{PC} and Y_{PC} represent the input and output matrix, while L_x and L_y relate to the matrix of the PCA linear coefficients of input and output data.

4. CASE STUDY RESULTS

Model proposed in previous section is tested on the set eight countries. Namely, in this paper we analyze the Global Logistics Efficiency Index of the eight countries: Bosnia and Herzegovina, Bulgaria, Croatia, Hungary, Macedonia, Romania, Russia and Serbia.

List of indicators that are used in observed example are shown in Table 1.

Table 1. Indicators for efficiency evaluation [5]

	I/O[a]	International/ Domestic[b]	Bosnia and Herz.	Bulgaria	Croatia	Hungary	Macedonia	Romania	Russian Fed.	Serbia
Infrastructure	I	IN	0.35	0.31	0.30	0.32	0.38	0.40	0.41	0.38
International shipments costs	I	IN	0.36	0.32	0.31	0.28	0.41	0.32	0.36	0.33
Customs speed and simplicity	I	IN	0.28	0.28	0.28	0.29	0.36	0.26	0.33	0.32
Lead time	I	D	3	3	2	2	2	5	5	3
Export costs	I	D	474	1277	641	866	1500	1225	5000	1061
Import agencies	I	D	2	2	2	3	2	4	2	2
Export agencies	I	D	2	2	2	2	1	3	2	2
Import forms	I	D	3	2	2	2	6	4	8	5
Exports forms	I	D	3	2	2	2	5	4	8	3
Physical inspection (% of import shipments)	I	D	50	7	14	3	42	11	61	6
Multiple inspection (% of shipments physically inspected)	I	D	6	2	1	3	42	3	61	6
Quality of logistics services	O	IN	2.93	3.1	2.92	3.18	2.66	2.83	2.65	2.8
Timeliness	O	IN	3.61	3.56	3.54	3.41	2.79	3.82	3.02	3.14
Quality of shipments (%)	O	D	89	87	74	95	90	65	88	57
Tracking & tracing	O	IN	2.81	3.16	3.2	3.52	2.41	3.1	2.76	3.07

[a] I-Input; O-Output; [b] IN-International indicator; D-Domestic indicator

Input and output category is indicated in the second column. As mentioned before the proposed approach integrates the six international and the nine domestic indicators.

The values in Table 1 are result of interviews with domestic and international logistics providers who evaluate logistics performances of particular countries.

4.1. Principal component analysis scores

The first phase of efficiency measuring is the PCA application for all groups of inputs and outputs separately. From each group main components were selected. All extracted components explain minimum 80% of total variance of each group. The results of principal component analysis are presented in Table 2.

As indicated the second column of Table 2 there are 11 input and 4 output variables. The two PCs are extracted from the group of input indicators. They explain a vast of the majority of the variance in the original data matrices, since they explain 83.91%.

Table 2. PCA scores

Inputs	PC 1	PC 2
Infrastructure	0.77	0.46
International shipments costs	0.79	-0.33
Customs speed and simplicity	0.77	-0.50
Lead time	0.42	0.87
Export costs	0.82	0.29
Import agencies	-0.31	0.75
Export agencies	-0.40	0.90
Import forms	0.96	0.15
Exports forms	0.95	0.28
Physical inspection (% of import shipments)	0.82	-0.09
Multiple inspection (% of shipments physically inspected)	0.97	-0.06
Variance explained	57.58%	26.33%
Outputs		
Quality of logistics services	0.91	0.35
Timeliness	0.82	-0.24
Quality of shipments (%)	-0.06	0.98
Tracking & tracing	0.92	-0.07
Variance explained	58.88%	28.92%

In the first PC which explains more than 57% of total variance number of import and export forms, physical inspection and multiple inspections have the greatest influence (Table 3). Slightly lower impact has the infrastructure, costs of international shipments and customs speed and simplicity. In that manner it can be concluded that in the first component greater importance have domestic than international indicators. In the second PCs domestic indicators (lead time and number of export agencies) are dominant.

On the output side two PCs are also extracted which explain 87.8% of total variance. Quality of logistics services and track and trace are dominant in the first PC which explain almost 59% while quality of shipments is dominant in the second PC. The first output PCs relates to international indicators, while the second relates to domestic indicators.

4.2. Efficiency scores

The second phase of efficiency measurement process is the PCA-DEA model for evaluating efficiency. The classical DEA models cannot be applied in this case. They do not have sufficient discriminatory power, considering the fact that almost all DMUs are efficient.

The LPI scores have some shortcomings. The LPI scores presented in the fourth column of Table 3 are based only on six international indicators. In order to obtain real measure of the GLEI of country it is necessary to include domestic and international measures.

Model described in this paper overcome shortcomings of the previous approaches (Table 3).

Table 3. Efficiency scores according different approaches

DMU	Benchmarks according PCA–DEA model	DEA model	LPI[a] score	PCA DEA model
Bosnia and Herzegovina	Hungary-0.85204,Croatia-0.070745	1	3.21 (1.00)	0.792147
Bulgaria	Hungary-0.67849,Croatia-0.30778	1	3.17 (0.99)	0.941696
Croatia	Croatia-1	1	3.16 (0.98)	1
Hungary	Hungary-1	1	3.00 (0.93)	1
Macedonia, FYR	Hungary-0.85897	1	2.99 (0.93)	0.667816
Romania	Hungary-0.94283	1	2.80 (0.87)	0.723258
Russian Federation	Hungary-0.86065	0.98	2.58 (0.80)	0.474099
Serbia	Croatia-0.69616,Hungary-0.23028	1	2.56 (0.80)	0.734125
	Average	1.00	0.91	0.79
	Standard deviation	0.01	0.08	0.18
[a]*(LPI normalized score)*				

The PCA DEA model simultaneously improves discrimination power of the standard DEA model and integrates domestic and international indicators. In the observed set two countries are efficient, Croatia and

Hungary. It roughly means that these countries have the best combination of inputs and outputs. The GLEI of Bulgaria is 0.94 and it significant higher than other countries. The lowest efficiency score has the Russia. This consequence of high cost and large number of import and export forms. The Serbia is also inefficient with the efficiency under average score. A low efficiency score is the result of relatively low logistics quality and competence as well as relatively low % of the shipments that meeting quality (only 57%).

