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Comparison of the Efficiency of Power Transmission Companiesin the Electric Power Industry of Iran Applying Conventional and Network Data Envelopment Analysis Methods

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Abstract

This study is an applied study conducted to evaluate and compare the efficiency of Iran's regional power companies using conventional and network Data Envelopment Analysis methods. Iran's regional power companies use two- phased process to transmit power. Using applied approach, the performance and efficiency of these companies were measured with network and conventional methods, and they were compared with each ther (input-oriented BCC). It was indicated that network models have wider application compared with other method since it provides vivid picture of the efficiency of regional power companies. The Wilcoxon test result shows there is significant difference between efficiency scores of Iran's regional power companies using BCC and network methods, and investigation of the quality of difference of scores also indicate that efficiency of companies in the network model is lower than efficiency scores of BCC model. In general, network models have higher application than to provide a vivid picture of the efficiency of regional electricity companies and more accurate comparison of them.

Keywords:
Performance evaluation
Efficiency
Network Data Envelopment Analysis
Iran's Electricity Industry
Regional Electricity Company

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INTRODUCTION

Power industry is the main part of economic development of countries, and rate of production and consumption of electrical energy represents an important index of economic growth and quality of life in communities. In terms of investment, power industry requires investment and based on the predictions, global investment in the production and supply of electricity includes two-thirds of the total investments in the energy supply area. The role of this industry in the establishment of economic activities is so significant that is known as the mother industry in most countries. Having these features, widespread use of electricity in all areas of human life, and its outstanding characteristics compared with other forms of energy require special attention at the global and national level (Ahmadi Movager, 2008).The importance of electrical energy and its role in development and flourishing of the country is so that governments have considered this industry as one of the infrastructure industries. By providing one of the most important forms of energy, electric industry plays an undeniable role in the flourishing of national economies of countries. Power has some advantages over other kinds of energy including the relatively easy transmission to distant areas, ease of distribution to subscribers and conversion to other forms of energy (Khosravi & Shahroodi, 2014). In general, an interrelated and complex electric power system consists of three main parts: generating stations, transmission lines and distribution of energy (Sueyoshi & Goto, 2012). Based on Iran's electricity industry, the companies of power production management are responsible for energy production and electric power distribution companies are responsible for electricity distribution. Regional electricity companies perform this task through the posts, power transmission lines and transmission to electrical power distribution companies through sale of energy in the electricity market of Iran (Monenco Iran, 2013). Given the importance of these companies to supply reliable and sustainable power, the statistics of factors related to the performance of this section in Iran suggests the low level of productivity compared with developed countries and even many developing countries (Khosravi & Shahroodi, 2014). A small percentage increase in the ability to better operation of power transmission networks leads into enormous savings. This suggests the high importance of the efficiency and productivity of factors involved in the electricity industry.Performance measurement has always been considered as one of the most important methods to evaluate the performance and efficiency or productivity of a company. Efficiency indicates that how much an organization has been able to use of its resources in line with production in a specified period. In other words, the efficiency is the degree of use of resources to produce a certain amount of product (Mehreghan, 2014). First step in improving efficiency is "measurement". Measuring the efficiency and productivity provides the conditions so that managers can know that in which positions they are, and they can design to improve the current situation (Emami Meibodi et al., 2009).Data envelopment analysis (DEA) is one of the nonparametric methods to measure efficiency and it is one of the most widely used methods (Kwon et al., 2016). DEA method is based on optimization approach using linear programming and it is used for relative measurement of Decision Making Units (DMU) that performs the same duties (Ma et al., 2017). Due to nature of the multi-phase nature of power transmission process, data envelopment analysis of network models was used to measure the efficiency of internal processes of regional electricity companies.Network models permit researchers to investigate the internal processes and working procedures of decision-making units, in addition to the overall efficiency of each DMU (Chen & Yan, 2011). Later, the obtained results of study were compared with result of efficiency of units by network models through calculating the calculation of the efficiency of Iran's regional power companies by conventional DEA (input-oriented BCC) models.

