Supplier Evaluation Through Data Envelopment Analysis

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Abstract

In this paper, a methodology is proposed for evaluating the efficiency and performance of the suppliers through Data Envelopment Analysis (DEA) technique. DEA is a multifactor productivity technique to measure the relative efficiency of the decision making units. Super Efficiency and Cross Efficiency methods are employed in this work to determine the efficiencies and the performance scores of the suppliers respectively. A numerical illustration is presented to demonstrate the proposed methodology. Twenty three suppliers are considered in the study. Each supplier has six inputs and five outputs. On the basis of super efficiency and cross efficiency scores, the suppliers are classified into different clusters. The suppliers' performance – efficiency score grid is developed, which helps the management to take effective decision in the selection of the suppliers of a company.

Keywords: Supplier evaluation, Data Envelopment Analysis, Super efficiency, Cross efficiency

1. Introduction

In the present competitive business environment, management of a firm has to take wise decision regarding supplier evaluation. Most of the experts agreed that there is no best way to evaluate and select the suppliers, thus organizations adopt variety of approach. But the overall objectives of any approach is to reduce purchase risk and maximize overall value to the purchaser (Elanchezhian et al., 2010). Purchasing managers need to periodically evaluate supplier performance in order to retain those suppliers which meet their requirements in terms of several performance criteria (Petroni and Braglia, 2000). Traditionally, the price and the cost were used to be the predominant dimensions in the evaluation of supplier performance. Dickson conducted a study that investigated the importance of supplier evaluation criteria for industrial purchasing managers. The study concluded that cost, quality and delivery performance were the most important criteria in supplier evaluation (Srinivas and Narasimhan, 2004). Over the years, a number of supplier selection criteria have been developed to meet the objectives of the respective organizations. Ho et al. (2010) reviewed the articles about supplier selection from 2000 to 2008 and they concluded that the most popular criterion considered by the decision makers is quality, followed by delivery, price/cost, manufacturing capability, service, and management. Supplier evaluation is a multi-criteria decision making problem. There are different decision making techniques to tackle this issue. Timmerman (1986), proposed linear weighting models in which suppliers are rated on several criteria and these ratings are combined into a single score. Nydic and Hill (1992), used Analytic Hierarchy Process (AHP) to structure the supplier selection process. Tam and Tummala (2001), formulated AHP-based model and applied to a real case study to examine its feasibility in selecting a vendor for a telecommunications system. Handfield et al. (2002), integrated environment issues in their supplier assessment decisions with the help of AHP. Elanchezhian et al. (2010), made an attempt to select the best vendor by using Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The conventional methods that are being used for supplier evaluation such as cost ratio method, weighted-cost method, etc., are purely subjective in nature. The weighted scoring methods primarily rely on subjective judgments and views of the purchasing managers involved in the supplier evaluation process. The experience and contextual knowledge of purchasing staff is utilized to assign weightages arbitrarily to the supplier performance attributes. Accordingly, the final ranking of the suppliers is heavily dependent on the assignment of these weights, which are often difficult to specify in an objective manner. It is the major limitation of the weighted scoring method for supplier evaluation (Narasimhan and Srinivas, 2001). Over the past two decades, Data Envelopment Analysis (DEA) has emerged as an important tool in the field of efficiency measurement. In this paper an attempt is made to adopt DEA approach for supplier evaluation. The overview of DEA technique is presented in section 2. In section 3, the proposed methodology is discussed. The application of the methodology is described with an illustrative example in section 4. Result of the study discussed through section 5. Finally, conclusion is presented in section 6.

2. Data Envelopment Analysis

Data Envelopment Analysis (DEA) was developed by Charnes Cooper and Rhodes in the year 1978. It is a mathematical programming approach for evaluating the relative efficiency of a set of homogenous organizational units called decision making units (Malekmohammadi et al., 2011). These decision making units (DMUs) utilize multiple inputs to produce multiple outputs and their efficiency is measured by the ratio of multiple outputs to multiple inputs. DEA measure the relative productivity of a DMU by comparing it with other homogeneous units transforming the same group of measurable positive inputs into the same types of measurable positive outputs (Sepehrdoust, 2011). DEA measure has been used to evaluate and compare educational departments, health care sector, agricultural production, banking, armed forces, sports, market research transportation sector etc. In the present days, the DEA approach is extended to supply chain management issues. There are several ranking methods in DEA. Sexton et al. (1986) were developed Super Efficiency (SE) and Cross Efficiency (CE) ranking methods. In the present work, super efficiency method is used to rank the efficient suppliers whereas cross efficiency method is employed to rank the performance of the suppliers.

