A data envelopment analysis approach for measuring the efficiency in continuous manufacturing lines: a case study

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Abstract: In the competitive contemporary world, every company tries to gain competitive edge. In order to gain which, managers need to consider and analyse the performance of their organisations and decide to improve it. There are various approaches to evaluate the performance, in which the criterion of efficiency of understudy units is being placed in efficiency frontier: Data envelopment analysis is one of these approaches that are designed in two radial and non-radial categories. In this paper, the method applied is proposed to compare and analyse similar units of industry on the basis of industry criteria using data envelopment analysis. Industry criteria are considered as inputs and outputs to resolve this problem with DEA. This methodology specifies the strengths and weaknesses of each industry units from industry criteria viewpoints. For a better description, 12 of parallel manufacturing lines from Chadormalu mining-industry company were analysed on the basis of maintenance, product and quality criteria.

Keywords: data envelopment analysis; DEA; slacks-based measure; SBM; analysing; performance assessment; manufacturing lines.

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Hadi Shirouyehzad graduated in Iran in 1999 and 2002 with BS and MS degrees in Industrial Engineering. He achieved his PhD in Industrial Engineering in 2012 from the Research and Science Branch, Islamic Azad University, Tehran, Iran. Currently, he is a faculty member of the Department of Industrial Engineering at Najafabad Branch, Islamic Azad University, Isfahan, Iran. He is the author of two books and more than 85 published papers at national and international levels in refereed journals and conferences since 2003.
1 Introduction

Performance measurement and ranking have been the subjects of enormous interest for decision makers to improve their management strategies and to strengthen their competitive advantages (Tsou and Huang, 2010). Nowadays, increasing competition between industries has lead them to employ various methods in order to increase the productions and to reduce the expenses which makes them to be preserved in the circle of competition. During the last years, most of the industries and service organisations have optimised their performance due to increasing competition and therefore resulting cost pressure. The most important issue to consider in increasing the performance of industries is specifying reasons of priority and infirmity. Analysis and comparing industry units and specifying reasons of priority and infirmity are the most important challenges for industry managers (Tseng et al., 2009).

Data envelopment analysis (DEA) as a non-parametric approach is able to provide relative efficiency for a series of decision making units (DMUs) based on multiple inputs/outputs with no assumptions of production function (Tsou and Huang, 2010). It uses linear programming (LP) to assess the performance of similar operations and makes an efficiency frontier for DMUs being evaluated (Sueyoshi et al., 2009). In their original DEA model, Charnes, Cooper and Rhodes (CCR model) displayed that the efficiency of a DMU can be obtained as the maximum of the ratio of weighted outputs to weighted inputs, subject to the condition that the same ratio for all DMUs must be less than or equal to one.

The DEA model must be run n times, once for each DMU, to get the relative efficiency of all DMUs (Azadeh et al., 2011). The envelopment in CCR is constant returns to scale meaning that a proportional rise in inputs results in a suitable increase in outputs. Banker et al. (1984) developed the BCC model to calculate the pure technical efficiency of DMUs with reference to the efficient frontier. It also identifies whether a DMU is operating in increasing, decreasing or constant returns to scale. So, CCR models are a specific type of BCC models (Toloo et al., 2009). The analysis models of DEA include CCR model (CCR), Banker-Charnes-Cooper model (BCC), bilateral, slack-based measure, and the free disposal hull (FDH) model (Lovell and Pastor, 1999) that these models are chosen in order to resolve various problems considering qualification and type of problems.

Indeed, the main purpose of this paper is displaying suitable method of analysing similar units in industries in order to specify the strengths and weaknesses of each industry unit from the industry criteria viewpoints. In this study, the method of DEA is used in order to compare and analyse similar units in manufacturing systems. Since DEA methodology requires some inputs and outputs, industrial criteria are considered as outputs and inputs for analysing similar units. Paying attention to any of these criteria which are demonstrators of different industry aspects, strengths and weaknesses of industry can be better determined. As a result, this method helps to specify critical criteria and indicates the strength and the weak points on the basis of industry criteria and so, choosing better strategies for development. To examine the proposed method, parallel continuous manufacturing lines of Chadormalu mining-industry factory (CMIC) were analysed in order to specify the best line on the basis of performance criteria.
The rest of this paper is structured as follows. In Section 2, the related literature is reviewed. In Section 3, the DEA method and the basic models are described. In Section 4, methodology is presented and a case study in order to describe the issue better, is announced. Also, our results and discussion are displaced in Section 5.

