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Efficiency Analysis of Paper Mill Using Data Envelopment Analysis Models (Case Study: Mazandaran Wood and Paper Company in Iran)

M. Zadmirzaei[1*], S. Mohammadi Limaei[1], and A. Amirteimoori [2]

ABSTRACT

In this study, the relative performance of Mazandaran Wood and Paper Company as a major supplier of paper products in Iran was measured. Network Data Envelopment Analysis (DEA) models with parallel structure were used to evaluate and measure its performance. GAMS software version 23.4 was used for data analysis. Results indicated that this company in all studied years had good performances based on the parallel DEA models. Also, according to the same models with parallel structure, 2007 and 2008 had better efficiency score than the other years. Finally, results indicated that, using the cross efficiency models, the company had the best performance in 2007. This result could be due to the input-oriented nature of the models. Consequently, by proper management and optimum consumption of the resources, the company had the best performance in 2007.

Keywords*:* DEA, Ranking model, Parallel production, Paper product.

INTRODUCTION

There are a few paper mills in Iran that produce paper from raw material supplied from Iranian natural forests and Mazandaran Wood and Paper Company (MWPC) is the most important and the biggest one. On the other hand, per capita consumption of cardboard and paper is 15-16 kg per year in Iran (Sepidehdam, 2003). Therefore, with regard to the rate of population growth in Iran and increase in per capita consumption of paper products, we expect that consumption of paper products will rapidly increase in the future. Hence, the important role of the MWPC as a great supplier of paper products in Iran could not be ignored. This company produces different kinds of paper and its production was about 180,263 tons in 2010 (Securities and Exchange Organization of Iran, 2010). With respect to increasing paper demand in the future, success of this company can be probably developed by new technology and products. Therefore, it should promote its products output via increasing the performance of its production units. To achieve this aim, measuring the performance of different production units is a rational approach. Performance assessment techniques that can usually be used for this purpose are divided into parametric and non-parametric methods.

Parametric methods can be used to evaluate the efficiency of production units that have one output or, if they have more than one, they can be converted into each other such as stochastic frontier production function and profit function method that are used to estimate the technical efficiency and to determine factors which influence the efficiency of

[1]Department of Forestry, Faculty of Natural Resources, University of Guilan, Islamic Republic of Iran.
*Corresponding author; email: majid.zadmirzai@gmail.com
[2]Department of Mathematics, Faculty of Science, Islamic Azad University, Rasht Branch, Islamic Republic of Iran.

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firms (Dhehibi *et al.*, 2014). On the other hand, non-parametric methods are used to evaluate the relative efficiency of similar units using mathematical techniques as well. This approach does not need to estimate the objective function; also, there are no problems for evaluating the relative efficiency if the units have several outputs.

In this regard, one of the non-parametric methods is Data Envelopment Analysis (DEA). Mathematically, DEA is a Linear Programming (LP)-based methodology for evaluating the relative efficiency of a set of Decision Making Units (DMUs) with multi-input and multi-output. DEA evaluates the efficiency of each DMU relative to an estimated production possibility frontier determined by all the DMUs. The advantage of using DEA is that it does not require any assumption on the shape of the frontier surface and it makes no assumptions concerning the internal operations of a DMU (Emrouznejad and Tavana, 2014).

Since DEA was first introduced in 1978 in its present form, researchers in a number of fields have quickly recognized that it is an excellent and easily used methodology for modeling operational processes for performance evaluations. This has been accompanied by other developments (Cooper *et al.*, 2011). It means DEA is receiving increasing importance as a tool for evaluating and improving the performance of manufacturing and service operations. It has been extensively applied in performance evaluation and benchmarking of schools, hospitals, bank branches, production plants, etc. (Charnes *et al.*, 1978).

There are some studies dealing with DEA application to forest industries in different countries. DEA models can easily incorporate inputs and outputs without any market values (Vahid and Sowlati, 2007). Kao and Yang (1991 and 1992) were the first people who used DEA to measure the efficiency of forest industries. Their research began to establish new branches in performance studies in forestry development in future, for example, (Joro and Viitala, 1999; Bogatoft *et al.*, 2003; Korkmaz, 2011; Mohammadi Limaei, 2012) in forest management, (Lebel and Stuat, 1998; Hailu and Veeman, 2003) in forest logging, (Fotiou, 2000; Nyrud and Baardsen, 2003; Salehirad and Sowlati, 2005) in sawmilling, (Salehirad and Sowlati, 2007 and Vahid and Sowlati, 2007) in wood-product manufacturing, (Yin, 2000; Hailu and Veeman, 2001) in pulp and paper factories. All previous attempts have used this non-parametric approach in the forest management area.