Super-efficiency DEA model can be used in ranking the performance of efficient DMUs. The Decision Making unit being evaluated is removed from the constraint set thereby allowing its efficiency score to exceed a value of 1.00. The efficiency score in the presence of multiple input and output factors is obtained by the computing the ratio of weighted sum of outputs to the weighted sum of inputs. The DMUs are ranked in accordance with the efficiency scores. The Cross-efficiency DEA model computes the efficiency of each unit with respect to the optimal weights of other units for a more comprehensive peer evaluation. This allows in effectively differentiating between good overall performers and niche performers.

3. Methodology

Super efficiency and cross efficiency models of DEA are used to develop the methodology, which is used for supplier evaluation. The step by step procedure is discussed as follows.

Step 1: Identification of Inputs and Outputs

Identify the inputs and outputs that are strategically important or critical to the buyer. The inputs and outputs are used as the selection criteria for the suppliers. Input variables are the assessment parameters of supplier capabilities (comprising the input dimensions of DEA) and the output variables reflects the supplier performance attributes (comprising the output dimension of DEA). In the process of data acquisition, the input and output dimensions to be utilized in the DEA model are defined through focus group discussions. The focus group includes managers of the different departments of the company. The specific product line to be examined is selected in the initial meetings. In the subsequent meetings, specific input and output dimensions to be used in the analysis were discussed and a final set of dimensions on which to collect data was compiled.

Step 2: Obtain data regarding the input and output variables

The data pertaining to input variables is obtained through questionnaire survey. A questionnaire is developed by the management of the company to assess supplier capability parameters. The questionnaire is known as Supplier Capability Questionnaire. The questionnaires are distributed to various suppliers of the company to obtain their responses. In order to obtain the responses regarding output variables, Supplier Performance Assessment Questionnaire is prepared and administered to the purchasing staff of the company.

Step 3: Formulation of mathematical model to obtain the efficiencies of suppliers

A mathematical model is formulated through DEA using super efficiency method, which is given below.

Objective function:

$$\text{Maximize } Z = \sum_{k=1}^{s} v_k y_{kp}$$

Subjected to constraints:

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \; \forall_i \neq p$$

$$\sum_{j=1}^{m} u_j x_{jp} = 1$$

$$v_k, u_j \geq \forall k, j$$

Where

i = Number of DMUs (suppliers); p = DMU (supplier) being evaluated

j = Inputs (1 to m), k = Outputs (1 to s),

y_{ki} = amount of input j utilized by supplier i,

x_{ji} = amount of output k produced by supplier i,

v_k = weight given to output k,

$u_{j\,=}$ weight given to input j.

Step 4: Formulation of mathematical model to evaluate the performance of the suppliers

A mathematical model is formulated through DEA using cross efficiency method, which is discussed as follows.

Objective function:

$$\text{Maximize } Z = \sum_{k=1}^{s} v_k \left[\sum_{i+p}^{s} y_{ki} \right]$$

Subjected to constraints

$$\sum_{j=1}^{m} u_j \left[\sum_{1 \neq p}^{s} x_{ji} \right] = 1$$

$$\sum_{k=1}^{s} v_k v_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \quad \forall i \leq p$$

$$\sum_{k=1}^{s} v_k y_{kp} - \theta_p \sum_{j=1}^{m} u_j x_{jp} = 0 \;\; v_k u_j \geq 0, \forall k, j$$

Where

(y_3)= Relative efficiency score of DMU p

Step 5: Determination of efficiency of suppliers using super efficiency and cross efficiency models

The efficiency of each supplier can be computed by determining the ratio of the weighted sum of outputs to weighted sum of inputs. Super Efficiency indicates the extent to which the efficient suppliers exceed the efficient frontier formed by other efficient suppliers. Cross efficiency provides the information on the performance of a particular DMU with the optimal DEA weights of other DMUs. In both these methods, the efficiency of DMUs is determined by using the ratio of weighted sum of outputs to the weighted sum of inputs.

