Available online at http://ijim.srbiau.ac.ir/
Int. J. Industrial Mathematics (ISSN 2008-5621)
Vol. 10, No. 3, 2018 Article ID IJIM-00965, 8 pages
Research Article

Network Data Envelopment Analysis Models For Measuring Efficiency Of a Four-Stage Supply Chain With Returned Outputs

M. Vaez-Ghasemi *†, Z. Moghaddas ‡, B. Rahmani Parchekolaee §

Received Date: 2016-10-30 Revised Date: 2017-09-27 Accepted Date: 2017-10-22

Abstract

In this paper, while data envelopment analysis (DEA) technique has been used, four-stage DEA model mooted in order to consider the situation in which there exist returned products. These products are neither final products nor inputs of the next sub-process. These returned products are the inputs of previous sub-processes that need to be processed again due to existence of flaws. Here a supply chain with four stages as supplier, manufacture, distributor and retailer with intermediate and return products has been considered and a DEA model formulated for analyzing it. Also, with an application validity of the proposed model has been demonstrated.

Keywords : Data Envelopment Analysis; Supply chain; Returned products; Efficiency.

1 Introduction

In competitive market what gains an important attention, for those firms would like to increase quality and decreasing costs, is selecting the best supplier. Thus in any supply chain management supplier selection is a fundamental aspect. Any supply chain can be managed from different methods. Therefore, many companies try to better evaluate and select suppliers.

As stated in literature, DEA is a mathematical based technique for performance evaluation of a set of Decision Making Units (DMUs) which use multiple resources to produce multiple outputs. One of the first models presented in this technique has been discussed in the CCR paper by Charnes et al. [4], and then this model developed by various researchers, as what banker et al. [1] have done. This method computes the relative efficiency of a set of DMUs.

In literature many researches considering supply chain and other techniques, to address a few consider the following.

In a paper Cakravastia et al. [2], for designing a supply chain network, developed an analytical model of the supplier selection process. It needs to note that the constraints on the capacity of each potential supplier are considered in the process.

In their paper Castro-Lacouture et al. [3] addressed the purchase of construction materials as the last component in the supply chain.

Xu et. al [10] studied the supply chain perfor-

*Corresponding author. Mohsen.vaez@gmail.com, Tel: +(98)9128168162

†Department of Mathematics, Rasht Branch, Islamic Azad University, Rasht, Iran.

‡Department of Mathematics, Qazvin Branch, Islamic Azad University, Qazvin, Iran.

§Department of Mathematics, Central Tehran Branch, Islamic Azad University, Tehran, Iran.

mance evaluation of a furniture manufacture industry. Moreover, they have identified them a in uncertainty factors affecting evaluation process, and using our rough data envelopment analysis (RDEA) formulate and analyze them. Also, they have created rough DEA by integrating classical DEA and rough set theory.

Lee and Farzipoor Saen [7] provided a new model, based on data envelopment analysis technique, for performance evaluation of corporate sustainability. They employed cross efficiency in the presence of dual role factors. Thus, introduced a new model for measuring corporate sustainability management. Their findings made a great contribute in literature of corporate sustainability management.

Kuo and Lin [6] presented a supplier selection method. The provided method considers considers green indicators due to environmental protection issues, while utilizing data envelopment analysis (DEA) and also analysis network process (ANP). The important feature of presented model is that it can provide accurate results while considering a few DMUs.

As discussed formerly DEA is a mathematical technique for performance evaluation of set of DMUs with multiple inputs and outputs. It needs to be noted that presence of units with conflicting data make evaluation more complex thus a technique with great ability is needed. Supply chain (SC) performance evaluation is also a complex problem, involving various criteria therefore due to this fact considering DEA for evaluating such problem is suitable. In DEA literature there exist models considered for undesirable or bad outputs in production system. Lozano [9] provided a linear model for assessing a general network with bad outputs foe efficiency evaluation of each stages, overall efficiency, and target DMUs. Liu et. al. [8] constructed a two-stage DEA models with undesirable indexes.