The aim of this research was to determine and evaluate the performance of MWPC because of the important role of this company in manufacturing pulp and paper products in Iran. To the readers' knowledge, this work is the first research regarding the application of DEA models using parallel structure model in forest industries in Iran.

MATERIALS AND METHODS

Data Collection

Data was collected from the financial balance sheets and profit and loss page of the company. Six production lines including paper, printing and writing paper, white kraft liner, brown kraft liner, paper fluting line1, and paper fluting line 2 were considered. Inputs and outputs data for each product line including fixed and variable costs, net sales, and gross profit were collected during 6 years. In details, fixed cost is an expense that does not change with an increase or decrease in the amount of goods or services produced. Fixed costs are expenses that have to be paid by a company, independent of any business activity and in this study it comprises insurance, maintenance costs, employees' salary, equipments depreciation cost, direct overhead cost (i.e. an accounting term that refers to all ongoing business expenses not including or related to direct labor, direct materials or thirdparty expenses that are billed directly to customers). Variable cost is a corporate expense that varies with production outputs. Variable costs are those costs that vary depending on a company's production volume; they rise as production increases and fall as production decreases and it includes raw material cost (logs, wood pulp etc.), electricity consumption cost, fuel and gas consumption cost, indirect overhead cost i.e. it is any overhead cost that is not part of overhead. Thus, indirect overhead is not directly related to a company's production of goods or provision of services to customers. Also, in this study, net sale is an obtained income from selling different kinds of papers per year and gross profit is an interest without levying tax on sales. Afterwards, the nominal monetary data was converted to real data using the Consumer Price Index (CPI) in the base year 2004 (Central Bank of Iran, 2010). Therefore, the real or adjusted data was used to evaluate the performance of the company (Table 1).

Models

Network DEA Models with Parallel Structure

Decision maker unit includes a set of components with the same inputs that produce the same outputs, such as MWPC with different units each of which act independently. It means that the inputs and outputs of each company is the sum of inputs and outputs of all its production units. The general case is a parallel production system k with q number of production units, where each production unit p (p= 1, . . ., q) converts inputs X_{ik}^{p}, (i= 1, . . . , m), into outputs Y_{rk}^{p}, (r= 1,. . . , s), independently. The sums of all X_{ik}^{p} over p, $\sum_{p=1}^{q} X_{ik}^{p}$ and all Y_{rk}^{p} over p, $\sum_{p=1}^{q} Y_{rk}^{p}$, are the inputs X_{ik} and

Table 1. Adjusted inputs and outputs data from 2005 to 2010 (Iranian million Rials).

Units	Inputs/Outputs	2005	2006	2007	2008	2009	2010
Paper	Fixed cost	81304.35	52858.3	47448.7	42062.19	11515.76	19344
	Variable cost	237536.2	154429.1	138625.9	122887.1	33644.83	56515.34
	Net sale	398550.7	259109.3	254896.7	225958	53762.56	91396.58
	Gross profit	79710.14	51821.86	68822.16	61008.73	8601.97	15537.25
Printing and writing	Fixed cost	130.43	117.41	857.73	1595.2	4095.07	11965.38
	Variable cost	536.23	485.02	3541.04	6585.92	16906.4	49394.83
	Net sale	833.33	753.04	6025.3	11207.31	25001.97	73928.13
	Gross profit	166.66	150.61	1626.54	3026.19	4000.49	12567.92
White kraft liner	Fixed cost	86.05	89.88	82.08	1111.84	523.64	29.36
	Variable cost	432.06	425.91	385.09	5241.68	2467.49	138.475
	Net sale	613.22	644.53	640.22	8703.76	3561.08	202.01
	Gross profit	122.28	128.74	173.05	2350.24	569.95	34.18
Brown kraft liner	Fixed cost	5965.58	6274.49	5690.15	5338.79	6526.11	10237.51
	Variable cost	24628.62	25901.21	23488.37	22040.92	26941.87	42263.37
	Net sale	38242.75	40219.43	39970.59	37506.27	39842.86	63254.16
	Gross profit	7648.55	8043.72	10792.07	10126.57	6374.88	10753.29
Fluting line (1)	Fixed cost	6652.17	7433.2	6503.42	11171.3	5275.86	7883.44
	Variable cost	19434.78	21716.6	19000.68	32636.66	15413.79	23032.43
	Net sale	32608.7	36437.25	34937.07	60010.91	24630.54	37248.03
	Gross profit	6521.74	7287.5	9432.97	16202.95	3940.89	6332.16
Fluting line (2)	Fixed cost	59869.57	66898.79	58531.46	60863.61	58024.63	57009.64
	Variable cost	174913	195449.4	171004.8	177817.2	169523.6	166557.4
	Net sale	293478.3	327935.2	314433	326960.2	270890.6	269358
	Gross profit	58695.65	65587.04	84896.72	88279.32	43342.36	45790.97