Step 6: Establishment of Performance -Efficiency score Grid

The performance – efficiency score grid helps to examine the supplier capability under the categories such as High Performance and Inefficient (HI), High Performance and Efficient (HE), Low Performance and Inefficient (LI) and Low Performance and Efficient (LE). The suppliers under the category HE possesses star performance. These suppliers are the type of suppliers with which company needs to develop a long-term relationship. LI suppliers are candidates for pruning. The LE suppliers are the candidates need to be further developed. Finally, the potential long-term risk is associated with the HI suppliers. Even though, they are performing satisfactorily now, but most likely they do not have a structure and organizational capabilities that can sustain performance in the near future.

4. Numerical Illustration

A case of evaluation of suppliers for a telecommunication company is considered to demonstrate the proposed methodology. The case considered in the work is available in the literature (Narasimhan and Srinivas, 2001). The inputs and outputs are presented in the table I.

Table I The Inputs and Outputs for the Selection Criteria of Supplier Evaluation

	Input variables		Output variables
y_1	Quality management practices and systems (QMP)	x_1	Quality
y_2	Documentation and self-audit (SA)	x_2	Price
y_3	Process/Manufacturing Capability (PMC)	x_3	Delivery
y_4	Management of the firm (MF)	x_4	Cost reduction performance (CRP)
y_5	Design and development capabilities (DD)	x_5	Other
y_6	Cost reduction capability (CR)		

The data on scaled composite scores for the 23 suppliers are obtained from the literature (Narasimhan and srinivas, 2001) which are shown in tables II and III.

Table II The Numerical Data for Input Variables (weightages)

Supplier	QMP (y_1)	SA (y_2)	PMC (y_3)	MF (y_4)	DD (y_5)	CR (y_6)
1	0.9662	0.9742	1.0385	1.0808	1.1417	0.7839
2	0.7054	1.0438	0.7500	0.8782	0.0000	0.8750
3	0.5611	0.8947	0.7789	0.7205	0.8372	0.7404
4	1.1272	1.0438	0.9520	0.9607	0.9661	1.1402
5	1.1272	1.0438	1.1251	1.0808	1.2560	1.2115
6	0.9877	1.0438	0.9376	1.0808	1.0466	09422
7	0.8051	0.8351	1.0385	0.9607	1.2560	1.0768
8	1.1809	1.0438	1.1251	1.0208	1.0627	1.0096
9	1.2346	1.0438	1.1251	1.0808	1.2560	1.1442
10	0.5904	1.0438	0.6058	0.7629	0.5796	0.4038
11	0.8642	0.8118	0.8182	0.9536	0.9661	0.8076
12	0.6441	0.8351	1.0227	1.0208	0.9661	1.0768
13	1.2346	1.0438	1.1251	1.0808	1.2560	1.2115
14	1.0662	1.0438	1.1251	1.0808	1.1593	1.2115
15	1.0100	1.0438	0.8654	1.0208	0.7322	0.6815
16	0.8978	0.9742	1.0385	1.0208	0.9420	0.8076
17	1.1272	0.9742	1.0385	1.0208	1.2560	1.0768
18	1.1809	1.0438	1.1251	1.0808	1.2560	1.2115
19	1.0735	1.0438	1.1251	0.9007	1.1593	0.9422
20	1.0735	1.0438	1.1251	1.0808	0.6762	1.1442
21	1.2346	1.0438	1.1251	1.0133	1.2560	1.2115
22	1.2346	1.0438	0.9520	1.0808	1.0456	1.2115
23	1.0735	1.0438	1.0385	1.0172	0.8695	1.0768

Table III The Numerical data for output variables (weightages)

Output variables / Supplier	Quality (x_1)	Price (x_2)	Delivery (x_3)	CRP (x_4)	Other (x_5)
1	0.6211	0.8922	0.1284	1.2107	0.6359
2	0.6932	0.8922	0.3855	0.0000	0.3179
3	1.0205	0.4341	1.5420	0.0000	1.2719
4	1.6639	1.1333	1.5420	1.2107	1.8019
5	0.9983	1.3503	1.1565	1.2107	0.9540
6	1.0426	1.3263	1.7990	2.4214	1.2719
7	1.2201	1.2056	0.7710	2.4214	1.2719
8	0.8429	1.1333	0.6424	1.2107	0.8479
9	0.6433	0.8922	0.3855	0.0000	0.5299
10	1.4419	0.4341	1.4135	0.0000	1.2719
11	0.4215	0.8922	1.0279	0.0000	0.8479
12	1.0205	1.3263	0.7710	1.2107	0.7418
13	0.5546	1.1092	1.0279	1.2107	1.1660
14	0.8208	0.8922	0.8994	1.2107	0.8479
15	1.2423	1.5674	1.4135	2.4214	1.2719
16	1.0205	0.8922	0.3855	0.0000	0.4240
17	1.0205	0.8681	0.7710	0.0000	0.5299
18	1.2201	0.2411	0.0000	0.0000	0.4240
19	1.1647	0.8922	0.4135	1.2107	1.0599
20	0.8429	1.0550	1.4135	1.2107	1.4839
21	0.7764	0.8922	1.0279	0.0000	0.9540
22	1.4642	1.3263	1.7990	2.4214	1.4839
23	1.2423	1.3503	1.2849	2.4214	1.5900