Khalili-Damghani and Shahmir [5] considered undesirable outputs into model formulation as well as uncertainty in data and proposed approach for efficiency assessment.

In this paper a new network models for achieving correct efficiency of a supply chain with four stages as supplier, manufacture, distributor and retailer with intermediate and return products is presented. Bad, and undesirable outputs are considered in evaluation process in theory and reseach in different fields, in this study one of great feature is considering returned output as this is very common in real world problems. Returned outputs are those outputs need to be repaired they are not bad or undesirable. These kind of outputs are neither final outputs nor independent inputs, they are intermediate output of a sub-process that need to be processed again, thus considered as inputs.

The current article proceeds as follows: At first some preliminaries about DEA and supply chain have been reviewed. In section 3 the main idea has been mooted, in section 4 an application of the proposed model has been performed for clarity. Section 5 concludes the paper.

2 DEA Priliminaries

Data envelopment (DEA) is a mathematical based programming for assessing a set of homogenous Decision Making Units (DMUs). Charnes et. al. [4] presented the fundamental model, called CCR after the name of the authors, which considers constant returns to scale technology. After that many DEA models have been presented each of which deals with specific issues and helps managers for better decision making. While considering DEA technique DMUs are classified into two subsets, efficient and inefficient DMUs. Those DMUs performs efficiently construct DEA frontier, through a comparison prossed with which relative efficiency of other units, those inefficient ones that are not located onto this frontier, obtained. Moreover, those efficient DMUs located onto the frontier can also be considered as benchmark units. In regard of these benchmarks managers can better guide system in future.

Considering basic assumptions of DEA and assume there exist a set of n DMUs with m inputs and s outputs to be evaluated. It should be noted that in DEA assumptions it is assumed that the input and output vectors are all semipositive.

As formerly discussed CCR model is as follows:

$$\begin{array}{ll} \min & \theta - \varepsilon(1S^- + 1S^+) \\ s.t. & X\lambda + S^- = \theta X_o, \\ & Y\lambda - s^+ = Y_o, \\ & \lambda \geq 0. \end{array} \tag{2.1}$$

The dual of the above model which is called multiplier form is as follows:

$$\begin{array}{ll} \max & U^t Y_o \\ s.t. & V^t X_o = 1, \\ & U^t Y_j - V^t X_j \leq 0, \quad \forall j, \\ & U \geq 0, \quad V \geq 0. \end{array} \tag{2.2}$$

In the above- mentioned model v and u are the input and output weight vectors.
Both of the aforesaid models are in input orientation where the input reduction is due to maximized. The above models can be written in output orientation where the output shortfall is due to minimized.

2.1 Supply Chain Management

Consider figure 1 in which the famous buyer-seller supply chain is depicted. In regards of this chain X_A is the input vector of the seller, and Y_A is corresponding output vector. Consider Y_A and X_B as the input vector of the buyer and Y_B as the output vector the buyer.
In accordance to the above mentioned information suppose there exist n such supply chains. The CCR DEA efficiency of the supply chain is measured as what has been provided by Charnes et. al. [4]:

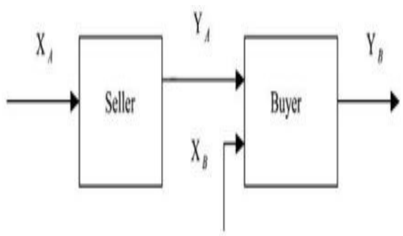

Figure 1: A DMU with two processes

$$\begin{array}{ll} \max & \frac{U^t\ Y_{Bo}}{V^t\ (X_{Ao},\ Y_{Bo})} \\ s.t. & \frac{U^t\ Y_{Bj}}{V^t\ (X_{Aj},\ Y_{Bj})} \leq 1, \quad \forall j, \\ & U \geq 0, V \geq 0. \end{array} \tag{2.3}$$