THEORETICAL FOUNDATUONS OF THE STUDY

Farrell (Farrell, 1957) determined the efficiency using non-parametric method for the first time. Then, Charnes et al (Charnes et al., 1978) generalized nonparametric method of Farrell for multiple inputs and outputs using mathematical design. Since that time, "data envelopment analysis" is referred to set of developed models of mathematical design in this regard. The model of Charnes, Cooper and Rhodes where output to scale is supposed to be constant, is known as CCR model (Kwon et al., 2016). Then, Banker et al (Banker et al., 1984) generalized the CCR method for variable scale that their model is known as BCC. The aim of DEA is to determine the efficacy of a system or decision-making unit through the process of transforming of inputs into outputs. In other words, the aim is to identify the units that obtain the maximum output from the minimum input. Such an unit in which efficiency is equal to one is known as working unit and other units in which efficiency is between zero to one are known as non-working units. DEA allows the managers have an accurate evaluation of his units and make the correct and logical decisions to optimized allocation of resource (Shahriari et al., 2013; Wang et al., 2016).

One shortcoming of traditional DEA models from the researchers perspective is that investigators is that these models are considered as closed set and the process within the system, performance, and relationship between them are overlooked.

This approach, known as "black box", loses a lot of valuable information about the decision-making units (DMU) and limits the efficiency analysis DMUs to primary inputs and final outputs (Ma et al., 2017; Fare & Grosskopf, 2009; Tone & Tsutsui, 2010; Fukuyama & Weber; Kao, 2009; Kao & Hwang, 2008; Castelli et al., 2004; Liang et al., 2006). In fact, the traditional models of data envelopment analysis face with problem in calculating the efficiency of complex systems and multi-phase processes that have middle sizes, and these models cannot calculate the efficiency of each of the internal processes correctly (Chen & Yan, 2011). Therefore, the measurement of efficiency by conventional methods of DEA may prevent us to access to valuable management information. The fundamental point is that many decision-making units have compound and various structures that type of structure and performance of these components has an impact on system efficiency. In fact, there are decision-making units in the real world in which manufacturing process can be considered as two-phase or multiple-phase process. In addition, several number of internal processes that may exist within DMUs to convert primary inputs to final output. While in the conventional models, inputs are used to produce outputs, without any attention to relationships of the internal parts of unit (Cook et al., 2010).In order to solve this problem, Fare and Grosskopf (Fare & Grosskopf, 2000) pointed out to weakness of conventional DEA model and introduced "network DEA" and they noted its importance in more accurate analysis of DMUs. This model considers a decision-making unit and its all subunits and relationships as a network structure. In this model, it is assumed that under the evaluation system includes several decision-making units, that each unit consists of several interrelated subunits (Salehzadeh et al., 2011). Since network models allow the investigation of internal processes of each decision-making unit, these models provide more accurate picture of efficiency of DMUs. In the traditional models of DEA, when each decision-maker unit has internal processes, the efficiency of internal processes and the whole process is calculated independently. While in the network models, the constraints of internal processes are added to the total process limitation, so the total efficiency score will be lower than efficiency score of internal processes. Thus, using network models are explaining the relationship between total efficiency and the efficiency of internal processes appropriately. However, in the conventional models, the efficiency of each of internal processes and the total process are measured independently. (Momeni, 2011؛ Shahkhah, 2011).

Model of study

To measure the efficiency of regional power companies by conventional method of DEA, input-oriented BCC was used, and in order to measure the efficiency by network method, network model of Li et al. (2012) was used Fig.1.