2 Literature review

Various articles have been written to evaluate similar units in industries among which we can mention: Sheu and Peng (2003) used DEA approach to assess seven major manufacturers in Taiwan. In this paper,

1. a manufacturing management model was developed for notebook plants
2. performance indices of the firm were prioritised
3. effective improvement drivers were identified
4. production as a single output and the number of critical facilities and the number of labours were considered in order to identify inefficiencies and quantitative references for improving productivity targets.

Ertay and Ruan (2005) presented a decision making approach based on DEA for determining the most efficient number of operators and the efficient measurement of labour assignment in cellular manufacturing system (CMS). Output variables are average operator utilisation and average lead time. However, number of operators, demand level and transferring batch size were considered as inputs of DEA model. Both inputs and outputs are procured by means of simulation of CMS.

Chiou and Chen (2006) proposed DEA approach to evaluate the performance of domestic air routes from the perspectives of cost efficiency, cost effectiveness and service effectiveness. A total of 15 routes operated by a Taiwanese domestic airline were examined. Three input variables, two production variables and two service variables were selected from the regression analysis.

Sofianopoulou (2006) presented an application of cellular manufacturing techniques and the evaluation of alternative production scenarios. The behaviour of the manufacturing system as a whole, for each one of the different scenarios, was investigated using the discrete events simulation technique for a period of two years. Finally, DEA was employed to evaluate the efficiency of each scenario. Results indicated that more than one of these scenarios could be efficient, while significant improvements can be achieved without actually changing the basic production parameters.

Düzakın and Düzakın (2007) recommended appropriate inputs and outputs to measure firms’ performance under different perspective. Data obtained from 500 major industrial enterprises of Turkey was used in this analysis.

Jablonsky (2007) determined how the AHP models can be used for the efficient evaluation of production units, and to compare the results given by the proposed Interval AHP model with the efficiency scores computed by DEA models.

Hashimoto and Haneda (2008) presented a DEA/Malmquist index methodology for measuring the change in R&D efficiency at both firm and industry levels. In this study, each of ten firms in each year considered as a separate decision-making unit, and employing one input and three outputs in a DEA case of R&D activity input-output lag.
Sangwan and Digalwar (2008) developed a multi attribute decision model, i.e., performance value analysis (PVA) for the evaluation of WCM systems. In this paper, a set of validated critical success criteria and their performance variables for WCM industries was presented. The reliability and validity analyses were carried out by using the SPSS® 11.5 statistical tool on the data.

Rehman and Babu (2009) presented an approach for the assessment of alternative configurations using multiple criteria. They considered a manufacturing system which produces 30 products using different conventional machines and process plans for each product. This system was simulated using ProModel 6.2. Subsequently, eight different alternative configurations were simulated, each under 24 experiments. They used Elimination and Choice-Translating Algorithm (ELECTRE) in order to analyse alternative configurations.

Sueyoshi and Goto (2010) investigated a linkage among environmental, operational and financial performance in Japanese manufacturing industry. They used DEA as an evaluation methodology.

Yu and Hu (2010) developed an integrated MCDM approach that combines the voting method and the fuzzy TOPSIS method to assess the performance of multiple manufacturing plants in a fuzzy environment. Fuzzy TOPSIS helps decision-makers carry out analysis and comparisons in ranking their preference of the alternatives with vague or imprecise data. Since the assessment result is often greatly affected by the weights used in the evaluation process, they employed the voting method in this study to determine the appropriate criteria weights.

Du et al. (2010) proposed two planning ideas. The first one is optimising the average or overall production performance of the entire organisation, measured by the CCR efficiency of the average input and output levels of all units. The other is simultaneously maximising total outputs produced and minimising total inputs consumed by all units. According to these two ideas, they developed two DEA-based production planning approaches to find the most preferred production plans. All these individual units, considered as DMUs, are supposed to be able to modify their input usages and output productions.