In this model U and V are corresponding weights of outputs and inputs, respectively.
As indicated in Zhu [11], model (2.3) suffers from describing the performance of supply chains accurately. The reason is that in this model only inputs and outputs of the supply chain have been accounted for and it pays no attention to Y_A related to supply chain members. In order to remove such difficulty Zhu [11] considered Y_A as input of the buyer and output of the seller. Moreover, he discussed that for better analyzing the system, supply chain, efficiency of each individual supply chain members needs to be computed. As it is obvious, performance of the whole system relates to performance of each and every members. A supply chain would be efficient in which all of the members performs efficiently. Now consider the following model in which the average efficiency of the buyer and seller considered as the objective function. The objective of this model is to maximize average efficiency of the buyer and seller, while each of the inequality constraints control efficiency of each member not to exceed one.

$$\begin{array}{ll} \max & \frac{1}{2}\left(\frac{U_A^t\ Y_{Ao}}{V_A^t\ X_{Ao}} + \frac{U_B^t\ Y_{Bo}}{V_B^t\ (X_{Bo}, X_{Ao})}\right) \\ s.t. & \frac{U_A^t\ Y_{Bj}}{V_A^t\ X_{Aj}} \leq 1, \quad j = 1, ..., n,, \\ & \frac{U_B^t\ Y_{Ao}}{V_B^t\ (X_{Bo}, X_{Ao})} \leq 1, \quad j = 1, ..., n,, \\ & U_A \geq 0, V_A \geq 0, \quad U_B \geq 0, V_B \geq 0. \end{array} \tag{2.4}$$

One important issue about this model is that although it considers Y_A, as output of the seller and input of the buyer, it attributed different weights for it. When Y_A is an input, corresponding value is defined by V_B and when it considered as output, corresponding weigh is U_B. Under such circumstances supply chain operation would

not be accurately considered.
In following section a DEA model will be presented in which relation between stages as well as performance of the chain has been considered accurately.

3 Network DEA for Supply chain

In order to obtain the efficiency of a supply chain, a general case of a supply chain with four stages, as portrayed in Figure 2, has been accounted for.
For better managing supply chains, efficiency of each supply chain should be considered and these measures should be considered as a criterion for selecting the best chain. This means if a supply chain is active in previous periods, then according to its efficiency further decisions for making changes should be made. Along with, if a chain performs inefficiently, then reasonable decisions should be taken for continuing cooperation with this unit. In doing so a mathematical model based on DEA technique provided for efficiency evaluation of a supply chain with four stages. Moreover, inn presented model every cases which may happen in a supply chain have been accounted for. Thus in this case it is possible to make minor changes in order to use it for other problems. Therefore, for every stages inputs, intermediate products and returned output have been considered. In reality, return from the distributor to manufacture is a common happening. As depicted, in Figure 2, a return as the output of the distributor to be the input of manufacture has been considered.
Assume that each of the units has sub process like the following figure. In the above figure X is the input vector and Z_o are the output vectors of the supplier. Z, Z_I and L_r are the input vectors (L_r is the return product from distributor), K and K_o are the outputs of the manufacture. K and K_I are the input vectors, L, L_o and L_r are the output vectors of the distributor. In the retailer L and L_I are the input vectors and Y is the output vector. It should be paid attention that each sub process can have outputs considered as the output of the system and it can have inputs from the previous section and those which can be considered as independent inputs.
Assume there exist a DMU with four stage series

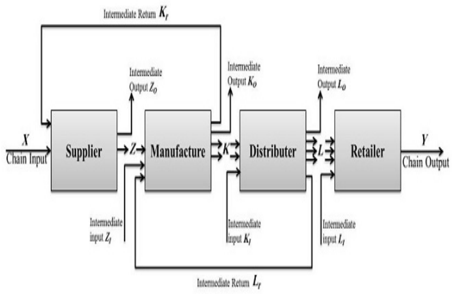

Figure 2: A Four-stage supply chain.