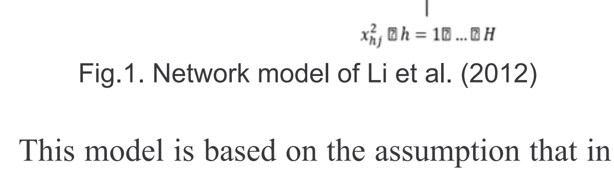

Fig.1. Network model of Li et al. (2012)

This model is based on the assumption that in a two-phase process structure, one of the phases is very important for management of organization. Li et al introduced this phase as "leader" and the other as "follower". Given the higher importance of the leader, the efficiency of this phase must be calculated and maximized firstly. Then, according to efficiency of the leader, the efficiency of follower stageis also determined. For example, if consider stage 1 in the as the leader, the efficiency of this unit is calculatedfrom the following equation:

$$
\begin{aligned}
e_1^{o*} = max \sum_{d=1}^{D} w_d z_{do} \\
s.t. \quad \sum_{i=1}^{m} v_i x_{io} = 1 \\
\sum_{d=1}^{D} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \quad \forall j \\
v_i, w_d, Q_h, u_r \ge 0, \forall i, d, h, r
\end{aligned} \qquad (1)
$$

And the efficiency of the second phase is calculated from the following equation:

$$
\begin{aligned}
e_2^{o*} = max \sum_{r=1}^{s} u_r y_{rj_o} \\
s.t. \quad \sum_{d=1}^{D} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \quad \forall j \\
\sum_{r=1}^{s} u_r y_{rj} - \sum_{h=1}^{H} Q_h x_{hj}^2 - \sum_{d=1}^{D} w_d z_{dj} \le 0 \quad \forall j \\
\sum_{h=1}^{H} Q_h x_{ho}^2 + \sum_{d=1}^{D} w_d z_{do} = 1 \\
\sum_{d=1}^{D} w_d z_{do} - e_1^{o*} \sum_{i=1}^{m} v_i x_{io} = 0 \\
v_i, w_d, Q_h, u_r \ge 0, \forall i, d, h, r
\end{aligned} \qquad (2)
$$

Some steps were taken to choose this model in measuring the efficiency of procedures and internal processes of regional electricity companies: in the first step, the provided models were studied and investigated in the field of network data envelopment analysis, including models of (Fare &Grosskopf, 2000), (Kao, 2009), (Cook et al., 2010), (Chen & Yan, 2011) and (Li et al., 2012). Then, mission and objectives, tasks and work processes of regional electricity companies were studied and the adaptation ofwork processes of regional electricity companies were examined by mentioned network models. Finally, the views of professors of the university who have expertise in the field of data envelopment analysis were, and by summarizing these cases, model of Li et al. (2012) was recognized that have higher adaptation with the process of transmit of power by regional electricity companies and this model was used in this study.

MATERIALS AND METHODS

This study examines the efficiency of the transmission of power in the electricity industry of Iran. Data used in this study related to the performance of Iran's regional electricity companies in 2014 and the information was derived from "Statistical Yearbook of Iran's electricity industry" (the transmission of power section) and "Summarized report of the position of electricity industry (for managers)" have been derived.

Determination of input and output variables of regional electricity companies

Selection of input and output variables is one of the most important steps in evaluating the efficiency of efficiency by using data envelopment analysis. In other words, lack of proper selection of variables makes the results invalid. For these reasons, three important points were considered in the selection of inputs and outputs In this study: 1. The variables used in previous studies regarding the evaluation of efficiency of electricity industry in the world 2. Accessibility and collect data of variables 3. Using the views of the power industry experts and senior experts in this area

Based on what was said above and conclusions of previous studies and the possibility of collecting data and considering the opinions of experts and specialists in the power industry, the input and output variables of this study are presented in Table 1.

Based on what was said above and considering the introduced variables, two-phase process of electrical power transmission and the relationship between input and output variables is based on Fig. 2.