For the purpose of DEA evaluation items on the supplier capability were grouped are the input variables. The items pertaining to supplier performance assessment are the output variables. Mathematical models to evaluate the suppliers through DEA super efficiency and cross efficiency are developed, which are discussed below.

Mathematical Model to Evaluate the Suppliers through DEA Super Efficiency

The problem formulation for evaluating supplier-2 through DEA Super Efficiency is enumerated as follows:

For Supplier -2 (DMU 2):

$$\text{Maximum Z} = 0.6932\,x_1 + 0.8922\,x_2 + 0.3855\,x_3 + 0.0000x_4 + 0.3179x_5 \tag{1}$$

Subjected to

$$0.7054\,y_1 + 1.0438y_2 + 0.7500y_3 + 0.8782y_4 + 0.0000y_5 + 0.8750y_6 = 1 \tag{2}$$

$$\begin{aligned}&0.6211x_1 + 0.8922x_2 + 0.1284x_3 + 1.2107x_4 + 0.6359x_5\\&-(0.9662\,y_1 + 0.9742\,y_2 + 1.0385\,y_3 + 1.0808\,y_4 + 1.1417\,y_5 + 0.7839\,y_6) \le 0\end{aligned} \tag{3}$$

$$1.0205x_1 + 0.4341x_2 + 1.542x_3 + 0.0000x_4 + 1.2719x_5 - (0.5611y_1 + 0.8947y_2 + 0.7789y_3 + 0.7205y_4 + 0.8372y_5 + 0.7404y_6) \le 0 \quad (4)$$

$$1.6639x_1 + 1.1333x_2 + 1.542x_3 + 1.2107x_4 + 1.8019x_5 - (1.1272y_1 + 1.0438y_2 + 0.9520y_3 + 0.9607y_4 + 0.9611y_5 + 1.1402y_6) \le 0 \quad (5)$$

$$0.9983x_1 + 1.3503x_2 + 1.1565x_3 + 1.2107x_4 + 0.914x_5 - (1.1272y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.2560y_5 + 1.2115y_6) \le 0 \quad (6)$$

$$1.0426x_1 + 1.3263x_2 + 1.799x_3 + 2.4214x_4 + 1.2719x_5 - (0.9877y_1 + 1.0438y_2 + 0.9376y_3 + 1.0808y_4 + 1.0466y_5 + 0.9422y_6) \le 0 \quad (7)$$

$$1.2201x_1 + 1.2056x_2 + 0.7710x_3 + 2.4214x_4 + 1.2719x_5 - (0.8051y_1 + 0.8351y_2 + 1.0385y_3 + 0.9607y_4 + 1.2560y_5 + 1.0768y_6) \le 0 \quad (8)$$

$$0.8429x_1 + 1.333x_2 + 1.6424x_3 + 1.2107x_4 + 0.8479x_5 - (1.1809y_1 + 1.0438y_2 + 1.1251y_3 + 1.0208y_4 + 1.0627y_5 + 1.0096y_6) \le 0 \quad (9)$$

$$0.6433x_1 + 0.8922x_2 + 0.3855x_3 + 0.0x_4 + 0.5299x_5 - (1.2346y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.2560y_5 + 1.1442y_6) \le 0 \quad (10)$$

$$1.4419x_1 + 0.4341x_2 + 1.4135x_3 + 0.0x_4 + 1.2719x_5 - (0.5904y_1 + 1.0438y_2 + 0.6058y_3 + 0.7629y_4 + 0.5796y_5 + 0.4038y_6) \le 0 \quad (11)$$