outputs Y_{rk} of the system, respectively.

The traditional DEA measures the performance of a DMU in terms of efficiency and the performance can also be measured from the deficiency viewpoint. As inefficiency $(1-E_k)$ is the complement of efficiency (E_k). The objective is to minimize inefficiency and the deficiency of DMUk is $1-\sum_{r=1}^{s} ur\, Y_{rk}$ that is equal to the slack (S_k) in $\sum_{r=1}^{s} ur\, Y_{rk} - \sum_{i=1}^{m} v_i\, X_{ik} + s_k = 0$. $\sum_{i=1}^{m} v_i\, X_{ik}$ is equal to the traditional model. Hence, the traditional DEA model is equivalent to the following model (Kao, 2009):

$$
\begin{aligned}
&Min \quad S_K \\
&s.t. \quad \sum_{i=1}^{m} v_i\, X_{ik} = 1, \\
&\quad \sum_{r=1}^{s} u_r\, Y_{rk} - \sum_{i=1}^{m} v_i\, X_{ik} + S_k = 0, \\
&\quad \sum_{r=1}^{s} u_r\, Y_{rj} - \sum_{i=1}^{m} v_i\, X_{ij} \le 0, \qquad j = 1,..,n,\ j \ne k, \\
&\quad u_r, v_i \ge \varepsilon, \quad r = 1,...,s, \quad i = 1,...,m.
\end{aligned} \tag{1}
$$

Where,

S_K = Company's overall inefficiency during all studied years

Yr_k = Output *r* (Net sale and Gross profit) produced by whole units *k* during all studied years (or DMUk),

xi_k = Input *i* (Fix Cost and Variable cost) used by whole units *k* during all studied years (or DMUk),

yrj= Output *r* (Net sale and Gross profit) produced by unit *j* (or sub -DMUs),

xij= Input *i* (Fix Cost and Variable cost) used by unit *j* (or sub -DMUs),

μr= The weight given to output *r*,

Vi = The weight given to input *i*,

ε= A small non-Archimedean quantity which prohibits any inputs/outputs factor to be ignored.

By the same manner, the constraint associated with each DMU other than *k* in model (1) is replaced by the same constraints corresponding to its *q* production units. Therefore, each DMU can have a different number of production units. Here, a common number *q* is used for simplification. For more general cases, the i_{th} DMU has q_j production units, one just replaces *q* by q_j, accordingly.

Consequently, the CCR input-oriented DEA model for calculating the relative inefficiency of a set of n DMUs, each with q parallel production units, is:

$$
\begin{aligned}
&Min \quad \sum_{p=1}^{q} S_k^p \\
&S.t. \quad \sum_{i=1}^{m} v_i\, X_{ik} = 1, \\
&\quad \sum_{r=1}^{s} u_r Y_{rk}^p - \sum_{i=1}^{m} v_i\, X_{ik}^p + S_k^p = 0, \quad P = 1,...,q, \\
&\quad \sum_{r=1}^{s} u_r Y_{rj}^p - \sum_{i=1}^{m} v_i\, X_{ij}^p \le 0, \\
&\quad p = 1,...,q;\ j = 1,...,n,\ j \ne k, \\
&\quad u_r, v_i \ge \varepsilon, \quad r = 1,...,s, \quad i = 1,...,m.
\end{aligned} \tag{2}
$$