Table 1: Input and Output Variables of the Study

Type of Variable	Phase No.	Name of Variable
Input	1st phase	Cost of power transmission plans (Million Rial)
Input	1st phase	Number of plan and development staff (person)
Input	2nd phase	Capacity of current transformers (MVA)
Input	2nd phase	Length of current network (km)
Input	2nd phase	Total number of staff (person)
Mean	1st phase-2nd phase	Increase in the capacity of transformers (MVA)
Mean	1st phase-2nd phase	Increase in the length of the network (km)
Final-Output	2nd phase	The amount of energy delivered (Million KWH)

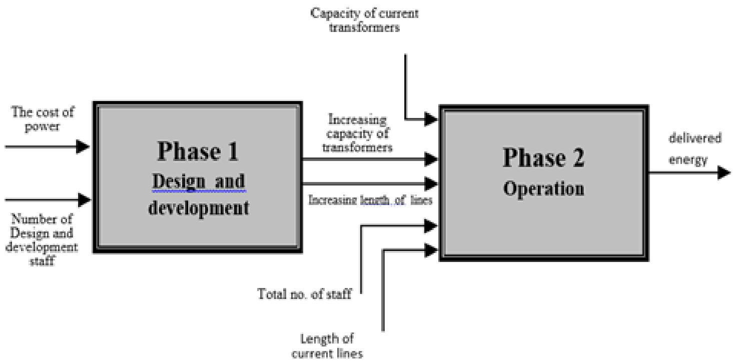

Fig.2. The Two-phase Process of Power Transmission

RESULTS OF STUDY

Results of study were presented in two sections of calculation of the company's efficiency and comparing the efficiency with network and conventional methods of data envelopment analysis through statistical hypothesis test.

Calculation of efficiency

By solving the linear programming model for regional power companies in the relations (1) and (2), their efficiency percentage is determined in each phases of design and development and operation based on Table 5. In the Table 2, the efficiency of each company has been specifiedat

Table 2: efficiency of Regional Electricity Companies

Name of company	First phase design and development		Second phase operation	
	BCC	Network	BCC	Network
Regional Electricity of Azarbayejan	0.81	0.82	0.88	0.79
Regional Electricity of Isfahan	1	1	1	1
Regional Electricity of Bakhtar	0.71	0.53	1	1
Regional Electricity of Tehran	0.34	0.34	1	1
Regional Electricity of Khorasan	0.27	0.17	1	1
Regional Electricity of Khouzestan	0.16	0.16	1	0.98
Regional Electricity of Zanjan	1	1	1	1
Regional Electricity of Semnan	1	1	1	0.95
Regional Electricity of Sistan	0.37	0.32	1	0.65
Regional Electricity of West	0.43	0.32	0.90	0.87
Regional Electricity of Fars	1	0.72	0.67	0.67
Regional Electricity of Kerman	1	1	1	1
Regional Electricity of Guilan	0.51	0.46	1	1
Regional Electricity of Mazandaran	0.38	0.37	0.92	0.83
Regional Electricity of Hormozgan	1	1	0.85	0.83
Regional Electricity of Yazd	0.69	0.50	1	0.90

Table 3: Ranks

Stage 1		N	Mean Rank	Sum of Ranks
	Negative Ranks	10[a]	6.50	65.00
	Positive Ranks	1[b]	1.00	1.00
Network - BCC		5[c]		
	Ties	16		
	Total			

a. stage1 Network < stage1 BCC
b. stage1 Network > stage1 BCC
c. stage1 Network = stage1 BCC

Table 4: Test Statistics[a]

	Network - BCC
Z	-2.845[b]
Asymp. Sig. (2-tailed)	.004

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

each phase of design, development, and operation by network and BCC models.

The results of efficiency of companies in the first phase (network model) suggest that the phase of design and development of the regional electricity company of Zanjan, Semnan, Kerman and Hormozgan, has an efficiency of 100 percent. In the second phase, the results also indicate that the operation phase of the regional electricity companies of Isfahan, Bakhtar, Tehran, Khorasan, Zanjan, Gilan, and Kerman have100% efficiency. In the first phase (design and development) of regional electricity companies of Zanjan, Semnan, Kerman and Hormozgan obtained thehighest rank and Khorasan and Khuzestan companies obtained the lowest rank. Additionally, in the second phase (operation,regional electricity companies of Isfahan, Bakhtar, Tehran, Khorasan, Zanjan, and Gilan Kerman, who have the efficiency of one, obtained the highest rank and the regional electricity companies of Fars and Sistan and Baluchestan showed the weakest performance.