Jain et al. (2011) presented a DEA-based approach for performance measurement and target setting of manufacturing systems. The approach is applied to two different manufacturing environments. The potential of a DEA-based generic performance measurement approach for manufacturing systems is provided. They used DEA to analyse two real scenarios, assembly line and wafer manufacturing.

Jayachitra and Prasad (2011) presented a simulation model in order to evaluate performance of virtual cellular layout, functional layout and cellular layout of an automotive component manufacturing industry. The results indicated that the performance of virtual cellular layout was relatively superior to that of functional layout and marginally inferior to cellular layout in terms of cost and other performance.

Lin and Pearn (2011) presented a systematic approach of test order \( k \) compares selected pairs of manufacturing lines along with the Bonferroni method, to screen a group of manufacturing lines and recognise the best one with the highest return.

Yalcin et al. (2012) developed a new financial performance assessment approach to rank the companies of each sector in the Turkish manufacturing industry. They made a hierarchical financial performance evaluation model based on the AFP and VFP main-criteria and their sub-criteria. They employed fuzzy analytic hierarchy process in
order to calculate the weights of the criteria. They ranked the companies according to their own manufacturing sector by utilising TOPSIS and VIKOR comparatively.

3 Data envelopment analysis

Farrell (1957) displayed a new method of measuring the productive efficiency of firms or DMUs to the Royal Statistical Society. Farrell constructed a piece-wise linear technology representing the best practice methods of production and then used LP to appraise a radial measure of technical efficiency. Two decades later, CCR (Charnes et al., 1978) and BCC (Banker et al., 1984), expanded and popularised Farrell’s method, naming it DEA. So far, numerous applications, extensions, and modifications of DEA have appeared in professional journals and books. In recent years DEA has been utilised in a large variety of applications for evaluating the performance of different systems. Through DEA, it has also been possible to acquire new perception into systems that until then were extremely complicated to study because of the number and nature of parameters involved. DEA employs mathematical programming techniques to evaluate the efficiency of homogeneous DMUs, where DMUs can be, for instance, universities units, retail stores, bank branches, etc. The efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs (Sofianopoulou, 2006).

The DEA methodology calculates a measure of the relative efficiency of each DMU. This is performed by comparing each DMU to all of the remaining ones. The problem of evaluating each DMU is formulated as a linear programme. Estimating the performance of n different DMUs involves the solution of n unusual LP problems. It is well known that adding or deleting an inefficient DMU does not alter the efficiencies of the existing DMUs and the efficient frontier. The inefficiency scores change only if the efficient frontier is altered. The performance of DMUs depends only on the identified efficient frontier, characterised by the DMUs with a unity efficiency score (Charnes et al., 1978).

If the performance of inefficient DMUs declines or improves, the efficient DMUs still may have a unity efficiency score. Although the performance of inefficient DMUs depends on the efficient DMUs, efficient DMUs are only characterised by an efficiency score of one. The performance of efficient DMUs is not influenced by the presence of inefficient DMUs. However, the appraisal is often influenced by the context. A DMUs performance will appear more attractive against a background of less attractive alternatives and less attractive when compared to more interesting alternatives (Yao and Iqbal, 2002). The efficiency score in the presence of multiple input and output factors is determined as:

\[
\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}
\]

Assuming that there are n DMUs, each with m inputs and s outputs, the relative efficiency score of a test DMU \( p \) is obtained by solving the following model (Charnes et al., 1978):

\[
\begin{align*}
\max & \quad \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \\
\text{s.t.} & \quad \sum_{k=1}^{s} v_k y_{kp} - \sum_{j=1}^{m} u_j x_{jp} = 0, \\
& \quad v_k, u_j \geq 0.
\end{align*}
\]
A DEA approach for measuring the efficiency in continuous manufacturing lines

\[
S.t. \quad \sum_{k=1}^{s} v_k y_{ki} \geq \sum_{j=1}^{m} u_j x_{ji}, \quad \forall i
\]

\[v_k, u_j \geq 0 \quad \forall k, j\]

where

- \( K \) 1 to \( s \)
- \( j \) 1 to \( m \)
- \( I \) 1 to \( n \)
- \( y_{ki} \) amount of output \( k \) produced by DMU \( i \)
- \( x_{ji} \) amount of input \( j \) utilised by DMU \( i \)
- \( v_k \) weight given to output \( k \)
- \( u_j \) weight given to input \( j \).

