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Using DEA Window Analysis to Measure the Efficiencies of Blowing Machines in Plastics Industry

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Abstract

Efficiency evaluation is vital in determining whether a production line can achieve its goals or not. The present study aims at assessing the efficiency of five blowing machines in a plastics industry using DEA window analysis in both day and night shifts for the period Feb., 2014 to Jun., 2014. The production quantity is set as the output, whereas the defect quantity and idle time (units) are set as the inputs for all windows. Utilizing the DEA models, the technical, pure technical and scale efficiency values are then calculated in both day and night shifts for each machine. A comparison is conducted between the day and night shifts for each machine. Moreover, comparisons are performed among the efficiency of five machines in both day and night shifts. Improvement actions are then suggested to reduce the inefficiency. Results showed that significant differences exist between day and night shifts for each machine. Directions for improvement are then suggested, which requires managerial as well as operational actions to improve process performance. In conclusions, the thorough analysis and discussion of the results in the present paper provide a valuable evaluation to production managers for improving the performance of blowing processes.

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1. Introduction

Plastics are one of the most used materials on a volume basis in the industrial and commercial life of the countries. Plastics are broadly integrated in today's life style and make a major, irreplaceable contribution to virtually all product areas. Measurement of a production unit-performance is vital in determining whether it has achieved its goals or not [1-2].

Data Envelopment Analysis (DEA) is a management tool employed to estimate the efficiency of number of decision making units (DMU's). DEA is a non-parametric approach that can be used to calculate the efficiency measures, and has a wide applicability in various service and industry sectors [3-6]. This approach has been widely used in cases which have been resistant to other approaches and it is related to the complex and unknown nature of the relations between the multiple inputs and multiple outputs involved in many of these activities [7-10].

1.1. The CCR and BCC Models

The CCR Model considers a fixed or constant return to scale (CRS), which means that a proportional increase in all inputs results in the same proportional increase in outputs [11]. The efficiency of a given DMU$_o$ is calculated using the CCR model as follows:

$$Min\ \theta \tag{1}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io} \qquad i = 1......m \tag{1a}$$

$$\sum_{j=1}^{n} \lambda_j y_{kj} \ge y_{ko} \qquad k = 1......s \tag{1b}$$

$$\lambda_j \ge 0 \qquad j = 1......n \tag{1c}$$

where θ represents the technical efficiency score of unit DMU$_o$, λ_j represents the dual variables that identify the benchmarks for inefficient units. If θ^* is equal to a value of one, then the examined DMU is considered technically efficient and lies on the efficiency frontier that is composed of the set of efficient units, DEA measures the efficiency of each observation relative to the frontier that envelopes all the observations. Inefficient DMUs can be improved (moved to the efficient frontier) with proposed directions for improvement which are the points

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along the frontier. The distance to the efficiency frontier provides a measure for the efficiency.

On the other hand, the BCC model by Banker-Charnes-Cooper changed the Constant Return to Scale (CRS) concept to Variable Return to Scale (VRS). The DMU operates under variable returns to scale if it is suspected that an increase in inputs does not result in a proportional change in the outputs. The BCC is represented as follows [12]:

$$Min\ \theta \tag{2}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io} \qquad i = 1......m \tag{2a}$$

$$\sum_{j=1}^{n} \lambda_j y_{kj} \ge y_{ko} \qquad k = 1......s \tag{2b}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad j = 1......n \tag{2c}$$

$$\lambda_j \ge 0 \tag{2d}$$

The BCC model divides the Technical Efficiency (TE) derived from the CCR model into two parts [13-16]: (*i*) Pure Technical Efficiency (PTE), which ignores the impact of scale size by only comparing a DMU to a unit of similar scale and measures how a DMU utilizes its sources under exogenous environment and (*ii*) Scale Efficiency (SE), which measures how the scale size affects efficiency. If after applying both CRS, VRS model on the same data, there is a difference in the two technical efficiencies, this indicates that DMU has a scale efficiency, and can be calculated by:

$$SE = TE/PTE \tag{3}$$

1.2. DEA Window Analysis

DEA window analysis is a non-parametric panel approach, which is a suitable tool technique to measure the efficiency level of a number of DMUs with respect to its own performance over time, as well as the performance of the relatively most productive decision units within the sample set [17-20]. The arrangement of the results in DEA window analysis facilitates the identification of trends in performance, the stability of reference sets and other possible insights. If N represents the number of DMUs (n = 1,2, 3 …..N) that all use m inputs to produce s outputs and are observed in T (t = 1, 2, 3 …..T) periods [20-24]. Let DMU_n^t represent an observation n in period t with input vector $\boldsymbol{X_n^t}$ and output vector $\boldsymbol{Y_n^t}$ respectively. Then,

$$\mathbf{X}_n^t = \begin{bmatrix} x_n^{1t} \\ \vdots \\ x_n^{mt} \end{bmatrix} \tag{4}$$

and

$$\mathbf{Y}_n^t = \begin{bmatrix} y_n^{1t} \\ \vdots \\ y_n^{st} \end{bmatrix} \tag{5}$$

If the window starts at time k ($1 \le k \le T$) with width w ($1 \le w \le T-k$), then the matrices of inputs and outputs, X_{kw}, are denoted respectively as follows:

$$X_{kw} = \begin{bmatrix} x_1^k & x_2^k & \cdots & x_N^k \\ x_1^{k+1} & x_2^{k+1} & \cdots & x_N^{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ x_1^{k+w} & x_2^{k+w} & \cdots & x_N^{k+w} \end{bmatrix} \tag{6}$$

and

$$Y_{kw} = \begin{bmatrix} y_1^k & y_2^k & \cdots & y_N^k \\ y_1^{k+1} & y_2^{k+1} & \cdots & y_N^{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ y_1^{k+w} & y_2^{k+w} & \cdots & y_N^{k+w} \end{bmatrix} \tag{7}$$

DEA window analysis is conducted by substituting inputs and outputs of DMU_n^t into the CCR or the BCC models [25-28]. In the present study, a plant specialized in the production of plastic containers seeks assessing the performance of blowing machines and determines opportunities for performance improvements. To achieve this objective, the present study utilizes DEA window analysis to measure the efficiency of the five identical blowing machines at both day and night shifts over the period February to July, 2014. The research results can provide a helpful guidance to product/process engineers in assessing existing process performance and help in deciding appropriate improvement actions. The remaining part of the study, including the introduction, is outlined in the following sequence: Section two is for Data Collection; Section three conducts DEA window analysis; Section four discusses and summarizes the research results; and finally, conclusions are provided in section five.

2. Data Collection

Data are obtained from the production report over a period of six months for both day and night shifts for the five blowing machine: M1, M2, M3, M4, and M5. The choice between input and output orientation depends on the unique characteristic of the set of DMUs under study. The input oriented model is deemed to be more appropriate in the present paper because there is only one output while multiple inputs are used; this model tends to minimize the inputs while satisfying at least the given output levels, and for this reason the Defect Quantities (DQ) and Idle Time (IT) are considered as inputs and need to be minimized while the Production Quantity (PQ) needs to be maintained at the same level. To compute efficiency scores, each month was divided into two periods and each period consisted of two weeks where (H1) represents the first half of the month and (H2) represents the second half of the month. Inputs and outputs data are presented in Table 1; Table 6 lists the descriptive statistics of the inputs and the output for both day and night shifts.

Table 1. The inputs and output data for M1 Day and Night shift.