Efficiency results of companies in the first phase (the BCC) shows that the design and development of the regional electricity company of Zanjan, Semnan, Iran, Fars, Kerman and Hormozgan has an efficiency of 100 percent. In the second phase, BCC model results also indicate that the operation phase of regional power companies Isfahan, Bakhtar, Tehran, Khorasan, Khuzestan, Zanjan, Semnan, Sistan and Baluchestan, Kerman, Yazd Gilan has 100% efficiency.

Statistical hypothesis test to compare the efficiency of companies

To compare the efficiency of Iran's regional power companies by network and BCC methods, the Wilcoxon test was used and the hypothesis that "efficiency scores in two of Iran's regional power companies are different in two methods of BCC method and network method" was tested.

Wilcoxon test result in the first phase (design and development) is shown in Table 3.

Significance level of Wilcoxon test (0.004) in the first phase (design and development) shows that there is significant difference between efficiency scores of Iran's regional power companies in BCC and network methods. Examination of the quality also indicates that efficiency scores of the design and development unit of companies in the network model is lower than efficiency scores of the BCC model. In addition, the Wilcoxon test result in the second phase (operation) is shown in Table 4.

Significance level of Wilcoxon test (0.008) in the second phase (operation) shows that there is significant difference between efficiency scores of Iran's regional power companies in BCC and network methods. Examination of the quality also indicates that efficiency scores of the design and development unit of companies in the network model is lower than efficiency scores of the BCC model.

Table 5: Ranks

Stage 1		N	Mean Rank	Sum of Ranks
	Negative Ranks	9[a]	5.00	45.00
	Positive Ranks	0[b]	.00	.00
Network - BCC		7[c]		
	Ties	16		
	Total			

a. stage1 Network < stage1 BCC
b. stage1 Network > stage1 BCC
c. stage1 Network = stage1 BCC

Table 6: Test Statistics[a]

	Network - BCC
Z	-2.666[b]
Asymp. Sig. (2-tailed)	.008

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

CONCLUSION

This study was investigated to compare the efficiency of power transmission companies in Iran's electricity industry using network and conventional methods of data envelopment analysis. The efficiency of Iran's regional power companies was calculated in two separate units of design and development as first unit and operation as second unit. To measure the efficiency by network method, network model of Li et al. (2012) was used, and to calculate the efficiency by conventional method, BCC model was used. The results of the efficiency measurement of regional power companies show that the mean of efficiency in the first phase (design and development) was 0.6 in the network model, while it was 0.67 in the conventional (BCC) method. The efficiency mean of of second phase (operation) was 0.9 in the network model, while it was 0.95 in the conventional (BCC) method. Therefore, efficiency scores are lower in the network model than conventional method. Additionally, in the first phase, results of network model show that 31% of companies are efficient, while the efficiency of companies increased to 38% in the BCC method. In the second phase, the number of efficient companies in the network model increased from 43% to 69% in the conventional model, which indicates that the conventional models shows more companies as efficient than network models. The obtained results were confirmed regarding the difference between the efficiency scores of network method and BCC method by Wilcoxon test that is one of the non-parametric tests to measure the difference between two groups of data. This means that in both units of design and the development and operation, Wilcoxon test result shows that there is significant difference between efficiency scores of Iran's regional power companies using BCC network and network methods. Additionally, investigation of the quality difference shows that the efficiency scores of the companies in the network model is lower than efficiency scores of BCC model. The results are in line with theoretical foundations of research that suggest that network method tend to show efficiency of companies lower. It can be recommended for regional power companies that they can use network of DEA to measure the efficiency of operational units since network models provide vivid and closer picture of efficiency of companies for each separate unit.

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