4.3. Hypotheses testing

In this section three hypotheses are tested. The fist hypothesis investigates the differences in LPI proposed approach rankings. In that sense the next hypothesis is defined:

H1: There is difference in ranking between proposed model and LPI scores

In order to test this hypotheses rank correlation is used. According p (0.125>0.05) value there is now significant correlation between compared approaches. This also means that the PCA–DEA ranking is different from the LPI rankings.

In recent years, quality indicators in logistics have become important. The Influence of quality indicators on efficiency scores is recognized in literature. In this paper we defined and tested next hypothesis:

H2: Quality indicators have the greatest influence on the efficiency scores

According Table 3 in both output PCs quality indicators are dominant. Namely quality of logistics services has the correlation coefficient 0.91 in the first PC, while quality of shipments 0.98 in the second output PC. This confirms hypothesis that quality indicators have the greatest influence on the efficiency scores. This is in accordance with the results presented in [4].

It is assumed that the EU countries are more efficient than other countries. Next hypothesis is formulated:

H3: There is the difference in the efficiency scores between countries of EU and other countries.

Table 4. Hypotheses tests statistics

H3	Mann-Whitney (α=0.05)
U	4.5
Z	-0.9
Asymp. Sig. (2-tailed) - *p*	0.393
	Kolmogorov - Smirnof (*α*=0.05)
Z	0.639
Asymp. Sig. (2-tailed) - *p*	0.809

In order to test previous hypotheses the non-parametrical Mann-Whitney and Kolmogorov-Smirnof tests are used (Table 4). In observed example tests indicate whether the efficiency scores differ between subgroups.

The results are relatively unexpected and can be explained with relatively small set of countries. The EU countries in this case are Bulgaria, Rumania and Hungary. These countries are the less developed the EU members with a relatively undeveloped infrastructure and logistics in general. It is important to note that results relate only to observed example and they are not general.

5. CONCLUSIONS

In order to improve trade flows and country economies it is necessary to measure, monitor and improve efficiency of logistics activities. The main problem is how to select, from a large number of indicators, those that best describe the logistics activity of a country. Model proposed in this paper combines domestic and international logistics performances in single measure of efficiency.

In order to investigate the importance of indicators the PCA method is used. It was observed that qualitative indicators, such as quality of the logistics services and quality of the shipments, are more important than other indicators. As mentioned, this paper is one of the first that develop the efficiency metric that assesses both environmental and logistics performances of the country from a global perspective. The central part of the proposed methodology is the efficiency measurement model. In observed example the standard DEA models that are commonly used in literature could not be applied.

The PCA–DEA approach is used in order to improve the discriminatory power of model. This model provides useful information about the benchmarks, as well as potential improvements of inefficient countries. Proposed model can be used for evaluation of logistics activities at the global level and improves existing approaches.

Three hypotheses are set in this paper. In the first hypotheses we confirm that there is significant statistical difference in ranking between proposed model and LPI scores developed in [4]. The discriminatory power of the proposed model is higher than the compared model. In second hypothesis we confirm that quality indicators are very important for the global efficiency measurement. The third hypotheses investigated difference in efficiency scores between countries of the EU and other countries. In the observed example there is no significant statistical difference between mentioned groups. It is important to note that the

results of three hypotheses are not general and relates only to observed example, but they are a good guideline for further research.

The proposed model represents good basis for the new models development. In future research is desirable to extend the observed set. It is also possible to use the proposed approach for analysis the efficiency change in time.

In future research it is also necessary to define appropriate corrective measures for efficiency improving.

5. ACKNOWLEDGMENT

This paper was supported by the Ministry of Science and Technological development of the Republic of Serbia, through the project TR 36006, for the period 2011 – 2015.

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REZIME

MERENJE GLOBALNE LOGISTIČKE EFIKASNOSTI PRIMENOM PCA-DEA PRISTUPA

U situaciji rasta globalne trgovine, koncentracije proizvodnje i ekonomske krize značaj logistike i transporta u međunarodnoj robnoj razmeni je sve veći. Logističke performanse u velikoj meri utiču na ekonomske performanse zemlje i regiona. Ovo se pre svega ogleda kroz povezanost određenog područja sa međunarodnom mrežom teretnih tokova. Merenje efikasnosti logističkih aktivnosti pojedinih zemalja značajno je sve učesnike u međunarodnoj trgovini. U ovom radu predložena je nova metodologija koja objedinjuje domaće i međunarodne pokazatelje u jedinstvenu meru efikasnosti. The Principal Component Analysis – Data Envelopment Analysis (PCA-DEA) pristup je korišćen u ovom radu. Predloženi pristup je testiran na numeričkom primeru koji čini skup od osam zemalja. Na osnovu dobijenih efikasnosti izvršeno je rangiranje zemalja. U radu su takođe identifikovani osnovni faktori koji utiču na globalnu logističku efikasnost. U radu je testirano više hipoteza. Rezultati pokazuju da se predloženi pristup može uspešno koristiti za ocenjivanje logističkih aktivnosti na globalnom nivou.

Ključne reči: *efikasnost, LPI, PCA-DEA pristup*