Period	Day Shift				Night Shift			
	Inputs			Output	Inputs			Output
	PP (units)	DQ (units)	IT (units)	PQ (units)	PP (units)	DQ (units)	IT (units)	PQ (units)
Feb. H1	24,192	192	1,446	22,000	24,192	185	1,426	22,300
Feb. H2	24,192	241	8,975	14,834	24,192	94	7,996	15,731
Mar. H1	24,192	251	5,202	18,763	24,192	69	3,149	21,419
Mar. H2	24,192	236	8,274	15,781	24,192	97	6,414	18,359
Apr. H1	20,736	197	2,329	18,000	20,736	176	1,935	17,221
Apr. H2	27,648	201	569	26,960	27,648	142	51	27,720
May H1	24,192	242	4,116	19,984	24,192	120	3,420	19,456
May H2	20,736	264	2,481	20,042	20,736	53	2,081	19,616
Jun. H1	13,824	79	1,621	11,955	13,824	32	678	13,500
Jun. H2	10,368	76	3,016	7,740	10,368	73	2,855	8,318
Jul. H1	15,552	118	3,609	12,600	15,552	115	2,962	13,350
Jul. H2	22,646	240	3,054	19,370	22,464	245	2,339	20,750

3. Application of DEA Window Analysis

The window analysis considers each blowing machine as a different machine in each of the halves listed at the top of the table in order to obtain the scores listed in the rows that constitute the window, while the stub on the left side indicates the window length and the periods covered. For example, the first row extends from the first half of February (Feb. H1) to the second half of April (Apr. H2) for a window length of six halves that is exhibited in the first row. The next row starts in second half of February (Feb. H2) and extends to the first half of May (May H1) which represents another window and so on. This results in seven windows (*w*) for each shift. Then, there are 210 different data points in each shift to which the DEA model is applied to obtain the efficiency scores. Firstly, the Technical Efficiency (TE) and Pure Technical Efficiency (PTE) are computed using CCR and BCC models, respectively. The Scale Efficiency (SE) is then calculated. Tables 2 and 3 present the TE, PTE and SE values for machine M1 in the day and night shifts, respectively. To illustrate, for machine M1 in the day shift (M1d) the first window extends from first half of February (Feb. H1) to the second half of April (Apr. H2) for a window length of 6 half's, TE (= 0.9326) in Table 2 is calculated using the CCR model as follows:

$$Min\,\theta$$

Subject to:

$$-24{,}192\lambda_1-24{,}192\lambda_2-24{,}192\lambda_3-24{,}192\lambda_4-20{,}736\lambda_5-27{,}648\lambda_6+24{,}192\boldsymbol{\theta}\geq 0$$
$$-192\lambda_1-241\lambda_2-251\lambda_3-236\lambda_4-197\lambda_5-201\lambda_6+192\boldsymbol{\theta}\geq 0$$
$$-1{,}446\lambda_1-8{,}975\lambda_2-5{,}202\lambda_3-8{,}274\lambda_4-2{,}329\lambda_5-569\lambda_5+1{,}446\boldsymbol{\theta}\geq 0$$
$$22{,}000\lambda_1+14{,}834\lambda_2+18{,}763\lambda_3+15{,}781\lambda_4+18{,}000\lambda_5+26960\lambda_6\geq 22000$$
$$\lambda_j\geq 0,\ j=1{,}2{,}3$$

The corresponding PTE (= 1.00) for M1d is calculated using BCC model as follows:

$$Min\,\theta$$

Subject to:

$$-24{,}192\lambda_1-24{,}192\lambda_2-24{,}192\lambda_3-24{,}192\lambda_4-20{,}736\lambda_5-27{,}648\lambda_6+24{,}192\boldsymbol{\theta}\geq 0$$
$$-192\lambda_1-241\lambda_2-251\lambda_3-236\lambda_4-197\lambda_5-201\lambda_6+192\boldsymbol{\theta}\geq 0$$
$$-1{,}446\lambda_1-8{,}975\lambda_2-5{,}202\lambda_3-8{,}274\lambda_4-2{,}329\lambda_5-569\lambda_5+1{,}446\boldsymbol{\theta}\geq 0$$
$$22{,}000\lambda_1+14{,}834\lambda_2+18{,}763\lambda_3+15{,}781\lambda_4+18{,}000\lambda_5+26960\lambda_6\geq 22000$$
$$\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6=1$$
$$\lambda_j\geq 0,\ j=1{,}2{,}3$$

Finally, the SE for M1d is calculated as:

$$SE = TE/PTE = \frac{0.9326}{1} = 1$$

The TE, PTE, and SE for the other windows in day shift and the windows in the night shift are calculated in a similar manner. The TE, PTE, and SE for the M2-M5 in the day and night shifts are calculated similarly.

4. Results and Discussions of DEA Window

An inefficient DMU can be made more efficient by projection onto the frontier, and in the input orientation the efficiency can be improved through proportional reduction of inputs. For practical considerations, a classification of all TE scores in all windows produced three categories; the first category is the highly efficient category (H-efficient), which includes the DMUs that have a value of efficiency equals to or larger than 95%; the second category is the efficient category (Efficient) and includes machines that have a value of efficiency between (90% - <95%); the third category is the inefficient category (Inefficient) and includes DMUs that have a value of efficiency less than 90%. Applying this classification means that the first four windows are (Inefficient) and the last three windows are (Efficient). The results in Table 4 are used for determining extra inputs and deficiency of efficiency for M1d and the specific quantity of input that inefficient machine needs to decrease in order to become efficient in order to stand on the efficiency frontier line for the smallest and largest TE and PTE average values.

Table 2. DEA window analysis for TE, PTE and SE over February-July 2014 for M1/day shift