structural sub-processes (members). Consider a four-stage process as shown in Figure 1. In this system Y is the final output, Z^o, K^o and L^o are the outputs of the first, second and third sub-processes, respectively. Moreover, X is the input of the first subprocess, Z^I, K^I and L^I are the inputs of the second, third and fourth sub-processes, respectively. Meanwhile, let us assume that in the third subprocess the produced output divided into L^o and L^R. Where, L^o is the produced output of the third subprocess that can be used or even sold and it can be viewed as the output of the system. L^R is an output which should be returned to be processed again thus is considered as the input of the second stage. Also, as depicted in Figure 1, in the second sub-process the produced output divided into K^o and K^R. Considering the second sub-process, K^o is the produced output of which can be used or even sold, moreover, it can be viewed as the output of the system. K^R is an output returned to be processed again thus is considered as the input of the first stage. Therefore, efficiency score relates to each subprocess and aggregate efficiency will be obtained via the following equations.

$$
\begin{aligned}
e_p^1 &= \frac{WZ_p+W^oZ_p^o}{VX_p+\mu^RK_p^R}, \\
e_p^2 &= \frac{\mu K_p+\mu^oK_p^o-\mu^RK_p^R}{WZ_p+W^IZ^pI+\lambda^RL_p^R} \\
e_p^3 &= \frac{\lambda L_p+\lambda^oL_p^o-\lambda^RL_p^R}{\mu K+\mu^IK_p^I} \\
e_p^4 &= \frac{UY_p}{\lambda L_p+\lambda^IL_p^I} \\
e_p^a &= \frac{WZ_p+W^oZ_p^o+\mu K_p+\mu^oK_p^o-\mu^RK_p^R+\lambda L_p+\lambda^oL_p^o-\lambda^RL_p^R+UY_p}{VX_p+\mu^RK_p^R+WZ_p+W^IZ^pI+\lambda^RL_p^R+\mu K+\mu^IK_p^I+\lambda L_p+\lambda^IL_p^I}
\end{aligned}
\tag{3.5}
$$

As regards to the above-mentioned definitions the relative efficiency score of DMU_p will be obtained by solving the following model:

$$Max \quad e_p^a =$$

$$\frac{WZ_p+W^oZ_p^o+\mu K_p+\mu^o K_p^o-\mu^R K_p^R+\lambda L_p+\lambda^o L_p^o-\lambda^R L_p^R+UY_p}{VX_p+\mu^R K_p^R+WZ_p+W^I Z^p I+\lambda^R L_p^R+\mu K+\mu^I K_p^I+\lambda L_p+\lambda^I L_p^I}$$

$$e_j^a =$$

$$\frac{WZ_j+W^oZ_j^o+\mu K_j+\mu^o K_j^o-\mu^R K_j^R+\lambda L_j+\lambda^o L_j^o-\lambda^R L_j^R+UY_j}{VX_j+\mu^R K_j^R+WZ_j+W^I Z_j^I+\lambda^R L_j^R+\mu K+\mu^I K_j^I+\lambda L_j p+\lambda^I L_j^I}$$

$$\leq 1, \quad j=1,......,n, (a)$$

$$e_j^1 = \frac{WZ_j+W^oZ_j^o}{VX_j-\mu^R K_j^R} \leq 1, \qquad j=1,.....,n,$$

$$e_j^2 = \frac{\mu K_j+\mu^o K_j^o-\mu^R K_j^R}{WZ_j+W^I Z^j I+\lambda^R L_j^R} \leq 1, \quad j=1,......,n,$$

$$e_j^3 = \frac{\lambda L_j+\lambda^o L_j^o-\lambda^R L_j^R}{\mu K+\mu^I K_j^I} \leq 1, \qquad j=1,......,n,$$

$$e_j^4 = \frac{UY_j}{\lambda L_j+\lambda^I L_j^I} \leq 1, \qquad j=1,......,n,$$

$$V \geq 1\varepsilon, \quad U \geq 1\varepsilon,$$

$$W \geq 1\varepsilon, \quad W^o \geq 1\varepsilon, \quad W^I \geq 1\varepsilon,$$

$$\lambda \geq 1\varepsilon \quad \lambda^o \geq 1\varepsilon, \quad \lambda^I \geq 1\varepsilon, \quad \lambda^R \geq 1\varepsilon,$$

$$\mu \geq 1\varepsilon, \quad \mu^o \geq 1\varepsilon, \quad \mu^I \geq 1\varepsilon. \tag{3.6}$$