$$0.4215x_1 + 0.8922x_2 + 1.0279x_3 + 0.0x_4 + 0.8479x_5 - (0.8642y_1 + 0.8118y_2 + 0.8182y_3 + 0.9536y_4 + 0.9661y_5 + 0.8076y_6) \le 0 \quad (12)$$

$$1.0205x_1 + 1.3263x_2 + 0.771x_3 + 1.2107x_4 + 0.7418x_5 - (0.6441y_1 + 0.8351y_2 + 1.0227y_3 + 1.0208y_4 + 0.9661y_5 + 1.0768y_6) \le 0 \quad (13)$$

$$0.5546x_1 + 1.1092x_2 + 1.0279x_3 + 1.2107x_4 + 1.166x_5 - (1.2346y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.2560y_5 + 1.2115y_6) \le 0 \quad (14)$$

$$0.8208x_1 + 0.8922x_2 + 0.8994x_3 + 1.2107x_4 + 0.8479x_5 - (1.0662y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.1593y_5 + 1.2115y_6) \le 0 \quad (15)$$

$$1.2423x_1 + 1.5674x_2 + 1.4135x_3 + 2.4214x_4 + 1.2719x_5 - (1.0100y_1 + 1.0438y_2 + 0.8654y_3 + 1.0208y_4 + 0.7322y_5 + 0.6815y_6) \le 0 \quad (16)$$

$$1.0205x_1 + .8922x_2 + .3855x_3 + .0x_4 + .424x_5 - (0.8978y_1 + 0.9742y_2 + 1.0385y_3 + 1.0208y_4 + 0.9420y_5 + 0.8076y_6) \le 0 \quad (17)$$

$$1.0205x_1 + .8681x_2 + .771x_3 + .0x_4 + .5299x_5 - (1.1272y_1 + 0.9742y_2 + 1.0385y_3 + 1.0208y_4 + 1.2560y_5 + 1.0768y_6) \le 0 \quad (18)$$

$$1.2201x_1 + 0.2411x_2 + 0.0000x_3 + 0.0000x_4 + 0.4240x_5 - (1.1809y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.2560y_5 + 1.2115y_6) \le 0 \quad (19)$$

$$1.1647x_1 + 0.8922x_2 + 1.4135x_3 + 1.2107x_4 + 1.0599x_5 - (1.0735y_1 + 1.0438y_2 + 1.1251y_3 + 0.9007y_4 + 1.1593y_5 + 0.9422y_6) \le 0 \quad (20)$$

$$0.8429x_1 + 1.055x_2 + 1.4135x_3 + 1.2107x_4 + 1.4839x_5 - (1.0735y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 0.6762y_5 + 1.1442y_6) \le 0 \quad (21)$$

$$0.7764x_1 + 0.8922x_2 + 1.0279x_3 + 0.0000x_4 + 0.9540x_5 - (1.2346y_1 + 1.0438y_2 + 1.1251y_3 + 1.0133y_4 + 1.2560y_5 + 1.2115y_6) \le 0 \quad (22)$$

$$1.4642x_1 + 1.3263x_2 + 1.799x_3 + 2.4214x_4 + 1.4839x_5 - (1.2346y_1 + 1.0438y_2 + 0.9520y_3 + 1.0808y_4 + 1.0466y_5 + 1.2115y_6) \le 0 \quad (23)$$

$$1.2423x_1 + 1.3503x_2 + 1.2849x_3 + 2.4214x_4 + 1.5900x_5 - (1.7350y_1 + 1.0438y_2 + 1.0385y_3 + 1.0172y_4 + 0.8695y_5 + 1.0768y_6) \le 0 \quad (24)$$

$$0.6932x_1 + 0.8229x_2 + 0.3855x_3 + 0.0000x_4 + 0.3179x_5 - (0.7054y_1 + 1.0438y_2 + 0.7500y_3 + 0.8782y_4 + 0.0000y_5 + 0.8750y_6) \le 0 \quad (25)$$

In the same way, the DEA model equations for the remaining 22 suppliers are developed and solved using LINGO solver.