TE	**Feb. (H1)**	**Feb. (H2)**	**Mar. (H1)**	**Mar. (H2)**	**Apr. (H1)**	**Apr. (H2)**	**May (H1)**	**May (H2)**	**Jun. (H1)**	**Jun. (H2)**	**Jul. (H1)**	**Jul. (H2)**	**Avg.**	**Std.**	**CV**	**Min.**	**Max.**
Feb. H1-Apr. H2	0.9326	0.6288	0.7954	0.6690	0.8902	1.0000							0.8193	0.1483	0.1810	0.6288	1.0000
Feb. H2-May H1		0.6288	0.7954	0.6690	0.8902	1.0000	0.8471						0.8051	0.1391	0.1727	0.6288	1.0000
Mar. H1-May H2			0.7954	0.6690	0.8902	1.0000	0.8471	0.9912					0.8655	0.1252	0.1447	0.6690	1.0000
Mar. H2-Jun. H1				0.6690	0.8902	1.0000	0.8471	0.9912	1.0000				0.8996	0.1301	0.1446	0.6690	1.0000
Apr. H1-Jun. H2					0.8902	1.0000	0.8471	0.9912	1.0000	0.7656			0.9157	0.0978	0.1068	0.7656	1.0000
Apr. H2-Jul. H1						1.0000	0.8471	0.9912	1.0000	0.7656	0.8309		0.9058	0.1037	0.1037	0.7656	1.0000
May H1-Jul. H2							0.8911	1.0000	1.0000	0.8405	0.9083	0.9204	0.9267	0.0630	0.0630	0.8405	1.0000
Avg.	0.9326	0.6288	0.7954	0.6690	0.8902	1.0000	0.8544	0.9930	1.0000	0.7906	0.8696	0.9204					
PTE	**Feb. (H1)**	**Feb. (H2)**	**Mar. (H1)**	**Mar. (H2)**	**Apr. (H1)**	**Apr. (H2)**	**May (H1)**	**May (H2)**	**Jun. (H1)**	**Jun. (H2)**	**Jul. (H1)**	**Jul. (H2)**	**Avg.**	**Std.**	**CV**	**Min.**	**Max.**
Feb. H1-Apr. H2	1.0000	0.8571	0.8815	0.8571	1.0000	1.0000							0.9326	0.0744	0.0797	0.8571	1.0000
Feb. H2-May H1		0.8571	0.8815	0.8571	1.0000	1.0000	0.9204						0.9194	0.0666	0.0725	0.8571	1.0000
Mar. H1-May H2			0.8626	0.8571	1.0000	1.0000	0.9006	1.0000					0.9367	0.0709	0.0757	0.8571	1.0000
Mar. H2-Jun. H1				0.7066	0.9235	1.0000	0.8650	1.0000	1.0000				0.9159	0.1163	0.1270	0.7066	1.0000
Apr. H1-Jun. H2					0.9235	1.0000	0.8650	1.0000	1.0000	1.0000			0.9648	0.0577	0.0598	0.8650	1.0000
Apr. H2-Jul. H1						1.0000	0.8650	1.0000	1.0000	1.0000	0.9243		0.9649	0.0575	0.0596	0.8650	1.0000
May H1-Jul. H2							1.0000	1.0000	1.0000	1.0000	0.9243	1.0000	0.9874	0.0309	0.0313	0.9243	1.0000
Avg.	1.0000	0.8571	0.8752	0.8195	0.9694	1.0000	0.9027	1.0000	1.0000	1.0000	0.9243	1.0000					
SE	**Feb. (H1)**	**Feb. (H2)**	**Mar. (H1)**	**Mar. (H2)**	**Apr. (H1)**	**Apr. (H2)**	**May (H1)**	**May (H2)**	**Jun. (H1)**	**Jun. (H2)**	**Jul. (H1)**	**Jul. (H2)**	**Avg.**	**Std.**	**CV**	**Min.**	**Max.**
Feb. H1-Apr. H2	0.9326	0.7336	0.9023	0.7805	0.8902	1.0000							0.8732	0.0988	0.1131	0.7336	1.0000
Feb. H2-May H1		0.7336	0.9023	0.7805	0.8902	1.0000	0.9204						0.8712	0.0975	0.1119	0.7336	1.0000
Mar. H1-May H2			0.9221	0.7805	0.8902	1.0000	0.9406	0.9912					0.9208	0.0803	0.0872	0.7805	1.0000
Mar. H2-Jun. H1				0.9468	0.9639	1.0000	0.9793	0.9912	1.0000				0.9802	0.0214	0.0218	0.9468	1.0000
Apr. H1 -Jun. H2					0.9639	1.0000	0.9793	0.9912	1.0000	0.7656			0.9500	0.0914	0.0962	0.7656	1.0000
Apr. H2-Jul. H1						1.0000	0.9793	0.9912	1.0000	0.7656	0.8990		0.9392	0.0932	0.0993	0.7656	1.0000
May H1-Jul. H2							0.8911	1.0000	1.0000	0.8405	0.9827	0.9204	0.9391	0.0659	0.0701	0.8405	1.0000
Avg.	0.9326	0.7336	0.9089	0.8221	0.9197	1.0000	0.9483	0.9930	1.0000	0.7906	0.9408	0.9204					

Table 3. DEA window analysis for TE, PTE and SE over February-July 2014 for M1/night shift

TE	Feb. (H1)	Feb. (H2)	Mar. (H1)	Mar. (H2)	Apr. (H1)	Apr. (H2)	May (H1)	May (H2)	Jun. (H1)	Jun. (H2)	Jul. (H1)	Jul. (H2)	Avg.	Std.	CV	Min.	Max.
Feb. H1-Apr. H2	0.9194	0.6929	1.0000	0.8032	0.8283	1.0000							0.8740	0.1214	0.1389	0.6929	1.0000
Feb. H2-May H1		0.6929	1.0000	0.8032	0.8283	1.0000	0.8094						0.8556	0.1215	0.1420	0.6929	1.0000
Mar. H1 -May H2			0.9295	0.7760	0.8283	1.0000	0.8052	1.0000					0.8898	0.0998	0.1121	0.8052	1.0000
Mar. H2-Jun. H1				0.7648	0.8283	1.0000	0.8034	0.9665	1.0000				0.8938	0.1067	0.1194	0.7648	1.0000
Apr. H1-Jun. H2					0.8283	1.0000	0.8034	0.9665	1.0000	0.8002			0.8997	0.0988	0.1099	0.8002	1.0000
Apr. H2-Jul. H1						1.0000	0.8034	0.9665	1.0000	0.8002	0.8562		0.9044	0.0954	0.1055	0.8002	1.0000
May H1-Jul. H2							0.8235	0.9687	1.0000	0.8215	0.8790	0.9459	0.9064	0.0762	0.0841	0.8215	1.0000
Avg.	0.9194	0.6929	0.9765	0.7868	0.8283	1.0000	0.8081	0.9736	1.0000	0.8073	0.8676	0.9459					
PTE	Feb. (H1)	Feb. (H2)	Mar. (H1)	Mar. (H2)	Apr. (H1)	Apr. (H2)	May (H1)	May (H2)	Jun. (H1)	Jun. (H2)	Jul. (H1)	Jul. (H2)	Avg.	Std.	CV	Min.	Max.
Feb. H1-Apr. H2	0.9954	0.9703	1.0000	0.9669	1.0000	1.0000							0.9888	0.0158	0.0159	0.9669	1.0000
Feb. H2-May H1		0.9703	1.0000	0.9669	1.0000	1.0000	0.9413						0.9798	0.0243	0.0248	0.9413	1.0000
Mar. H1-May H2			1.0000	0.8571	1.0000	1.0000	0.8571	1.0000					0.9524	0.0738	0.0775	0.8571	1.0000
Mar. H2-Jun. H1				0.7669	0.8411	1.0000	0.8108	1.0000	1.0000				0.9031	0.1087	0.1204	0.7669	1.0000
Apr. H1-Jun. H2					0.8411	1.0000	0.8108	1.0000	1.0000	1.0000			0.9420	0.0904	0.0960	0.8108	1.0000
Apr. H2-Jul. H1						1.0000	0.8108	1.0000	1.0000	1.0000	0.8825		0.9489	0.0824	0.0868	0.8108	1.0000
May H1-Jul. H2							0.8497	1.0000	1.0000	1.0000	0.8825	1.0000	0.9554	0.0699	0.0732	0.8497	1.0000
Avg.	0.9954	0.9703	1.0000	0.8895	0.9364	1.0000	0.8468	1.0000	1.0000	1.0000	0.8825	1.0000					
SE	Feb. (H1)	Feb. (H2)	Mar. (H1)	Mar. (H2)	Apr. (H1)	Apr. (H2)	May (H1)	May (H2)	Jun. (H1)	Jun. (H2)	Jul. (H1)	Jul. (H2)	Avg.	Std.	CV	Min.	Max.
Feb. H1-Apr. H2	0.9236	0.7141	1.0000	0.8307	0.8283	1.0000							0.8828	0.1125	0.1274	0.7141	1.0000
Feb. H2-May H1		0.7141	1.0000	0.8307	0.8283	1.0000	0.8599						0.8722	0.1109	0.1271	0.7141	1.0000
Mar. H1-May H2			0.9295	0.9054	0.8283	1.0000	0.9394	1.0000					0.9338	0.0644	0.0690	0.8283	1.0000
Mar. H2-Jun. H1				0.9973	0.9848	1.0000	0.9909	0.9665	1.0000				0.9899	0.0129	0.0130	0.9665	1.0000
Apr. H1-Jun. H2					0.9848	1.0000	0.9909	0.9665	1.0000	0.8002			0.9571	0.0778	0.0813	0.8002	1.0000
Apr. H2-Jul. H1						1.0000	0.9909	0.9665	1.0000	0.8002	0.9702		0.9546	0.0770	0.0807	0.8002	1.0000
May H1-Jul. H2							0.9692	0.9687	1.0000	0.8215	0.9960	0.9459	0.9502	0.0661	0.0696	0.8215	1.0000
Avg.	0.9236	0.7141	0.9765	0.8910	0.8909	1.0000	0.9569	0.9736	1.0000	0.8073	0.9831	0.9459					