This model will be iterated for *n* times (one time for each DMU) to calculate the inefficiency slacks of the systems and their subordinated production units. From the inefficiency decomposition, the decision maker is able to identify the production units with large inefficiency slacks and make subsequent improvements. The efficiency score of the w_{th} production unit of the k_{th} DMU is not $1-S_K^W$. Because $\sum_{i=1}^{m} v_i\, X_{ik}^w$ is not equal to 1. Based on the second constraint of model (2), S_k^w must be divided by $\sum_{i=1}^{m} v_i\, X_{ik}^w$ to get the efficiency score of: $1-\dfrac{S_k^w}{\sum_{i=1}^{m} v_i\, X_{ik}^w}$

Difference between the parallel DEA model and the traditional models is that the constraint of each DMU is replaced by those associated with its subordinated production units. The sum of the constraints associated with the production units is equal to the constraint of the system. On the other hand, the constraints in parallel model are stronger than traditional models. Hence, the efficiency score of parallel DEA model is smaller than the traditional DEA model.

Model (2) is the input-oriented network model with parallel structure and under Constant Returns to Scale (CRS) that measures the aggregate efficiency. This means that the relative increase in the inputs will increase outputs in the same size. By adding a convexity constraint (u_{0e}) , it becomes the input-oriented model under variable returns to scale or (BCC). In this model, each DMU with units that are the same scale, are compared. Therefore, this model measures the technical efficiency, which can be model (2), considering the following:

$$\begin{aligned}
Min \quad & \sum_{p=1}^{q} S_k^p \\
S.t. \quad & \sum_{i=1}^{m} v_i X_{ik} = 1, \\
& \sum_{r=1}^{s} u_r Y_{rk}^p - \sum_{i=1}^{m} v_i X_{ik}^p - u_{0e} + S_k^p = 0, \ P = 1,\ldots,q, \\
& \sum_{r=1}^{s} u_r Y_{rj}^p - \sum_{i=1}^{m} v_i X_{ij}^p - u_{0e} \le 0, \\
& p = 1,\ldots,q; \ j = 1,\ldots,n, \ j \ne k, \\
& u_r, v_i \ge \varepsilon, \ r = 1,\ldots,s, \ i = 1,\ldots,m.
\end{aligned} \tag{3}$$

Where u_{0e} identifies the returns to scale of the unit under evaluation (DMU_0). Hence, if $u_{0e} < 0$, DMUo exhibits Increasing Returns to Scale (IRS); otherwise if $u_{0e} > 0$, DMU_o exhibits Decreasing Return to Scale (DRS) , then DMU_o exhibits CRS if $u_{0e} = 0$.

Here, this approach is extended to show how to decompose these inefficiencies into their component parts. Based on the CCR and BCC scores, units gain efficiencies in fixed and variable returns to scale. Thus, the Scale Efficiency (SE) for the units in a network with a parallel structure is calculated by comparing the scores of CCR with BCC approach; as the following model (Mehregan, 2008):

$$SE = \frac{\theta_{CCR}}{\theta_{BCC}} \tag{4}$$

Ranking Model Based on DEA

In most DEA models, the best performers have efficiency score of unity. From previous studies, it is obvious that usually there are plural decision making units which have the efficient status. To distinguish between these efficient DMUs is an important issue (Tone, 2002). To overcome the inability of DEA to discriminate between DEA efficient units, various methods have been proposed. One of them is used to evaluate the cross efficiency evaluation (Sexton *et al.*, 1986; Doyle and Green, 1994; Doyle and Green 1994, 1995) has been suggested in the DEA literature.

In the cross-efficiency evaluation, each DMU determines individually a set of inputs and outputs weights, leading to n sets of weights for n DMUs. The *n* sets of weights are then used to assess the efficiencies of the n DMUs, resulting in n efficiency values for every DMU. The *n* efficiency values for each DMU are finally averaged as an overall efficiency value of the DMU. The cross-efficiency evaluation can guarantee a unique ordering for the DMUs and can be used with few DMUs (i.e. four or five) to produce a unique ordering (Doyle and Green, 1995). Also, in this study, cross evaluation is used with a benevolent viewpoint to rank and distinction between efficient performance (cross-efficiency) as mentioned in the following proposed models by Wang and Chin 2010):