4.2. Mathematical model to evaluate the suppliers through DEA cross efficiency

The problem formulation for evaluating supplier-2 through DEA Cross Efficiency is enumerated as follows:

For Supplier -2 (DMU 2):

$$\text{Maximize } Z = 0.6932(x_1+x_2+x_3+x_4+x_5) + 0.8922(x_1+x_2+x_3+x_4+x_5) + 0.3855(x_1+x_2+x_3+x_4+x_5) + 0.0000(x_1+x_2+x_3+x_4+x_5) + 0.3179(x_1+x_2+x_3+x_4+x_5) \quad (26)$$

Subjected to

$$0.7054(y_1+y_2+y_3+y_4+y_5+y_6) + 1.0438(y_1+y_2+y_3+y_4+y_5+y_6) + 0.750(y_1+y_2+y_3+y_4+y_5+y_6) + 0.8782(y_1+y_2+y_3+y_4+y_5+y_6) + 0.000(y_1+y_2+y_3+y_4+y_5+y_6) + 0.8750(y_1+y_2+y_3+y_4+y_5+y_6) = 1 \quad (27)$$

$$0.6932x_1 + 0.8922x_2 + 0.3855x_3 + 0.0000x_4 + 0.3179x_5 - (0.7054y_1 + 1.0438y_2 + 0.7500y_3 + 0.8782y_4 + 0.0000y_5 + 0.8750y_6) \le 0 \quad (28)$$

$$1.0205x_1 + 0.4341x_2 + 1.5420x_3 + 0.0000x_4 + 1.2719x_5 - (0.5611y_1 + 0.8947y_2 + 0.7789y_3 + 0.7205y_4 + 0.8372y_5 + 0.7404y_6) \le 0 \quad (29)$$

$$1.6639x_1 + 1.1333x_2 + 1.5420x_3 + 1.2107x_4 + 1.8019x_5 - (1.1272y_1 + 1.0438y_2 + 0.9520y_3 + 0.9607y_4 + 0.6610y_5 + 1.1402y_6) \le 0 \quad (30)$$

$$0.9983x_1 + 1.3503x_2 + 1.1565x_3 + 1.2107x_4 + 0.9540x_5 - (1.1272y_1 + 1.0438y_2 + 1.1251y_3 + 1.0808y_4 + 1.2560y_5 + 1.2115y_6) \le 0 \quad (31)$$

$$1.0426x_1+1.3263x_2+1.7990x_3+2.4214x_4+1.2719x_5 -\left(0.9877y_1+1.0438y_2+0.9376y_3+1.0808y_4+1.0466y_5+0.9422y_6\right)\le 0 \quad (32)$$

$$1.2201x_1+1.2056x_2+0.7710x_3+2.4214x_4+1.2719x_5 -\left(0.8051y_1+0.8351y_2+1.0385y_3+0.9607y_4+1.2560y_5+1.0768y_6\right)\le 0 \quad (33)$$

$$0.8429x_1+1.1333x_2+1.6424x_3+1.2107x_4+0.8479x_5 -\left(1.1809y_1+1.0438y_2+1.1251y_3+1.0208y_4+1.0627y_5+1.0096y_6\right)\le 0 \quad (34)$$

$$0.6433x_1+0.8922x_1+0.3855x_1+0.0000x_1+0.5299x_1- \left(1.2346y_1+1.0438y_2+1.1251y_3+1.0808y_4+1.2560y_5+1.1442y_6\right)\le 0 \quad (35)$$

$$1.4419x_1+0.4341x_2+1.4135x_3+0.0000x_4+1.2719x_5 -\left(0.5904y_1+1.0438y_2+0.6058y_3+0.7629y_4+0.5796y_5+0.4038y_6\right)\le 0 \quad (36)$$

$$0.4215x_1+0.8922x_1+1.0279x_1+0.0000x_1+0.8479x_1 -\left(0.8642y_1+0.8118y_2+0.8182y_3+0.9536y_4+0.9661y_5+0.8076y_6\right)\le 0 \quad (37)$$

$$1.0205x_1+1.3263x_2+0.7710x_3+1.2107x_4+0.7418x_5 -\left(0.6441y_1+0.8351y_2+1.0227y_3+1.0208y_4+0.9661y_5+1.0768y_6\right)\le 0 \quad (38)$$

$$0.5546x_1+1.1092x_2+1.0279x_3+1.2107x_4+1.1660x_5 -\left(1.2346y_1+1.0438y_2+1.1251y_3+1.0808y_4+1.2560y_5+1.2115y_6\right)\le 0 \quad (39)$$

$$0.8208x_1+0.8922x_2+0.8994x_3+1.2107x_4+0.8479x_5 -\left(1.0662y_1+1.0438y_2+1.1251y_3+1.0808y_4+1.1593y_5+1.2115y_6\right)\le 0 \quad (40)$$