From Tables 2 and 4, the following results are obtained:

- In Table 2, the TE relates to processing inputs to achieve the output as supposed when compared to its maximum potential for doing so. The second window of TE for M1d (Feb. H2-May H1) produced the smallest TE average value (= 0.8051). The TE for M1d in Feb. H2 (= 0.6288) implies that the same level of output could be produced with 62.88% of the resources if this machine was performing on the frontier. It could be interpreted also that 37.12% of overall resources could be saved by raising the performance of this machine to the highest level. In Table 4, in order for M1d in this half to become efficient, it needs to decrease 41 units of the Defect Quantity (DQ) in addition to decrease 5331 units of the Idle Time (IT). On the one hand, M1d in Apr. H2 stands on the efficiency frontier line and does not need to decrease any of the inputs. On the other hand, the last window of TE for M1d (May H1-Jul. H2) produced the largest TE average value (= 0.9267), TE for M1d in May H1 (= 0.8911) implies that the same level of output could be produced by 89.11% of the resources if this machine was performing on the frontier, it could be interpreted also that 10.89% of the overall resources could be saved by raising the performance of this machine to the highest level. In order for M1d in this half to become more efficient and to stand on the efficiency frontier, it needs only to decrease the idle time (IT) by 1109 units.
- In window DEA, the columns define the stability. The columns in window DEA are used to examine stability properties. The TE values of M1d in Table 2 showed a stable performance for all periods. For example, the TE in Mar. H2 equals 0.7954 for three windows; also TE in Apr. H1 was (=0.8902) for five windows. But, the row window is monitored to identify the performance trends. For example, in the first row the TE average is 0.8193 and a standard deviation equals to 0.1483. It is found that the Coefficient of Variation (CV) for TE values in all of the windows for M1d are larger than 5%, which means that indicates the existence of trends in the efficiencies of the same window. Finally, the technical inefficiency (TIE) average values for M1d over February-July 2014 are depicted in Fig. 1, where a decreasing trend in the TIE average values is observed starting Feb. H2-May H1 window. This means that the M1d is improved in processing the inputs to achieve the output as supposed when compared to its maximum potential for doing so through the covered period. Nevertheless, the minimal and maximal TE average values indicate that the performance of the machine M1 alternates between inefficient and efficient. None of the windows indicates a highly-efficient performance. On the other hand, M1d in Apr. H2 and Jun. H1 stand on the efficiency frontier line and do not need to decrease any of their inputs.

Table 4. The TE, PTE, inputs, output and slacks for of M1/d.

Smallest TE average= 0.8051													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3:IT	Output 1:PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
Feb. H2	0.6288	24,192	241	8,975	14,834	0.4134E-04	0	0	0.4239E-04	0	40.9	5330.6	0
Mar. H1	0.7954	24,192	251	5,202	18,763	0.4134E-04	0	0	0.4239E-04	0	59.7	3741.6	0
Mar. H2	0.6690	24,192	236	8,274	15,781	0.4134E-04	0	0	0.4239E-04	0	40.2	5201.9	0
Apr. H1	0.8902	20,736	197	2,329	18,000	0.4823E-04	0	0	0.4946E-04	0	41.2	1693.4	0
Apr. H2	1.0000	27,648	201	569	26,960	0.3617E-04	0	0	0.3709E-04	0	0	0	0
May H1	0.8471	24,192	242	4,116	19,984	0.4134E-04	0	0	0.4239E-04	0	56.0	3065.1	0
Largest TE average= 0.9267													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3:IT	Output 1:PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
May H1	0.8911	24,192	242	4,116	19,984	0.3487E-04	0.6465E-03	0	0.4459E-04	0	0	1108.5	0
May H2	1.0000	20,736	264	2,481	20,042	0.3902E-04	0.7234E-03	0	0.4989E-04	0	0	0	0
Jun. H1	1.0000	13,824	79	1,621	11,955	0.6541E-04	0.1213E-02	0	0.8365E-04	0	0	0	0
Jun. H2	0.8405	10,368	76	3,016	7,740	0.8491E-04	0.1574E-02	0	0.1086E-03	0	0	1508.3	0
Jul. H1	0.9083	15,552	118	3,609	12,600	0.5637E-04	0.1045E-02	0	0.7209E-03	0	0	1612.7	0
Jul. H2	0.9204	22,646	240	3,054	19,370	0.3691E-04	0.6843E-03	0	0.4719E-04	0	0	329.9	0
Smallest PTE average= 0.9159													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3: IT	Output: PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
Mar. H2	0.7066	24,192	236	8,274	15,781	0.4134E-04	0	0	0.3533E-04	0	0.2	3818.6	0
Apr. H1	0.9235	20,736	197	2,329	18,000	0.4624E-04	0.2088E-03	0	0.4429E-04	0	0	310.1	0
Apr. H2	1.0000	27,648	201	569	26,960	0.3502E-04	0.1581E-03	0	0.3354E-04	0	0	0	0
May H1	0.8650	24,192	242	4,116	19,984	0.3955E-04	0.1786E-03	0	0.3789E-04	0	0	1723.9	0
May H2	1.0000	20,736	264	2,481	20,042	0.4560E-04	0.2059E-03	0	0.4369E-04	0	0	0	0
Jun. H1	1.0000	13,824	79	1,621	11,955	0.7234E-04	0	0	0	0	0	0	0
Largest PTE average= 0.9874													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3: IT	Output: PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
May H1	1.0000	24,192	242	4,116	19,984	0.1533E-04	0.2599E-02	0	0.7257E-04	0	0	0	0
May H2	1.0000	20,736	264	2,481	20,042	0.4823E-04	0	0	0.4122E-04	0	0	0	0
Jun. H1	1.0000	13,824	79	1,621	11,955	0.5605E-04	0	0.1389E-03	0	0	0	0	0
Jun. H2	1.0000	10,368	76	3,016	7,740	0.5605E-04	0	0.1389E-03	0	0	0	0	0
Jul. H1	0.9243	15,552	118	3,609	12,600	0.6430E-04	0	0	0.5496E-04	0	15.3	1646.3	0
Jul. H2	1.0000	22,646	240	3,054	19,370	0.1608E-04	0.3497E-02	0.4063E-04	0.8572E-04	0	0	0	0

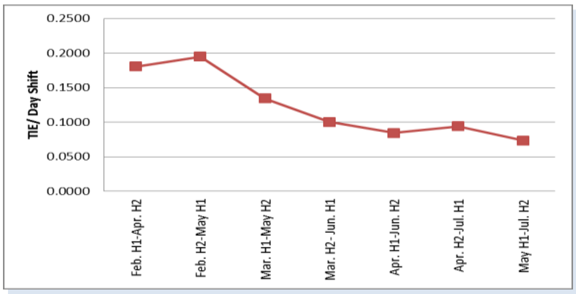


Figure 1. The TIE values for M1 in day shift over February-July 2014

Further, the PTE is a measure obtained by estimating the efficient frontier under the assumption of variable returns-to-scale and measures the technical efficiency without scale efficiency by comparing a production machine only to other machines of similar scale. In practice, the PTE purely reflects the managerial performance to organize the inputs in the production process. In Table 2 for the PTE values, the following results are obtained:

- The PTE for M1d in Mar. H2 (= 0.7066) implies that the same level of output could be produced by 70.66% of the resources if this unit was performing on the frontier taking into consideration that the scale size is ignored, also it is interpreted that 29.34% of overall resources could be saved by raising the performance of this machine to the highest level. In order for M1d in this half to become efficient, it needs to decrease one unit of Defect Quantity (DQ) and to decrease 3819 units of the Idle Time (IT). Finally, Apr. H2, May H2, Jun. H1, Jun. H2, and Jul. H2 lie on the efficiency frontier line and do not need to decrease any of the inputs. It is noticed that the number of periods identified efficient by BCC model are larger than that using CCR model.
- The PTE for Mar. H2-Jun. H1 incurs the smallest PTE average value (= 0.9159), the specific quantity of inputs that inefficient unit needs to decrease in order to become efficient are determined to stand on the efficiency frontier line ignoring the scale size. However, the May H1-Jul. H2 window corresponds to the largest PTE average value (= 0.9874). Using the BCC model some windows are identified highly-efficient, whereas none of the windows is found using the CCR model.
- The PTE for M1d in Jul. H1 (= 0.9243) implies that the same level of output could be produced by 92.43% of the resources if this unit was performing on the frontier taking into consideration that the scale size is ignored, also it is interpreted that 7.57% of overall resources could be saved by raising the performance of this machine to the highest level. In order for M1d in this half to become efficient, it needs to decrease 16 units of the Defect Quantity (DQ) and decrease 1647 units of the idle time in units (IT). M1d in May H1, May H2, Jun. H1, Jun. H2 and Jul. H2 lie on the efficiency frontier line and doesn't need to decrease any of the inputs. The columns in window DEA are used to

examine stability properties, the values for PTE of M1d showed a stable performance for all windows, for example PTE in Apr. H2 is (= 1.00) and frequented with the same value for three windows, also PTE in Jul. H1 is (= 0.9243) frequented with the same value for three windows.

- In Window DEA, the row window is monitored to identify the performance trends. For example, in the first row PTE average is (= 0.9326) with a standard deviation that is equal to (= 0.0744). The corresponding Coefficient of Variation (CV) for PTE values in all windows are larger than 5% except in the last window (May H1-Jul. H2), which means that there is a trend in the efficiencies of the same window.
- Applying the classification on PTE scores means that the first four windows are (Efficient) and the last three windows are (H-efficient). Figure 2 presents the pure technical inefficiency (PTIE) average values for M1d over February-July 2014. In this figure, a fluctuation in the PTIE average values during the first four windows then a decreasing trend in PTIE average values is observed starting March H2-Jun.H1 window. The maximum PTIE average value corresponds to March H2-Jun. H1. Typically, PTE is used to measure how a firm utilizes its resources under exogenous environments, hence the results reveal than M1d effectively utilizes its resources over the covered period; in other words, the managerial performance in organizing the inputs in the production process has been improved.

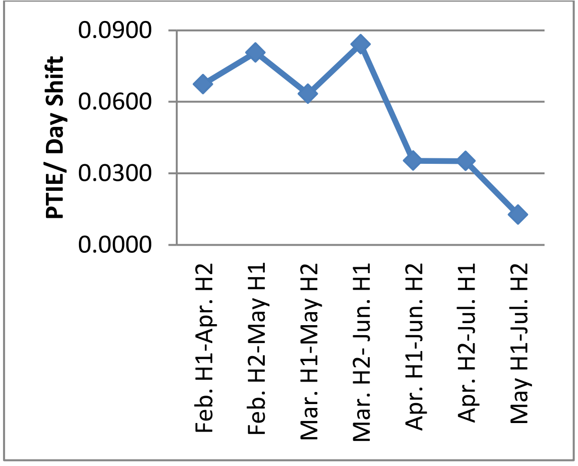


Figure 2. PTIE values for M1 in day shift over February-July 2014.

Furthermore, the SE measure provides the ability of the management to choose the optimum size of resources in order to choose the scale of production that will attain the expected production level. From Table 2, the following results are found:

- The largest SE average for M1d was (= 0.9802), which occurs in the fourth window (Mar. H2- Jun.H1), whereas the smallest SE average was (= 0.8712) which corresponds to the second window (Feb. H2-May H1). Applying the classification on SE scores, the first and the second windows are (Inefficient), the third window is (Efficient), the fourth and fifth windows are (H-efficient) and finally the sixth and last window are (Efficient).
- The values for SE of M1d showed a stable performance for all windows. For example, the SE in Mar. H2 of 0.7805 frequented repeated for three windows. In addition, the coefficient of variation (CV) for SE values in all of the windows for M1d was larger than 5% except in the fourth window (Mar. H2- Jun.H1) which means that there is a trend in the efficiencies of the same window.
- Figure 3 displays the scale inefficiency (SIE) average values for M1d over Feb.-July 2014, in which a decreasing trend in SIE average values starting Feb. H2-May H1 window till Mar. H2-Jun H2 window after which a slight increase in SIE average values is observed. Practically, the SE provides the ability of management to choose the optimum size of operations. Hence, the results reveal that the management reconsidered the scale of production that attained the maximum expected production level over the covered period.

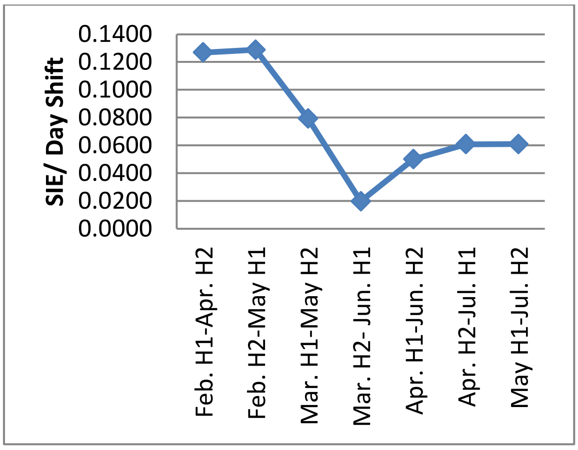
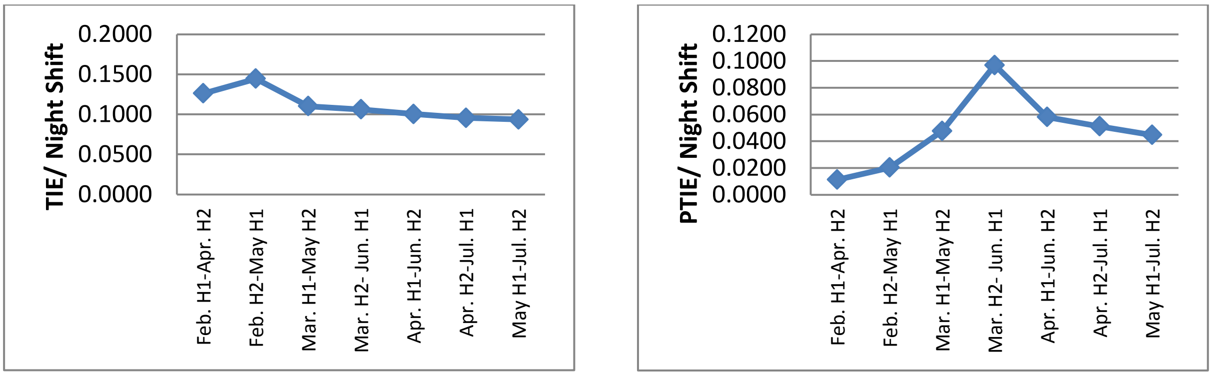


Figure 3. SIE values for M1 in day shift over February-July 2014.