$$Min \quad \sum_{\substack{j=1 \\ j \neq k}}^{n} \sum_{p=1}^{q} S_j^p$$

$$S.t. \quad \sum_{i=1}^{m} \sum_{p=1}^{q} v_i X_{ik}^p = 1$$

$$\sum_{r=1}^{s} u_t Y_{rk}^p - \sum_{i=1}^{m} v_i X_{ik}^p + S_k^{p^*} = 0 \quad P = 1,...,q,$$

$$\sum_{r=1}^{s} u_r Y_{rj}^p - \sum_{i=1}^{m} v_i X_{ij}^p + S_j^p = 0$$

$$P = 1,...,q, \; j = 1,...,n, \; j \neq k,$$

$$u_t, v_i \geq \varepsilon, \; r = 1,...,s, \; i = 1,...,m, \; S_j^p \geq 0 \qquad (5)$$

In which the aim of model (5) is to reduce inefficiency p subunit from decision unit of *j*. Where, *n* is number of decision making units (DMU) or the study years, *J* is the number of the years, *k* is evaluation unit DMUk, *q* is the number of units. $S_k^{p^*}$ is subunit of inefficiency within DMUk previously calculated by the network model with parallel structure.

Finally, the efficiency of decision making unit j (DMUj) can be calculated based on DMUk weights as follows:

$$E_{Kj} = \frac{\sum_{r=1}^{s} \sum_{p=1}^{q} u_r^k Y_{rj}^p}{\sum_{i=1}^{m} \sum_{p=1}^{q} v_i^k X_{ij}^p} \qquad (6)$$

Therefore, index rating is calculated based on average performance.

RESULTS

The inefficiency score of each production unit was determined by using input-oriented parallel DEA models. The results of network DEA models with parallel structure were varied in most units and years under variable and constant returns to scale. Paper production unit in the first year (2005) by both models were inefficient, but the inefficiency by the model with constant returns to scale was more than variable returns to scale. Paper production unit in the second year (2006) was still inefficient by both models, and also inefficiency scores by both models (2) and (3) were identical as well. In both the third and fourth years (2007 and 2008), the inefficiency scores were zero (or 100% efficient). In the fifth year (2009), model 2 was inefficient. In comparison, model (3) was efficient. In the last year (2010), both models were inefficient. Printing and writing production unit was inefficient by both model in the first year, but, in the second year, it was inefficient and efficient by models (2) and (3), respectively. The inefficiency scores were zero by both models (100% efficient) in both the third and fourth year. According to both models (2) and (3), the printing and writing production unit was inefficient in the fifth year. Although it was inefficient based on model (2), it was efficient based on model (3) in the last year (2010). White kraft liner production unit was inefficient by both models in the first and second years. In the third and fourth years, their inefficiency scores were zero (or 100% efficient). In the fifth year, both models were inefficient. White kraft liner production unit based on model (2) was inefficient. In comparison, according to model (3), it was efficient in the last year. The rests of production units were inefficient in the first, second, and fifth years, however, the inefficiency scores were zero by both models in the third and fourth years. It was remarkable that all of the production units were efficient based on both models in the third and fourth years (Table 2).

The results of input-oriented models indicated that the higher efficiency score occurred in 2007 and 2008. The production units of the other years were inefficient and their inefficiency scores were approximately higher based on model (2) than model (3) (Table 3).

Results of the scale efficiency model showed that the distance between the boundary fixed and variable returns to scale was low. Therefore, more years (2006, 2007 and 2008) became efficient by this model (Figure 1).

Finally, the results of the rankings cross-efficiency model showed that the third year (2007) had the lowest inefficiency (or 100% efficient) with 0.998789 efficiency score. The second and fourth years (2006 and 2008) were located in the second and third place with scores of 0.998484 and 0.90 742, respectively (Table 4).

Table 3. Inefficiency scores in studied years (DMUk) by the models (2) and (3).

Year	Model	
	CCR	BCC
2005	0.09	0.07
2006	0.09	0.09
2007	0	0
2008	0	0
2009	0.14	0.07
2010	0.13	0.09

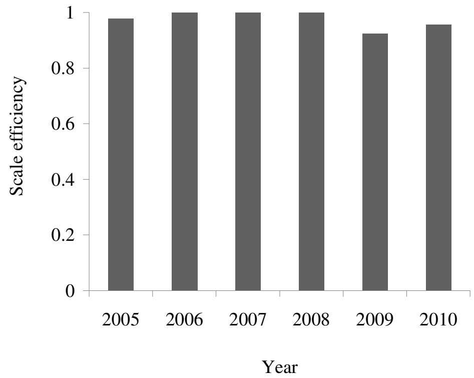

Figure 1. Efficiency scores during the studied years by the scale efficiency model.