Theorem 3.1 *The aggregate efficiency of DMU_p is equal to one if and only if efficiency score of each sub-processes of DMU_p equals one.*

Proof. As regards to this fact that the aggregate efficiency score is the convex combination of the efficiency scores of sub-processes, which means:

$$\exists\bar{\lambda} \geq 0; \quad e_p^a = \bar{\lambda_1} e_p^1 + \bar{\lambda_2} e_p^2 + \bar{\lambda_3} e_p^3 + \bar{\lambda_4} e_p^4$$

where

$$\bar{\lambda_1} + \bar{\lambda_2} + \bar{\lambda_3} + \bar{\lambda_4} = 1$$

thus:

$$e_p^a = 1 \Leftrightarrow e_p^1 = 1, e_p^2 = 1, e_p^3 = 1, e_p^4 = 1$$

According to what has been proved it is evident that in the following model the bundle of constraints (a) are redundant. Therefore, it is possible to be omitted, and corresponding linear counterpart of this model will be as follows:

$$Max \quad e_p^a =$$

$$UY_p + W^oZ_p^o + \mu^o K_p^o + \lambda^o L_p^o + WZ_p + W^oZ_p^o + \mu K_p + \mu^o K_p^o - \mu^R K_p^R + \lambda L_p + \lambda^o L_p^o - \lambda^R L_p^R + UY_p$$

$$S.t \quad VX_p + \mu^R K_p^R + WZ_p + W^I Z^p I + \lambda^R L_p^R + \mu K + \mu^I K_p^I + \lambda L_p + \lambda^I L_p^I = 1,$$

$$e_j^1 = WZ_j + W^oZ_j^o - VX_j - \mu^R K_j^R \leq 0, \quad j=1,.....,n,$$

$$e_j^2 = \mu K_j + \mu^o K_j^o - \mu^R K_j^R - WZ_j - W^I Z^j I - \lambda^R L_j^R \leq 0, \quad j=1,......,n,$$

$$e_j^3 = \lambda L_j + \lambda^o L_j^o - \lambda^R L_j^R - \mu K - \mu^I K_j^I \leq 0, \quad j=1,......,n,$$

$$e_j^4 = UY_j - \lambda L_j - \lambda^I L_j^I \leq 0, \quad j=1,......,n,$$

$$V \geq 1\varepsilon, \quad U \geq 1\varepsilon,$$

$$W \geq 1\varepsilon, \quad W^o \geq 1\varepsilon, \quad W^I \geq 1\varepsilon,$$

$$\lambda \geq 1\varepsilon \quad \lambda^o \geq 1\varepsilon, \quad \lambda^I \geq 1\varepsilon, \quad \lambda^R \geq 1\varepsilon,$$

$$\mu \geq 1\varepsilon, \quad \mu^o \geq 1\varepsilon, \quad \mu^I \geq 1\varepsilon. \tag{3.7}$$

4 Numerical example

As regards of what has been discussed above and the provided models the main portray of the problem is as portrayed in Figure 2. This is a example consists of four stages. Each stage received its inputs from the previous stage and moreover has an independent input as well. According to this application it means that manufacture supply raw materials from the supplier, which is the output of the previous stage. Moreover, it should obtain specific inputs as jacks, fixtures, human resource and other costs as intermediate inputs. Furthermore, returned products of distributors, in production line, should be considered as raw material. Also, Wastes of manufacture or returned raw materials in production step of manufacture will return to supplier.

In regards of mentioned situations the problem will be as follows. Consider Table 1 through 4, in which corresponding data of supplier, manufacture, distributor and retailer have been gathered.