$$1.2423x_1+1.5674x_2+1.4135x_3+2.4214x_4+1.2719x_5 -\left(1.0100y_1+1.0438y_2+0.8654y_3+1.0208y_4+0.7322y_5+0.6815y_6\right)\le 0 \quad (41)$$

$$1.0205x_1+.08922x_2+0.3855x_3+0.0000x_4+0.4240x_5 -\left(0.8978y_1+0.9742y_2+1.0385y_3+1.0208y_4+0.9420y_5+0.8076y_6\right)\le 0 \quad (42)$$

$$0.0205x_1+0.8681x_2+0.7710x_3+0.0000x_4+0.5299x_5 -\left(1.1272y_1+0.9742y_2+1.0385y_3+1.0208y_4+1.2560y_5+1.0768y_6\right)\le 0 \quad (43)$$

$$1.2201x_1+0.2411x_2+0.0000x_3+0.0000x_3+0.4240x_4 \quad (44)$$

$$-\left(1.1809y_1+1.0438y_2+1.1251y_3+1.0808y_4+1.2560y_5+1.2005y_6\right)\le 0 \quad (45)$$

$$0.8429x_1+1.0550x_2+1.4135x_3+1.2107x_4+1.4839x_5 -\left(1.0735y_1+1.0438y_1+1.1251y_1+1.0808y_1+0.6762y_1+1.1442y_1\right)\le 0 \quad (46)$$

$$0.7764x_1+0.8922x_2+1.0279x_3+0.0000x_4+0.9540x_4 -\left(1.2346y_1+1.0438y_2+1.1251y_3+1.0133y_4+1.2560y_5+1.2115y_6\right)\le 0 \quad (47)$$

$$1.4642x_1+1.3263x_2+1.7990x_3+2.4214x_4+1.4839x_5 -\left(1.2346y_1+1.0438y_2+0.9520y_3+1.0808y_4+1.0456y_5+1.2115y_6\right)\le 0 \quad (48)$$

$$1.2423x_1 + 1.3503x_2 + 1.2849x_3 + 2.4214x_4 + 1.5900x_5 - \left(1.0735y_1 + 1.0438y_2 + 1.0385y_3 + 1.0172y_4 + 0.8695y_5 + 1.0763y_6\right) \le 0 \quad (49)$$

$$.6932x_1 + 0.8922x_2 + 0.3855x_3 + 0.0000x_4 + 0.3179x_5 - \left(0.7054y_1 + 1.0438y_2 + 0.7500y_3 + 0.8782y_4 + 0.0000y_5 + 0.8750y_6\right) \le 0 \quad (50)$$

In the same way, the DEA model equations for the remaining 22 suppliers are developed and solved using LINGO solver. The results of the above models are discussed in the following section.

5. RESULTS AND DISCUSSION

The amounts of inputs utilized by each supplier and the amounts of outputs produced by each supplier under DEA super efficiency and cross efficiency models are given in table IV.

Table IV Amounts of Inputs Utilized and Outputs Produced under DEA Super Efficiency and Cross Efficiency Methods

DEA super efficiency method				*DEA cross efficiency method*			
Input variables	Amount utilized	Output variables	Amount produced	Input variables	Amount utilized	Output variables	Amount produced
QMP	0.0000	Quality	0.0000	QMP	0.1446	Quality	0.1194
SA	0.0000	Price	1.2152	SA	0.0000	Price	0.04524
PMC	0.0000	Delivery	0.0000	PMC	0.0000	Delivery	0.0000
MF	1.1387	CRP	0.0000	MF	0.0240	CRP	0.0000
DD	1.0139	Other	0.0000	DD	0.0664		
CR	0.0000	CR	0.0000			Other	0.0000

The procedure discussed in step 5 of the section 3 is used to compute super and cross efficiencies. The values of super efficiency and cross efficiency for the supplier 2 are 1.08 and 0.38 respectively.

Similarly super efficiency and cross efficiency values for all the remaining 22 suppliers are computed and are tabulated in the table V.