DISCUSSION

Paper is considered as a strategically important commodity that plays an important role in economic, cultural, and social development. Per capita consumption of paper and paperboard is one of the criteria to compare the countries in economic and cultural development (Tajdini and Roohnia, 2008). Nevertheless, there are serious problems for supplying the raw materials for producing of lignocelluloses. Furthermore, a few forest industries in Iran produce sawn

Table 2. Inefficiency scores of production units by the models (2) and (3).

Units	Years											
	2005		2006		2007		2008		2009		2010	
	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC	CCR	BCC
Paper	0.0484	0.0040	0.0359	0.0359	0	0	0	0	0.0174	0	0.0215	0.0112
Print and writing paper	0.0001	0.0024	0.0001	0	0	0	0	0	0.0081	0.0389	0.0174	0
White kraft liner	0.0001	0.0017	0.0001	0.0001	0	0	0	0	0.0012	0.0048	0	0.0038
Brown kraft liner	0.0046	0.0053	0.0056	0.0057	0	0	0	0	0.0129	0.0136	0.0149	0.0052
Fluting line (1)	0.0040	0.0124	0.0050	0.0050	0	0	0	0	0.0080	0	0.0088	0.0095
Fluting line (2)	0.0357	0.0458	0.0454	0.0454	0	0	0	0	0.0879	0.0116	0.0633	0.0632

Table 4. Cross efficiency matrix.

	1	2	3	4	5	6	Cross efficiency	Efficiency	Rank
1	1.000	0.904	0.905	0.907	0.908	0.912	0.907200	0.91	4
2	0.907	1.000	0.905	0.907	0.908	0.912	0.907242	0.91	3
3	1.000	0.996	1.000	0.999	0.998	1.000	0.998789	1	1
4	1.000	0.996	0.997	1.000	0.998	1.000	0.998484	1	2
5	0.861	0.859	0.860	0.861	1.000	0.867	0.861755	0.86	6
6	0.872	0.870	0.871	0.872	0.874	1.000	0.872735	0.87	5

wood, wood-based panels, as well as pulp and paper from hardwood species. Moderate volumes of forest products, mainly paper, are imported (Zadmirzaei and Mohammadi Limaei, 2013). Hence, to surmount this undesirable situation and satisfy the paper demand, first of all, we have to evaluate the efficiency of companies, then, propose appropriate solutions for improving their performance. Therfore, to achieve this aim, MWPC as the biggest and major supplier of paper products in Iran was considered.

Considering the company's structure, the parallel structure of network DEA model was used to determine the efficiency of the firm. Input-oriented DEA models were used for efficiency evaluation, because the production units could be optimized using their proper inputs. This means that the company could reduce its inputs consumption while keeping a constant output level and, consequently, increase its efficiency and profitability. The results indicated that the parallel model with fixed and variable returns to scale (CCR and BCC models) in most units and years were different. These differences could be due to the property of returns to scale model in these two models. In CCR, a small unit, regardless of its optimum scale, can be compared with the other units which could be bigger than it. Consequently, the small units get lower efficiency score than the other units. However, in BCC, each unit is compared with the same optimum scale units. Thus, the number of units that are efficient by constant returns to scale models are less than those under variable returns to scale, as shown in Tables 2 and 3. In total, the third and fourth years were completely efficient (Tables 2 and 3). It means that, with regard to the nature of input-oriented model, the entire production unit consumed optimally all of the inputs during the studied period in each production unit. On the other hand, the production unit had the same outputs each year compared to the other years. This could be due to the optimum resource management of the company during these years.

The results of scale efficiency model indicated that 3 years were efficient, because the distance between the boundary of fixed and variable returns to scale which indicate the scale inefficiency was too short in this study. Therefore, more years have scale efficiency and the scale efficiency less than 1 for the other years indicated that the overall efficiency maybe improved by changing the practical scale. Based on the previous researches, the decision units with parallel structure usually are efficient (Tone, 2002). Therefore, the distinction between these units is an important issue. For this purpose, the cross-efficiency ranking models were used. According to this model, the highest score belonged to the third year and the second and fourth years ranked in the next places (Table 4).