Table 1: First stage data (Supplier)

	X	Z_o	Z	Z_I	K_R
	Input	*Output*	*Output*	*Output*	*input*
1	0.18	12.05	52.38	1125	20.39
2	0.17	11.94	22.88	1192	24.37
3	0.18	12.08	45.00	1344	15.88
4	0.06	12.09	22.05	1489	13.93
5	0.19	11.99	43.70	420	16.39
6	0.21	13.54	48.30	333	1.10

Table 2: Second stage data (Manufacture)

	Z	Z_o	L_r	K		K_o	K_R
				K_1	K_2		
	Input	Input	Input	Output		Output	Output
1	52.38	12.05	0.0768	571	1325	83	20.39
2	22.88	11.94	0.0111	501	1183	56	24.37
3	45.00	12.08	0.0148	537	1222	49	15.88
4	22.05	12.09	0.0043	394	904	35	13.93
5	43.70	11.99	0.0176	904	395	30	16.39
6	48.30	13.54	0.0183	395	333	9	1.10

Table 3: Third stage data (Distributor)

	K	K_I	L_O	L			L_r
				L_1	L_2	L_3	
	Input	*Input*	*Output*	*Output*			*Output*
1	1325	0.0319	0.0313	0.2893	0.0325	0.2396	0.0768
2	1183	0.0361	0.0341	0.4540	0.0321	0.2000	0.0111
3	1222	0.0334	0.0325	0.2600	0.0341	0.2100	0.0148
4	904	0.0341	0.0332	0.3320	0.0312	0.2930	0.0043
5	395	0.0339	0.0325	0.4450	0.0343	0.2420	0.0176
6	333	0.0350	0.0337	0.7900	0.0374	0.3400	0.0183

By using above data and model (3.5) we can calculate aggregate efficiency of chain and the result of this model is listed as below.

As we mentioned above, aggregate efficiency of a network is a convex combination of each stage efficiency and this aggregate efficiency will be efficient if and only if, all of stages be efficient, separately. Consider any DMU, by improving corresponding inefficient stages, it is possible to improve aggregate efficiency of a chain. In order to analyze a supply chain efficiency score of each stage needs to be computed, separately, to investigate the extend of inefficiency of each chain. Here, you can see each stage efficiency scores separately in below table.

Table 4: Forth stage data (Retailer)

	L	L_I	Y
	Input	Input	Output
1	2.80	20	3.60
2	2.80	20	3.60
3	2.80	20	3.60
4	2.80	20	3.60
5	2.80	20	3.60
6	2.35	28	3.68

Table 5: Aggregate result

Chain1	Chain2	Chain
0.9839	0.9699	0.9401
Chain4	Chain5	Chain6
1.0000	0.9666	1.0000

Table 6: Stages efficiencies

Supply Chain	1	2	3
Supplier	0.8	0.47	0.71
Manufacture	1.00	1.00	0.95
Distributor 3	0.99	0.6	0.98
Retailer	1.00	1.00	1.00
Supply Chain	4	5	6
Supplier	1.00	0.67	1.00
Manufacture	1.00	1.00	1.00
Distributor 3	1.00	0.98	1.00
Retailer	1.00	0.86	1.00

As indicated in Table 6, units 4 and 6 performs efficiently. These units perform efficiently in all stages of supply chain and thus corresponding aggregate efficiencies are also equal to 1. Also, in regards of corresponding data it is clear that units 4 and 6 have much fewer returns in comparison to other units. Unit 4 has fewer returns from the distributor and unit 6 has fewer returns form manufacture in comparison to other units. Noted that these returns are considered as undesirable outputs thus have direct affect in efficiency of supply chain.