### 3.1 CCR model

The CCR input-oriented model (2) minimises the inputs while keeping the outputs at current levels.

\[
\text{Max } Y_p = \sum_{r=1}^{s} Y_{rp} U_r, \quad (2)
\]

S.t.

\[
\sum_{r=1}^{s} Y_{rp} U_r = \sum_{i=1}^{m} x_{ip} V_i \leq 0, \quad (j = 1, 2, \ldots)
\]

\[
\sum_{i=1}^{m} V_i X_{ip} = 1,
\]

\[
U_r, V_i \geq 0
\]

### 3.2 BCC model

The CCR model is designed with the assumption of constant returns to scale. This means that there is no assumption that any positive or negative economies of scale exist. In order to refer this, BCC developed the BCC model (Banker et al., 1984).

\[
\text{Max } Y_p = \sum_{r=1}^{s} Y_{rp} U_r + W, \quad (3)
\]

S.t.

\[
\sum_{j=1}^{m} Y_{jp} U_r = \sum_{i=1}^{m} x_{ip} V_i + W \leq 0, \quad (j = 1, 2, \ldots)
\]

\[
\sum_{i=1}^{m} V_i X_{ip} = 1,
\]
$U_i, V_j \geq 0, \ W \text{ is free}$

3.3 SBM model

The second adaptation to the basic CCR model is the slacks-based measure (SBM) of efficiency, the motivation for the development of this model is the observation that while both the CCR and the BCC models estimate efficiency scores neither is able to take into account the resulting amount of slack for inputs and outputs. The explanation of a SBM of efficiency will be given, along with its interpretation as a product of input and output inefficiencies before description of SBM model, properties are considered as important an designing the measures.

- (P1) units invariant: the measure must be in variant with respect to the units of data
- (P2) monotone: the measure must be monotone decreasing in each slack in input and output
- (P3) translation invariant: the measure must be invariant under parallel translation of the coordinate system applied (Poster, 1996)
- (P4) reference-set dependent: the measure must be determined only be consulting the reference-set of the DMU concerned.

We will deal with $n$ DMUs with the input and output matrices $X = (x_{ij}) \in \mathbb{R}^{m \times n}$ and $Y = (y_{ij}) \in \mathbb{R}^{s \times n}$ respectively. We assume that the data set is positive, i.e., $x > 0$ and $y > 0$.

The production possibility set is $P$ defined as:

$$p = \{(x, y) | x \geq X \geq \lambda, y \leq Y, \lambda \geq 0\}.$$ (4)

where $\lambda$ is a non-negative vector in $\mathbb{R}^n$ (we can impose some constraints on $\lambda$, such as $\sum_{j=1}^{n} \lambda_j = 1$ (the BCC model), if it is needed to modify the production possibility set.)

we consider an expression for describing a certain DMU $(x_0, y_0)$ as:

$$x_0 = X_A + S^-,$$ (5)

$$y_0 = y_A - S^+.$$ (6)

With $\lambda \geq 0, S^- \geq 0, S^+ \geq 0$. The vectors $S^- \in \mathbb{R}^m$ and $S^+ \in \mathbb{R}^s$ show the input excess and output shortfall of this expression, respectively, and are called slacks. From the conditions $X \geq 0$ and $\lambda \geq 0$, it holds:

$$x_0 \geq S^-,$$ (7)

Using $S^-$ and $S^+$, index $\rho$ is defined as follows:

$$\rho = \frac{1 - \left(\frac{1}{m}\right) \sum_{i=1}^{m} S^- / X_{i0}}{1 - \left(\frac{1}{s}\right) \sum_{r=1}^{s} S^+ / y_{r0}},$$ (8)
It can be verified that $\rho$ satisfies the properties (P1) (unites invariant) and (P2) (monotone). Furthermore, from (7) it holds:

$$0 < \rho \leq 1$$  \hspace{1cm} (9)

In an effort to estimate the efficiency of $(x_0, y_0)$, we formulate the following fractional programme in $\lambda$, $S^+$ and $S^-$ (Tone, 2001).