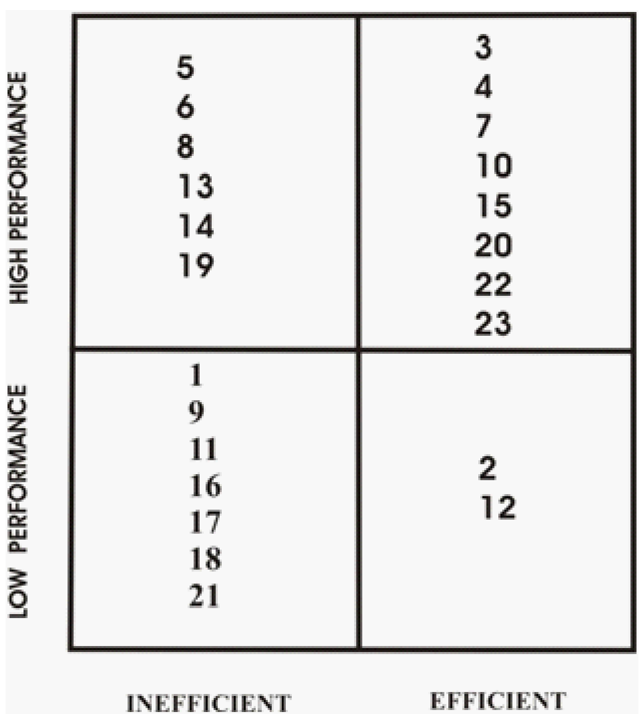
Table V Supplier Classification Based on DEA Super Efficiency and Cross Efficiency scores

Supplier	*Super Efficiency*	*Cross Efficiency*	*Classification*
1	0.60	0.43	LI
2	1.08	0.38	LE
3	1.63	0.69	HE
4	1.27	0.87	HE
5	0.85	0.61	HI
6	1.17	0.95	HE
7	1.25	0.85	HE
8	0.72	0.64	HI
9	0.56	0.26	LI
10	1.97	0.84	HE
11	0.80	0.42	LI

12	1.32	0.61	HE
13	0.77	0.52	HI
14	0.60	0.50	HI
15	1.64	1.09	HE
16	0.76	0.34	LI
17	0.70	0.36	LI
18	0.73	0.18	HE
19	0.90	0.54	HI
20	1.10	0.69	HE
21	0.65	0.36	LI
22	1.13	0.95	HE
23	1.11	0.92	HE

The twenty three suppliers are classified in to the categories of High performance and Inefficient (HI), High Performance and Efficient (HE), Low Performance and Inefficient (LI) and Low Performance and Efficient (LE) on the basis of super efficiency and cross efficiency scores. The classification of suppliers is also shown in table V. The performance-efficiency grid is prepared on the basis of efficiency scores and is shown in figure I.

Figure I Suppliers Performance –Efficiency Score Grid



It can be observed from the figure. I, that the suppliers 3, 4, 7, 10, 15, 20, 22, and 23 are grouped together under HE. These eight suppliers possess star performance. Therefore the managers of the company need to maintain long-term relationship with them. The group LI includes the suppliers 1,9,11,16,17,18 and 21. These suppliers have to be pruned. As the suppliers 2 and 12 come under LE category, they have to develop further. Therefore, the company has to invest in terms of supplier development programs and initiatives for making this cluster of suppliers improve their performance. The performance of the suppliers 5,6,8,13,14 and 19 is satisfactory at present, but their performance may not sustain in near future. Therefore DEA performance –efficiency score grid helps management can take effective decision in selecting suppliers to the company.

CONCLUSIONS

However, several attempts have been made to apply different methods of DEA, super efficiency and cross efficiency techniques are the most popular for efficiency measurement in manufacturing or service sectors. The implementation of DEA in the paper helps in supplier evaluation for managers under purchasing environment. In the present work, twenty-three suppliers are evaluated using super efficiency and cross efficiency methods. Eleven supplier evaluation attributes are considered, out of which, the six attributes namely, Quality management practices and systems (QMP), Documentation and Self-audit (SA), Process / manufacturing capability (PMC), Management of the firm (MF), Design and Development capabilities (DD), Cost reduction capability (CR) are the input variables. The Quality, Price, Delivery, Cost reduction performance (CRP) and other factors are the output variables. Super efficiency and cross efficiency models are established and are solved using LINGO 8.0. The scores of super efficiency and cross efficiency are computed and on the basis of which the suppliers are evaluated. Performance - Efficiency score Grid (PEG) is developed for the suppliers. The PEG guides the management of the firm to take wise decision for selecting the suppliers. In order to demonstrate the proposed methodology, a numerical illustration is considered from the literature. But, the work can be applied to evaluate suppliers in any manufacturing firm.

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