On the other hand, units 1, 2, 3 and 5, respectively, gain best aggregate efficiency which can be easily analyzed due to inefficiency of different stages of the chain.
In supply chains, inefficiency in the first stages ia much more better than in final ones. In fact, inefficiency in the first stages of a supply chain can be easily removed and improved by decreasing inputs. Indeed, if distributor is inefficient it must decrease its input more than the increase of manufacture output thus inputs of distributor will be decreased. On the other hand, for increasing efficiency by increasing the output, it must increase its output and also decrease undeniable returned output which does not lead to an increase in returned input for manufacture. Noted that increasing output of distributor will result in increasing the input of retailer. Thus this increase must be performed to the extent which does not decrease the efficiency of retailer. As discussed above, it is better to have inefficiency in the firsts stages of a supply chain which can be improved with less complexity.
Analyzing other chains can be performed likewise. In deed, inefficiency in a chain s depends on the type of operations that take place within it. Considering the proposed model it is possible to investigate stage and aggregate efficiencies accurately. Having such information it is possible to make changes and improvements in a supply chain.

5 Conclusion

As stated formerly performance evaluation of a set of supply chains by DEA model had a lot of errors. Some models are provided for overcoming such difficulty. In this paper the aim is to formulate a model which can deal with real world problems. Here a model presented which evaluate efficiency of a supply chain along with efficiency scores of corresponding four sub-processes (members). Here a supply chain with four stages as supplier, manufacture, distributor and retailer with intermediate and return product has been considered. Moreover, as it is so common in reality, returned outputs are also incorporated in presented model. This is the case that may happen frequently. With an application the ability of presented model has been demonstrated. Also, for further discussion can develop this model by share inputs and outputs.Benchmarking for an inefficient chain or subprocess can be one of the further discussions.

References

[1] R. D. Banker, A. Charnes, W. W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis, *Manag Sci* 30 (1984) 1078-92.

[2] A. Cakravastia, Isa S. Tohab, N. Nakamur, A two-stage model for the design of supply chain networks, *Int. J. Prod Econ* 80 (2002) 231-248.

[3] D. Castro-Lacouture, A. L. Medaglia, M. Skibniewski, Supply chain optimization tool for purchasing decisions in B2B construction marketplaces, *Autom in Const* (2006)

[4] A. Charnes, W. W. Cooper, E. Rhodes, Measuring the efficiency ofdecision making units, *Euro J of Oper Res* 2 (1978) 429-444.

[5] Kaveh Khalili-Damghani, Zohreh Shahmir, Uncertain network data envelopment analysis with undesirable outputs to evaluate the efficiencyof electricity power production and distribution processes Author links open overlay panel, *Comp* & *Indus Eng* 88 (2015) 131-150.

[6] R. J. Kuo, Y. J. Lin, *Int J of Prod Res* 50 (2012) 2852-2863.

[7] K. Lee, R. Farzipoor Saen, Measuring corporate sustainability management: A data envelopment analysis approach. *Int J of Prod Econo* 140 (2012) 219-226.

[8] W. Liu, Z. Zhou, C. Ma, D. Liu, W. Shen, Two-stage DEA models with undesirable input-intermediate-outputs, *Omega* 56 (2015) 74-87.

[9] S. Lozano, Slacks-based inefficiency approach for general networks with bad outputs: An application to the banking sector, *Omega* 60 (2016) 73-84.

[10] J. Xu, B. Li, D. Wu, Rough data envelopment analysis and its application to supply chain performance evaluation, *Int. J.Produ Econ.* 112 (2009) 683-699.

[11] J. Zhu, Quantitative Models for Performance Evaluation and Benchmarking: Data Envelopment Analysis with Spreadsheets, *Boston: Kluwer Academic Publishers* (2003).

Mohsen Vaez-Ghasemi is an assistant professor at the Department of Mathematics, Rasht Branch, Islamic Azad University, Rasht, Iran. His research interests include operation research and data envel opment analysis.

Zohreh Moghaddas is an assistant professor at the Department of Mathematics, Qazvin Branch, Islamic Azad University, Qazvin, Iran. Her research interests include operation research and data envelopment analysis.

Bijan Rahmani Parchikolaee is an assistant professor at the Department of Mathematics, central Tehran Branch, Islamic Azad University, Tehran, Iran. Her research interests include operation research and data envelopment analysis.