Slack-based measure model displayed to multiple aspects: (Tone and Tsutsui, 2010)

- **Primal model**

$$\text{Max } Y_p = \sum_{j=1}^{s} Y_p u_j - \sum_{i=1}^{m} X_ip + W$$  \hspace{1cm} (10)

s.t.

$$\sum_{j=1}^{s} Y_p u_j - \sum_{i=1}^{m} X_ip + W \leq 0 \hspace{1cm} (j = 1, 2, \ldots, n)$$

$$\sum_{r=1}^{s} u_r \geq 1 \hspace{1cm} (r = 1, 2, \ldots, s)$$

$$\sum_{i=1}^{n} v_i \geq 1 \hspace{1cm} (i = 1, 2, \ldots, m)$$

$U_r, V_i \geq 0, W$ is free

- **Dual model**

$$\text{Min } Z = -\sum_{r=1}^{s} S_r^+ - \sum_{i=1}^{n} S_i^-$$  \hspace{1cm} (11)

s.t.

$$\sum_{j=1}^{s} Y_p u_j - S_r^+ = Y_{ip} \hspace{1cm} (r = 1, 2, \ldots, s)$$

$$\sum_{i=1}^{m} X_ip - S_i^- = Y_{ip} \hspace{1cm} (i = 1, 2, \ldots, m)$$

$$\sum_{j=1}^{n} = 1 \hspace{1cm} (j = 1, 2, \ldots, n)$$

$\lambda_j, S_r^+, S_i^- \geq 0$

4 **Methodology and case study**

Comparing and analysing similar units are among the most serious problems of managers of companies. Analysis and comparison can help manufacturing companies investigate their performance considering various criteria and signify their strong and weak points. Decisions taken in organisations are generally based on the results of various units’ analysis and their comparisons in different time periods. It is worth mentioning that it is ideal if the comparison and analysis have been done based on different criteria.
A number of methods for comparison and analysis has been presented, one of which is DEA. DEA that is a mathematical programming method for evaluating the relative efficiency of DMUs with multiple outputs and inputs. The DEA is designed to measure relative efficiency in situations that there are one or multiple inputs and outputs. The goal of this method is to estimate a ratio of total weighted output to total weighted input. This ratio is the relative efficiency of a DMU. The strength of the DEA is allowing each DMU to choose the weights that maximise its own efficiency. On the other hand, the efficiency does not mean that the DMUs are absolutely efficient but they are efficient among the other units.

In this paper, a practical methodology is proposed to specify the strength and the weak points of each manufacturing unit considering industry criteria. This methodology helps the managers to have better understanding of their performance to make proper decisions. It also helps them to specify the best and the worst industry units in the viewpoint of performance. Also, using this methodology, one can specify significant criteria that increase the performance of manufacturing units. In addition, it helps them to recognise which of these criteria are the most important ones to increase manufacturing lines performance. This methodology tries to provide an appropriate pattern for other industry units. The suggested method in this paper has been clarified exploiting a case study.

For a better description, parallel continuous manufacturing lines of CMIC were compared through the displayed methodology in this paper, and specified the best line on the basis of industry criteria. CMIC is located between the cities of Yazd and Tabas at the centre of Iran and produces iron concentrate. This factory, converts iron stone to iron concentrate through chemical and physical operations. Due to the great volume of production and the critical role of this product in industrial development of Iran, this company is considered as one of the most important production companies of the country. This plant has 12 parallel manufacturing lines that manufacturing method and equipments are similar in each one.