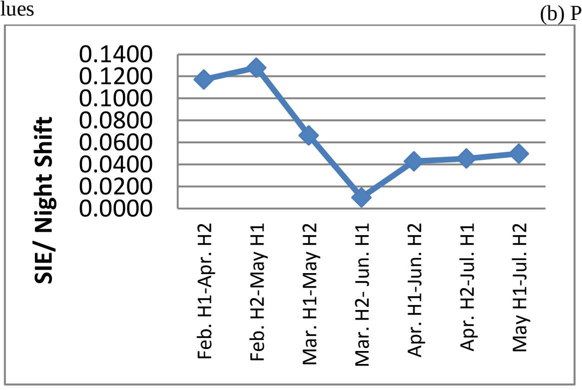
In a similar manner, the TE, PTE, SE values in Table 3 are analyzed for M1 in the night shift. Table 5 displays the obtained results for the smallest and largest TE and PTE values, where the needed reductions in which window inputs can be determined. The corresponding TIE, PTIE, and SIE values are depicted in Figure 4, where similar patterns to day shift are observed in the night shift. Finally, Table 6 displays the efficiency categories for M1 in the day and night shifts over Feb.-July 2014.

Table 5. The TE, PTE, inputs, output and slacks for of M1/n.

Smallest TE average= 0.8556													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3:IT	Output 1:PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
Feb. H2	0.6929	24,192	94	7,996	15,731	0.3255E-04	0.2261E-02	0	0.4405E-04	0	0	4331.9	0
Mar. H1	1.0000	24,192	69	3,149	21,419	0.3450E-04	0.2396E-02	0	0.4667E-04	0	0	0	0
Mar. H2	0.8032	24,192	97	6,414	18,359	0.3233E-04	0.2246E-02	0	0.4375E-04	0	0	3886.3	0
Apr. H1	0.8283	20,736	176	1,935	17,221	0.4823E-04	0	0	0.4810E-04	0	57.6	1571.9	0
Apr. H2	1.0000	27,648	142	51	27,720	0.3617E-04	0	0	0.3608E-04	0	0	0	0
May H1	0.8094	24,192	120	3,420	19,456	0.3074E-04	0.2135E-02	0	0.4160E-04	0	0	2538.8	0
Largest TE average= 0.9064													
DMU	θ	Input 1:PP	Input 2:DQ	Input 3:IT	Output 1:PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
May H1	0.8235	24,192	120	3,420	19,456	0.4134E-04	0	0	0.4233E-04	0	52.7	1839.3	0
May H2	0.9687	20,736	53	2,081	19,616	0.4823E-04	0	0	0.4938E-04	0	4.8	1030.7	0
Jun. H1	1.0000	13,824	32	678	13,500	0.7234E-04	0	0	0.7407E-04	0	0	0	0
Jun. H2	0.8215	10,368	73	2,855	8,318	0.9645E-04	0	0	0.9877E-04	0	40.3	1927.7	0
Jul. H1	0.8790	15,552	115	2,962	13,350	0.6430E-04	0	0	0.6584E-04	0	69.4	1933.2	0
Jul. H2	0.9459	22,464	245	2,339	20,750	0.4416E-04	0	0	0.4522E-04	0	180.7	1152.5	0
Smallest PTE average= 0.9031													
DMU	θ	Input 1: PP	Input 2: DQ	Input 3: IT	Output: PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
Mar. H2	0.7669	24,192	97	6,414	18,359	0.4134E-04	0	0	0.4018E-04	0	4.8	4453.8	0
Apr. H1	0.8411	20,736	176	1,935	17,221	0.4823E-04	0	0	0.4688E-04	0	87.3	113.6	0
Apr. H2	1.0000	27,648	142	51	27,720	0.3617E-04	0	0	0.3516E-04	0	0	0	0
May H1	0.8108	24,192	120	3,420	19,456	0.4134E-04	0	0	0.4018E-04	0	19.2	2356.4	0
May H2	1.0000	20,736	53	2,081	19,616	0.4409E-04	0.1619E-02	0.7663E-03	0.5538E-04	0	0	0	0
Jun. H1	1.0000	13,824	32	678	13,500	0.3476E-04	0	0	0	0	0	0	0
Largest PTE average= 0.9888													
DMU	θ	Input 1: PP	Input 2: DQ	Input 3: IT	Output: PQ	Variables				Slack/Surplus			
						u1	u2	u3	v	PP	DQ	IT	PQ
Feb. H1	0.9554	24,192	185	1,426	22,300	0.4134E-04	0	0	0.2721E-04	0	24.6	395.79	0
Feb. H2	0.9703	24,192	94	7,996	15,731	0.3673E-04	0.1186E-02	0	0	0	0	4861.9	0
Mar. H1	1.0000	24,192	69	3,149	21,419	0.2740E-04	0.1681E-02	0.7019E-04	0	0	0	0	0
Mar. H2	0.9669	24,192	97	6,414	18,359	0.3659E-04	0.1182E-02	0	0	0	0	3333.9	0
Apr. H1	1.0000	20,736	176	1,935	17,221	0.2740E-04	0.1681E-02	0.7019E-04	0	0	0	0	0
Apr. H2	1.0000	27,648	142	51	27,720	0.3617E-04	0	0	0.2381E-04	0	0	0	



(a) TIE values (b) PTIE values



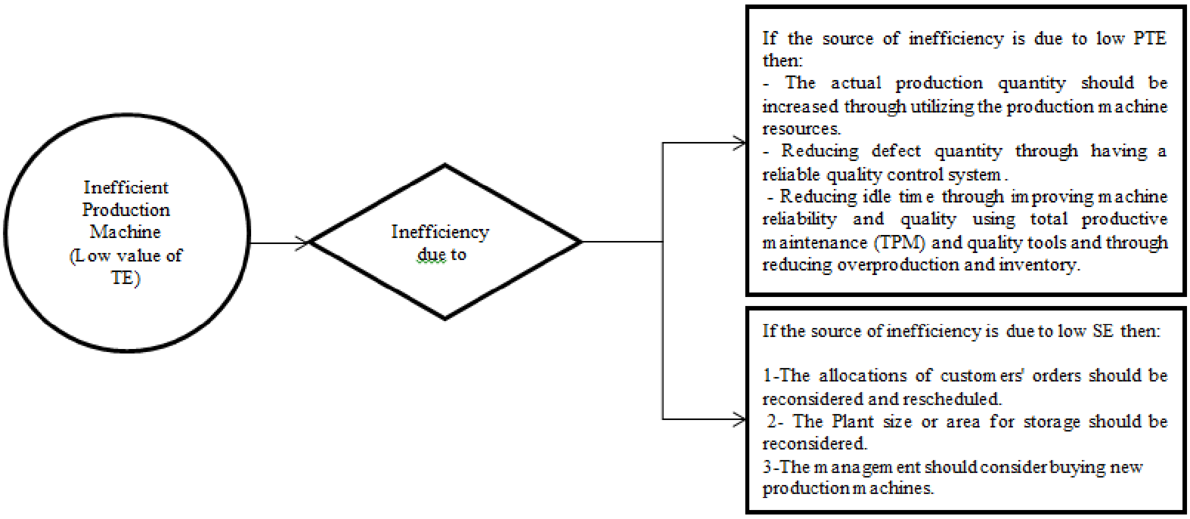
(c) SIE values.

Figure 4. SIE values for M1 in night shift over February-July 2014.