Mohammadi Limaei (2012) dealt with the efficiency of the Iranian forest companies using traditional DEA model and two-stage (harvesting and marketing sub-processes) DEA model. Wilcoxon's signed-rank test

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was used to identify the main reason of weakness between efficiency average of harvesting sub-process and marketing sub-process. Results showed that weakness performance of the companies in harvesting sub-process was the cause of their low efficiency in 2010.

There are a few studies that dealt with measuring the efficiencies using parallel structure of DEA model. Castelli *et al*. (2004) presented hierarchical structures of DEA model where each unit is composed of consecutive stages of parallel subunits all with constant returns to scale. Färe and Grosskopf (2000) proposed a network model for measuring the efficiency of the system. However, the operation of each component of the system is treated independently, without considering the relationship among the components. Also, there is only one study using parallel structure of DEA model in forestry (Kao, 2009). The performance of eight forest areas in Taiwan was evaluated using parallel model of DEA. The results indicated that all of them were inefficient, while based on the results of the traditional models, only two forest areas were inefficient. These results could be due to the capability of higher resolution of network models with parallel structure to distinguish between the inefficient and efficient units.

The result of this research is similar to the results of previous studies by parallel structure of DEA model because there is a significant point: the constraints in parallel model are stronger than traditional models. Hence, the efficiency score of parallel DEA model has higher resolution than traditional DEA model for distinguishing between the inefficient and efficient units.

It should be noted that the results reported in this paper are based on the factors included in the DEA models with available crisp/precise data. However, the observed values of the input and output data in real-world problems are often vague or random. Indeed, DMUs may encounter a hybrid uncertain environment where fuzziness and randomness coexist in a problem. For future studies, it is recommended that the other researchers use various proposed fuzzy and stochastic methods for dealing with the ambiguous and random data in DEA to hedge against risk and uncertainty in real-world problems.

CONCLUSIONS

To sum up, using input-oriented DEA models indicated that the production units could be optimized by the use of their proper inputs. It means that the MWPC in Iran can reduce its inputs (fixed and variable costs) consumption while keeping a constant outputs level and, consequently, increase its efficiency. Moreover, success of this company can probably be enhanced by new technology and products. Therefore, MWPC should raise its production and promote its products and also respond to the increasing per capita consumption of paper products in Iran to generate more revenue and eventually increase the profitability. The results of this study showed that the inappropriate consumption of resources and poor strategies for managing financial inputs reduce the efficiency of production units i.e. inefficient units in the studied years. Therefore the company managers should consider the efficient year (2007) as a sample and guideline for the other years, including their production lines.

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اندازه گیری کارایی کارخانه کاغذ سازی با استفاده از مدل های تحلیل پوششی داده ها (مطالعه موردی: شرکت چوب و کاغذ مازندران ایران)

م. زاد میرزایی، س. محمدی لیمائی، و ع. امیر تیموری

چکیده

در این تحقیق با توجه به اهمیت شرکت و چوب کاغذ مازندران به عنوان مهم ترین تامین کننده فراورده های کاغذی ایران، به اندازه گیری کارایی نسبی آن پرداخته شد. برای ارزیابی و اندازه گیری کارایی شرکت مذکور از مدلهای شبکه ای تحلیل پوششی داده ها با ساختار موازی استفاده شد. برای آنالیز مدل ها نیز از نرم افزار گمز ۲۳.۴ استفاده شد. نتایج نشان داد که مبنی بر مدل های موازی تحلیل پوششی داده ها، شرکت مزبور در تمام سال های مطالعه دارای عملکرد خوبی می باشد. در مجموع، مطابق مدل های شبکه ای با ساختار موازی، سال های ۱۳۸۶ و ۱۳۸۷ دارای کارایی بیشتری نسبت به سایر سال ها بودند. نهایتا، با استفاده از مد ل های رتبه بندی متقاطع شرکت مذکور در سال ۱۳۸۶ دارای بالاترین کارایی بوده است این امر را می توان به دلیل ماهیت ورودی-محور بودن مدل ها دانست. در نتیجه، این شرکت به دلیل مدیریت صحیح منابع و استفاده بهینه از آن ها بهترین عملکرد را در سال ۱۳۸۶ داشته است.

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