The procedure of displaced methodology in this paper goes as follow:

\subsection{Determining and calculating important criteria}

Multiple criteria for comparison and ranking should come into consideration. Traditional single-criterion decision-making is no longer able to handle analysis properly. Maybe one unit of organisation is better than other units on the basis of one criterion but is not better on the basis of other criteria. To this point, various criteria for comparison should be considered. Selection of proper variables to define and to evaluate efficiency is always an extremely important decision. It is especially in using DEA for such evaluation and measurements as different outcomes may result from different set of variables used on the very same set of units. All of criteria that are used to analyse manufacturing lines in CMIC are divided to three aspects. Important criteria for CMIC were specified and quantities of these criteria for one work year were calculated, the result of which is shown in Table 1.
### Table 1: Quantities of criteria

<table>
<thead>
<tr>
<th>Line</th>
<th>Maintenance criteria</th>
<th>Product criteria</th>
<th>Quality criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line MTBF</td>
<td>MTTR</td>
<td>SN</td>
</tr>
<tr>
<td>1</td>
<td>55.24</td>
<td>1.06</td>
<td>156</td>
</tr>
<tr>
<td>2</td>
<td>55.11</td>
<td>1.20</td>
<td>156</td>
</tr>
<tr>
<td>3</td>
<td>75.4</td>
<td>0.99</td>
<td>115</td>
</tr>
<tr>
<td>4</td>
<td>48.82</td>
<td>1.37</td>
<td>175</td>
</tr>
<tr>
<td>5</td>
<td>82.12</td>
<td>0.93</td>
<td>96</td>
</tr>
<tr>
<td>6</td>
<td>65.11</td>
<td>1.16</td>
<td>117</td>
</tr>
<tr>
<td>7</td>
<td>54.53</td>
<td>1.58</td>
<td>141</td>
</tr>
<tr>
<td>8</td>
<td>60.84</td>
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<td>129</td>
</tr>
<tr>
<td>9</td>
<td>84.04</td>
<td>0.11</td>
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</tr>
<tr>
<td>10</td>
<td>55.26</td>
<td>0.18</td>
<td>142</td>
</tr>
<tr>
<td>11</td>
<td>69.59</td>
<td>0.16</td>
<td>112</td>
</tr>
<tr>
<td>12</td>
<td>64.31</td>
<td>0.19</td>
<td>122</td>
</tr>
</tbody>
</table>
4.1.1 Maintenance criteria

- **MTBF**: Mean time between failures is the predicted elapsed time between inherent failures of a system during operation. MTBF can be calculated as the arithmetic mean (average) time between failures of a system (Moubray, 1991).

- **MTTR**: Mean time to repair is a basic measure of the maintainability of repairable items. It represents the average time required to repair a failed component or device (Moubray, 1991).

- **Stoppage numbers (SN)**
- **Stoppage times (ST)**.

4.1.2 Product criteria

- **Product (P)**: quantities of iron concentrate that produce with any line.
- **Feed (F)**: quantities of iron stone that feed to lines.
- **Water consumption (WC)**: quantities of water consume with any lines for produce.
- **Power consumption (PC)**: quantities of electricity consume with any lines for produce.
- **Ball consumption (BC)**: quantities of ball consume for grinding iron stone in lines.
- **Recovery% (R%)**: product/feed.

4.1.3 Quality criteria

- **Moisture % (M%)**: this indicator show moisture of iron concentrate produced.
- **FEO%**: this indicator is oxide of iron that is relevant to iron concentrate produced.
- **P%**: this indicator is grade of phosphor that is relevant to iron concentrate produced.
- **FE%**: this indicator is grade of iron that is relevant to iron concentrate produced.

Stoppage time and the number of stoppage are recorded daily by maintenance unit. However, MTTR and MTBF criteria are calculated monthly. Yet, quality criteria are calculated daily by central laboratory. Performance criteria are calculated three times in a day (one time in an eight hours shift). As considerable in Table 1, none of the manufacturing lines have the best performance in all criteria. For example, the best performance of manufacturing line nine refers to MTBF criterion (equal to 84.04 hours). However, this line is in the fourth rank according to the production criterion. Therefore, it is important to evaluate performance of line through multiple criteria. It is important to note that the units of measures are not similar. However this problem will be resolved in the third stage of methodology.
4.2 Determining type of criteria (outputs or inputs)

In order to use DEA, we need some outputs and inputs, to this point we consider industry criteria as outputs and inputs. In this stage, we should determine type of criteria to find out which of these criteria are outputs or inputs.