Table 6 displays a classification of TE, PTE, and SE efficiency values in each window for M1 in the day and night shifts. Figure 5 suggests the recommended actions to improve the efficiency values. Decomposing technical efficiency scores into PTE and SE provides guidance on what can be achieved in the short and long terms. If the majority of inefficiency in any production machine is due to low value of SE which means a small size of operations, then the machine needs to be expanded. On the other hand, the PTE value can be usually addressed in the short term without changing the scale of operations; low value of PTE is due to managerial underperformance problem in organizing the inputs in the production process. It should be noted that it is easier to reduce the TIE than to reduce SIE; only when a production machine becomes technically efficient does it make sense to deal with SIE, so production manager should focus on removing the TIE of those production machines before addressing ways to restructure the scale of operation. Following this reasoning, the five blowing machines that were not efficient can be evaluated based on the PTE and SE scores. For example, in Table 6, the TE for M1d in the first window (Feb. H1-Apr. H1) of 0.8193 is considered inefficient because of low SE (= 0.8732), PTE in this window is 0.9326. Then, the low TE value in this window is attributed to the low performance in scale efficiency and the expansion is the solution in this case. Moreover, the TE for M1n in the fourth window of 0.8938 is inefficient because of low PTE (= 0.9031), SE in this window is 0.9899. Then, the low TE value in this window is attributed to the low performance in PTE due to low utilization of the inputs or a problem in transforming inputs into outputs and the number of actual production quantity of the product should be increased. To summarize, for M1 in the day shift the TE values of the first four windows are inefficient due to the low values of SE. However, the TE values are improved in the last three windows due to an improvement in TE values, i.e., reflected through the decrease of DQ and IT plus the increase of output PQ, due to the improvement in the PTE and SE values.

Table 6. Efficiency categories for M1 in the day and night shifts over February-July 2014.

	M1 / Day Shift						M1 / Night Shift					
Window	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category
Feb. H1-Apr. H2	0.8193	Inefficient	0.9326	Efficient	0.8732	Inefficient	0.8740	Inefficient	0.9888	H-Efficient	0.8828	Inefficient
Feb. H2-May H1	0.8051	Inefficient	0.9194	Efficient	0.8712	Inefficient	0.8556	Inefficient	0.9798	H-Efficient	0.8722	Inefficient
Mar. H1-May H2	0.8655	Inefficient	0.9367	Efficient	0.9208	Efficient	0.8898	Inefficient	0.9524	H-Efficient	0.9338	Efficient
Mar. H2-Jun. H1	0.8996	Inefficient	0.9159	Efficient	0.9802	H-Efficient	0.8938	Inefficient	0.9031	Efficient	0.9899	H-Efficient
Apr. H1-Jun. H2	0.9157	Efficient	0.9648	H-Efficient	0.9500	H-Efficient	0.8997	Inefficient	0.9420	Efficient	0.9571	H-Efficient
Apr. H2-Jul. H1	0.9058	Efficient	0.9649	H-Efficient	0.9392	Efficient	0.9044	Efficient	0.9489	Efficient	0.9546	H-Efficient
May H1-Jul. H2	0.9267	Efficient	0.9874	H-Efficient	0.9391	Efficient	0.9064	Efficient	0.9554	H-Efficient	0.9502	H-Efficient



If the source of inefficiency is due to low PTE then:
- The actual production quantity should be increased through utilizing the production machine resources.
- Reducing defect quantity through having a reliable quality control system.
- Reducing idle time through improving machine reliability and quality using total productive maintenance (TPM) and quality tools and through reducing overproduction and inventory.

If the source of inefficiency is due to low SE then:

1-The allocations of customers' orders should be reconsidered and rescheduled.
2- The Plant size or area for storage should be reconsidered.
3-The management should consider buying new production machines.

Figure 5. Recommended actions for inefficiency reduction

Finally, a comparison of the TE, PTE, and SE values between the day and night shifts are presented in Figure 6. Obviously, there are slight differences in the TE, PTE, and SE values between the day and night shifts; that is, simalr patterns are exibited in both work shifts.

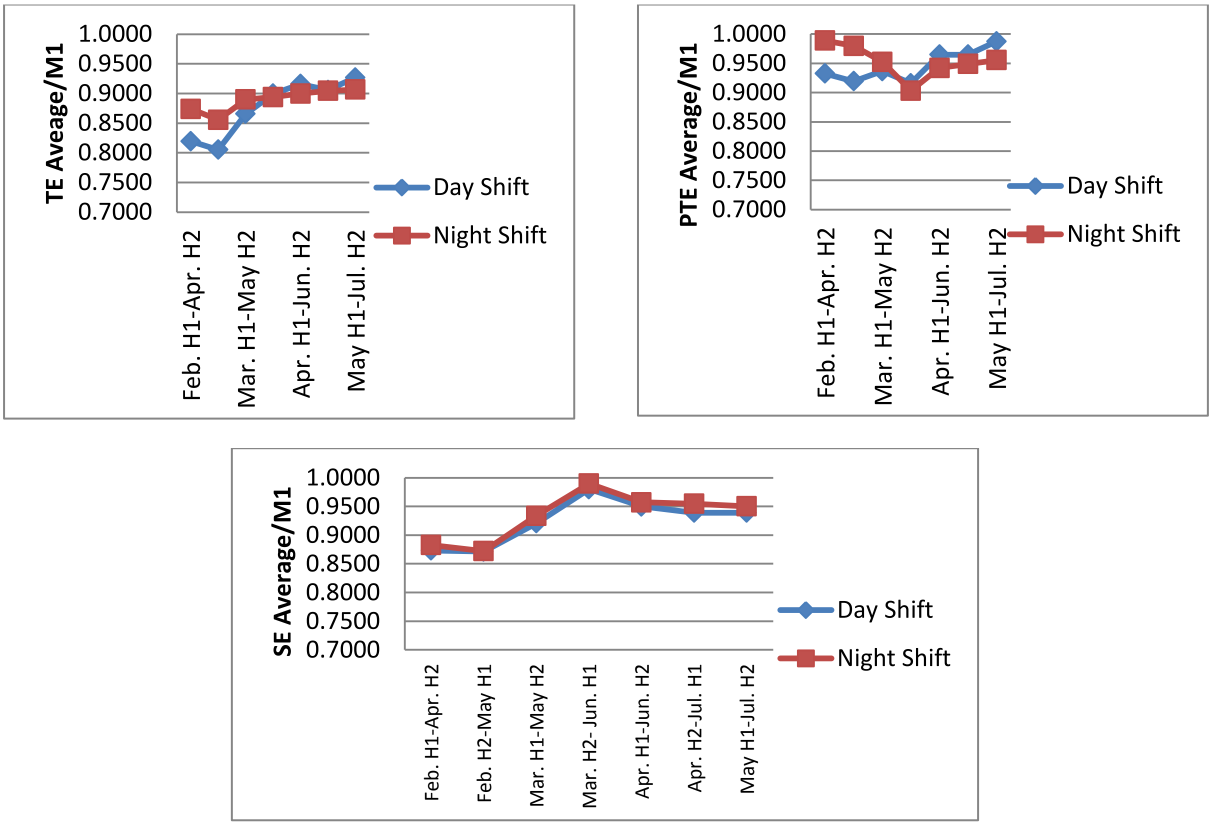


Figure 6. The TE, PTE, and SE average for M1 in day and night shifts over February-July 2014.

In a similar manner, the DEA window analysis is conducted for M2 to M5. The related classification of machine TE, PTE, and SE values in both day and night shifts are displayed in Tables 7 to 10, respectively.