4.3 Normalising data

Calculation methods of these criteria are various and it may numbers of criteria has been very different, because its better which normalise quantities of criteria to solve this model with use of DEA. A glance at the quantities of criteria for manufacturing lines reveals that numbers are very different. It may influence on the results of analysis. Hence, quantities of criteria were normalised, the result are shown in Table 2.

Table 2  Normalised quantities of criteria

<table>
<thead>
<tr>
<th>Line</th>
<th>Maintenance criteria</th>
<th>Product criteria</th>
<th>Quality criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MTBF</td>
<td>MTTR</td>
<td>SN</td>
</tr>
<tr>
<td>1</td>
<td>0.245</td>
<td>0.228</td>
<td>0.342</td>
</tr>
<tr>
<td>2</td>
<td>0.244</td>
<td>0.256</td>
<td>0.342</td>
</tr>
<tr>
<td>3</td>
<td>0.334</td>
<td>0.212</td>
<td>0.252</td>
</tr>
<tr>
<td>4</td>
<td>0.216</td>
<td>0.294</td>
<td>0.383</td>
</tr>
<tr>
<td>5</td>
<td>0.364</td>
<td>0.199</td>
<td>0.210</td>
</tr>
<tr>
<td>6</td>
<td>0.289</td>
<td>0.249</td>
<td>0.256</td>
</tr>
<tr>
<td>7</td>
<td>0.242</td>
<td>0.338</td>
<td>0.309</td>
</tr>
<tr>
<td>8</td>
<td>0.270</td>
<td>0.208</td>
<td>0.283</td>
</tr>
<tr>
<td>9</td>
<td>0.372</td>
<td>0.234</td>
<td>0.206</td>
</tr>
<tr>
<td>10</td>
<td>0.245</td>
<td>0.151</td>
<td>0.311</td>
</tr>
<tr>
<td>11</td>
<td>0.308</td>
<td>0.182</td>
<td>0.245</td>
</tr>
<tr>
<td>12</td>
<td>0.285</td>
<td>0.618</td>
<td>0.267</td>
</tr>
</tbody>
</table>

4.4 Specifying weights of between criteria

Industries have different criteria that are generally divided to three aspects: maintenance, product and quality. Any of these criteria have special significance for any industry and significance of these criteria is different. To this point, the weight between criteria should be identified. The method of weight control by using opinion’s experts was employed to this model. In this stage, the importance of criteria is compared and questionnaire to calculate weights of these criteria was prepared. It is completed with the viewpoints of CMIC managers, and the results of weight control were applied as restrictions in this problem. Results of these comparisons are shown in Table 3.
Table 3  Weights of between criteria

<table>
<thead>
<tr>
<th>$U_4 \geq 3U_1$</th>
<th>$U_{11} \geq U_{14}$</th>
<th>$U_2 \geq U_1$</th>
<th>$U_3 \geq U_7$</th>
<th>$U_{10} \geq U_1$</th>
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<td>$U_6 \geq U_7$</td>
<td>$U_1 \geq 3U_2$</td>
</tr>
</tbody>
</table>

4.5 Determining suitable model to calculate efficiency

DEA has various models to resolve problems which include as: CCR, BCC, SBM and FDH models. The selection of any of these models is based on qualification and type of problems. Because all of data in our case study are the output type, we use slack-based model. The efficiency of continuous manufacturing lines was calculated with SBM model, results of calculating efficiency are shown in Table 4.

Table 4  Results of efficiency (SBM model)

<table>
<thead>
<tr>
<th>Inputs and Outputs</th>
<th>Line 1</th>
<th>Line 2</th>
<th>Line 3</th>
<th>Line 4</th>
<th>Line 5</th>
<th>Line 6</th>
<th>Line 7</th>
<th>Line 8</th>
<th>Line 9</th>
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<tr>
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<td>-0.331</td>
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</table>
4.6 Analysing and deduction

In the last stage, using the results of stage E, one can specify the strength and the weak points. Determining important criteria for any industry and analysing similar units in industry are based on important industry criteria. We can also specify a suitable pattern for other units and the reasons of inefficiency based on criteria.

5 Discussion

Manufacturing companies have always been following two general aims, increasing the efficiency and reducing the costs, using various methods. The most important goal that a company should pursue in order to achieve those goals, is determining the strong and weak points of company units. A comprehensive understanding of an organisation from its performance in different time periods and an investigation of their progression comparing with other organisations help find more appropriate strategies to enhance the efficiency, some of which may have little or no effect for the company. This issue occurs as a result of exploiting an inappropriate strategy among the existing strategies, or using a strategy for a part of the organisation which performs well and it was not necessary to apply various strategies there. Therefore, it is crucial for organisations to evaluate themselves with various criteria and focus more on the aspects in which the organisation was deficient. Consequently, an organisation should have comprehensive information from its performance.

Companies have different criteria and characteristics each of which represents an aspect of organisations through which they evaluate their performance in different time periods or use them to investigate different parts of their organisations. Organisations, concerning various criteria, exploit different methods to investigate their performance. Further comparison is done in two ways: comparing similar organisation units, or similar time periods. One of these methods is DEA. DEA is a mathematical programming method for evaluating the relative efficiency of DMUs with multiple outputs and inputs.

In this study, a new method to analyse similar units in manufacturing companies using DEA approach was presented. Production industries have different aspects including maintenance, quality, and production each of which own criteria through investigating which the organisation status can be specified. These criteria were considered as inputs and outputs of DEA problem and the efficiency of manufacturing lines was calculated using SBM model. Maintenance and quality and product criteria were considered as outputs and inputs in DEA method. Significance of these criteria is not equal, since importance of these criteria was specified. For this, the method of weight control was used. Weights between criteria are obtained through asking experts. In addition, because all data in this case study are output type, SBM model was employed to resolve the problem.

The above-mentioned method has been explained thoroughly in Section 4 and the results are as follows: Table 4 displays results of analysis of parallel manufacturing lines on the basis of maintenance and quality and production criteria in CMIC. DEA method displays line 12 has the best efficiency. The results of this method reveal that manufacturing line 12 is the only efficient line and the rest are inefficient. This method helps specify the best lines on the basis of performance. In fact, we can use line 12 as pattern for other lines. Indeed, line 12 helps specify the strength for other lines, criteria
that cause inefficiency and determines the distance of any of the lines from the ideal boundary and specifies important criteria for CMIC.

6 Conclusions

In fact, reasons for efficiency of the line 12 should be investigated by its performance on criteria. With more detailed attention, it can be concluded that production criteria are the main reason for this. Manufacturing line 12 has the best performance on BC, PC, WC and also this line is good at other criteria. Only in maintenance criteria it has a moderate performance which with its lower importance, it has less impact on the performance of the manufacturing line 12. Therefore, it can be concluded that production criteria are very important in determination of the efficiency of the manufacturing lines.

6.1 Research limitations and managerial implications

Inputs and outputs have effect on results of proposed method. Because of that, to analyse manufacturing lines, industry managers are supposed to employ inputs and outputs which are more important in the industry. In this study, criteria weights are according to experts’ opinion, because of that, they’re supposed to have sufficient information about criteria and their relation with each other.

The suggested method in this study may be applied in manufacturing systems that are similar to each others. Industrial managers may also employ this method to compare their organisation with others organisations, this method may also be utilised to evaluate other system as well. For instance, evaluating performance of hospitals, airline companies and so on. One of the most important advantages of presented method is analysing function of similar manufacturing units for large industries. Results extracted from this methodology makes managers able of choosing various strategies for improving this system. Another possible application of this approach for the management is comparing its own industry with other similar ones, and as a result he is able to identify its industry’s strengths and weaknesses, adopting proper solutions to eliminate weaknesses. One of the limitations in this method is the large amount of calculations to utilise it. And because of employing DEA, managers ought to be familiar with DEA models to analyse manufacturing units.

6.2 Future study

Industry managers may employ this method to assess their industry with similar industries. This research may be done with more inputs and outputs in other industries, manufacturing lines. In this study, DEA methodology is employed to analyse and compare manufacturing systems. For further researches multi-criteria decision making methods are suggested. A combination of multi-criteria decision making and GP method is also suggested for evaluating manufacturing systems. In this study 14 inputs and outputs are employed to compare manufacturing lines, while employing other inputs and outputs is also possible.
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References