Table 7. Efficiency categories for M2 in the day and night shifts over February-July 2014

	M2 / Day Shift						M2 / Night Shift					
Window	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category
Feb. H1-Apr. H2	0.9601	Hi-Efficient	0.9968	Hi-Efficient	0.9633	Hi-Efficient	0.9719	Hi-Efficient	0.9837	Hi-Efficient	0.9881	Hi-Efficient
Feb. H2-May H1	0.9605	Hi-Efficient	0.9912	Hi-Efficient	0.9690	Hi-Efficient	0.8459	Inefficient	0.9192	Efficient	0.9222	Efficient
Mar. H1 -May H2	0.9605	Hi-Efficient	0.9912	Hi-Efficient	0.9690	Hi-Efficient	0.8859	Inefficient	0.9397	Efficient	0.9421	Efficient
Mar. H2-Jun. H1	0.9605	Hi-Efficient	0.9910	Hi-Efficient	0.9692	Hi-Efficient	0.8852	Inefficient	0.9423	Efficient	0.9386	Efficient
Apr. H1-Jun. H2	0.8945	Inefficient	0.9585	Hi-Efficient	0.9332	Efficient	0.9164	Efficient	0.9270	Efficient	0.9885	Hi-Efficient
Apr. H2-Jul. H1	0.8767	Inefficient	0.9782	Hi-Efficient	0.8967	Inefficient	0.9150	Efficient	0.9627	Hi-Efficient	0.9517	Hi-Efficient
May H1-Jul. H2	0.8767	Inefficient	0.9861	Hi-Efficient	0.8891	Inefficient	0.9217	Efficient	0.9696	Hi-Efficient	0.9515	Hi-Efficient

Table 8. Efficiency categories for M3 in the day and night shifts over February-July 2014

	M3 / Day Shift						M3 / Night Shift					
Window	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category
Feb. H1-Apr. H2	0.9583	Hi-Efficient	0.9792	Hi-Efficient	0.9786	Hi-Efficient	0.9576	Hi-Efficient	0.9797	Hi-Efficient	0.9773	Hi-Efficient
Feb. H2-May H1	0.9374	Efficient	0.9635	Hi-Efficient	0.9735	Hi-Efficient	0.9283	Efficient	0.9647	Hi-Efficient	0.9630	Hi-Efficient
Mar. H1-May H2	0.9114	Efficient	0.9397	Efficient	0.9705	Hi-Efficient	0.9352	Efficient	0.9647	Hi-Efficient	0.9700	Hi-Efficient
Mar. H2-Jun. H1	0.8862	Inefficient	0.9275	Efficient	0.9560	Hi-Efficient	0.9336	Efficient	0.9717	Hi-Efficient	0.9615	Hi-Efficient
Apr. H1-Jun. H2	0.9063	Efficient	0.9441	Efficient	0.9598	Hi-Efficient	0.9502	Hi-Efficient	0.9857	Hi-Efficient	0.9639	Hi-Efficient
Apr. H2-Jul. H1	0.8858	Inefficient	0.9495	Efficient	0.9340	Efficient	0.9262	Efficient	0.9838	Hi-Efficient	0.9406	Efficient
May H1-Jul. H2	0.9248	Efficient	0.9693	Hi-Efficient	0.9536	Hi-Efficient	0.9219	Efficient	0.9552	Hi-Efficient	0.9652	Hi-Efficient

Table 9. Efficiency categories for M4 in the day and night shifts over February-July 2014

	M4 / Day Shift						M4 / Night Shift					
Window	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category
Feb. H1-Apr. H2	0.9703	Hi-Efficient	0.9958	Hi-Efficient	0.9744	Hi-Efficient	0.9755	Hi-Efficient	1.0000	Hi-Efficient	0.9755	Hi-Efficient
Feb. H2-May H1	0.9353	Efficient	0.9789	Hi-Efficient	0.9555	Hi-Efficient	0.9582	Hi-Efficient	0.9953	Hi-Efficient	0.9628	Hi-Efficient
Mar. H1-May H2	0.9441	Efficient	0.9845	Hi-Efficient	0.9593	Hi-Efficient	0.9581	Hi-Efficient	0.9832	Hi-Efficient	0.9748	Hi-Efficient
Mar. H2-Jun. H1	0.9556	Hi-Efficient	0.9841	Hi-Efficient	0.9712	Hi-Efficient	0.9688	Hi-Efficient	0.9825	Hi-Efficient	0.9862	Hi-Efficient
Apr. H1-Jun. H2	0.9473	Efficient	0.9851	Hi-Efficient	0.9618	Hi-Efficient	0.9639	Hi-Efficient	0.9822	Hi-Efficient	0.9816	Hi-Efficient
Apr. H2 -Jul. H1	0.9033	Efficient	0.9753	Hi-Efficient	0.9230	Efficient	0.9661	Hi-Efficient	0.9862	Hi-Efficient	0.9798	Hi-Efficient
May H1-Jul. H2	0.9681	Hi-Efficient	0.9739	Hi-Efficient	0.9940	Hi-Efficient	0.9727	Hi-Efficient	0.9796	Hi-Efficient	0.9930	Hi-Efficient

Table 10. Efficiency categories for M5 in the day and night shifts over February-July 2014

	M5 / Day Shift						M5 / Night Shift					
Window	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category	TE Avg.	Category	PTE Avg.	Category	SE Avg.	Category
Feb. H1-Apr. H2	0.9819	Hi-Efficient	0.9851	Hi-Efficient	0.9965	Hi-Efficient	0.9299	Efficient	0.9775	Hi-Efficient	0.9510	Hi-Efficient
Feb. H2-May H1	0.9797	Hi-Efficient	0.9841	Hi-Efficient	0.9953	Hi-Efficient	0.9523	Hi-Efficient	0.9888	Hi-Efficient	0.9631	Hi-Efficient
Mar. H1-May H2	0.9604	Hi-Efficient	0.9990	Hi-Efficient	0.9614	Hi-Efficient	0.9410	Efficient	1.0000	Hi-Efficient	0.9410	Efficient
Mar. H2-Jun. H1	0.9645	Hi-Efficient	0.9787	Hi-Efficient	0.9853	Hi-Efficient	0.9272	Efficient	0.9500	Hi-Efficient	0.9761	Hi-Efficient
Apr. H1-Jun. H2	0.9385	Efficient	0.9646	Hi-Efficient	0.9726	Hi-Efficient	0.9272	Efficient	0.9500	Hi-Efficient	0.9761	Hi-Efficient
Apr. H2-Jul. H1	0.9140	Efficient	0.9369	Efficient	0.9747	Hi-Efficient	0.9444	Efficient	0.9653	Hi-Efficient	0.9785	Hi-Efficient
May H1-Jul. H2	0.9346	Efficient	0.9553	Hi-Efficient	0.9774	Hi-Efficient	0.9490	Efficient	0.9698	Hi-Efficient	0.9788	Hi-Efficient

5. Conclusions

The present research study successfully evaluated the efficiency of five blowing machines in a plastics industry using DEA window analysis in both day and night shifts during the period Feb., 2014 to Jun., 2014. The production quantity is set as the output, whereas the defect quantity and idle time (units) are set as the inputs for all windows. The technical, pure technical, and scale efficiency values are then calculated. A comparison is conducted between the day and night shifts for each machine. Moreover, comparisons are performed among the efficiency of the five machines in both day and night shifts. Improvement actions are finally suggested to reduce the inefficiency. It is found that there exist significant differences between day and night shifts for each machine. Thus, managerial as well as operational actions are required to improve the process performance. If the source of inefficiency is due to low PTE, then production engineers should increase the actual production quantity through utilizing the production machine resources, reduce defect quantity through having a reliable quality control system, and/or reduce idle time through improving machine reliability and quality using Total Productive Maintenance (TPM) and quality tools and through reducing overproduction and inventory. On the other hand, if the source of inefficiency is due to low SE, then the production engineer should reconsider and reschedule the allocations of customers' orders, the plant size or the area for storage, and/or purchase new production machines.

The thorough analysis and discussion of the results in the present paper provide a valuable evaluation to production managers for improving the performance of blowing processes.

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