Performance Evaluation of Suppliers and Manufacturer using Data Envelopment Analysis (DEA) Approach

Yaman Saini, Arvind Jayant*

Department of Mechanical Engineering, SLIET Deemed University, Longowal 148106, India
Department of Mechanical Engineering, SLIET Deemed University, Longowal 148106, India

Abstract

An appropriate performance measurement system is an important requirement for the effective management of a supply chain. Two hurdles are present in measuring the performance of a supply chain and its members. One is the existence of multiple measures that characterize the performance of chain members, and for which data must be acquired; the other is the existence of conflicts between the members of the chain with respect to specific measures. Conventional data envelopment analysis (DEA) cannot be employed directly to measure the performance of supply chain and its members, because of the existence of the intermediate measures connecting the supply chain members. In this paper, it is shown that a supply chain can be deemed as efficient while its members may be inefficient in DEA-terms. The current study develops a DEA-based approaches for characterizing and measuring supply chain efficiency when intermediate measures are incorporated into the performance evaluation. The model is illustrated in a supplier-manufacturer supply chain context, when the relationship between the supplier and manufacturer is treated first as one of leader-follower, and second as one that is cooperative. In the leader-follower structure, the leader is first evaluated, and then the follower is evaluated using information related to the leader's efficiency. In the cooperative structure, the joint efficiency which is modelled as the average of the supplier's and manufacturer efficiency scores is maximized, and both supply chain members are evaluated simultaneously. Non-linear programming problems are developed to solve these new supply chain efficiency models. It is shown that these DEA-based non-linear programs can be treated as parametric linear programming problems, and best solutions can be obtained via a heuristic technique.

Keywords : Supply chain; Performance; Data Envelopment Analysis; Supplier; Manufacturer

1. INTRODUCTION

Supply chain management is an important competitive strategy used by modern enterprises. Effective design and management of supply chains assists in the production and delivery of a variety of products at low costs, high quality, and short lead times. Recently, data envelopment analysis (DEA) has been extended to examine the efficiency of supply chain operations. Thecurrentproblem developsaDEAmodelformeasuringtheperformanceofsuppliersandmanufacturersinsupply chain operations. Additive efficiency decomposition for suppliers and manufacturers in supply chainoperationsisproposed.

Ganeshan(1995), "A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers."

Effective management of an organization's supply chains has proven to be a very effective mechanism for providing prompt and reliable delivery of high-quality products and services at the least cost. To achieve this, performance evaluation of the entire supply chain is extremely important. This means utilizing the combined resources of the supply chain members in the most efficient way possible to provide competitive and cost-effective products and services.

2. LITERATURE REVIEW

Data envelopment analysis (DEA), originated from the work of Charnes et al. [1], is a linear programming, nonparametric technique used to measure the relative efficiency of peer decision making units with multiple inputs and outputs. This methodology has been applied in a wide range of applications over the last three decades, in setting that include banks, hospitals, and maintenance. See for instances Amirteimoori and Emrouznejad[2], Amirteimoori and Kordrostami [3], Amirteimoori [4], and Cooper et al. [5]. Recently, a number of studies have looked at production processes that have two-stage network structure, as supply chain operations. Due to the existence of intermediate measures, the usual procedure of adjusting the inputs or outputs, as in the standard DEA approach, does not necessarily yield a frontier projection. Many researchers have applied standard DEA models to measure the performance of supply chain members. See for instances, Weber and Desai [6], Easton et al. [7], Talluri and Baker [8], Liang et al. [9], Chen et al. [10], and Chen [11]. Weber and Desai [6] employed DEA to construct an index of relative supplier performance. Fare and Grosskopf[12] developed a network DEA approach to model the general multistage processes. Easton et al. [7] suggested a DEA model to compare the purchasing efficiency of firms in the petroleum industry. Talluri and Baker[8] proposed a multiphase mathematical programming approach for effective supply chain design. Their methodology applies a combination of multi criteria efficiency models, based on game theory concepts, and linear and integer programming methods. Liang et al. [9] and Chen et al. [10] developed several DEA-based approaches for characterizing and measuring supply chain efficiency when intermediate measures are incorporated into the performance evaluation. Chen [11] proposed a structured methodology for supplier selection and evaluation in a supply chain, to help enterprises establish a systematic approach for selecting and evaluating potential suppliers in a supply chain. Feng et al. [13] defined two types of supply chain production possibility sets, which are proved to be equivalent to each other.

3. METHODOLOGY

3.1 Data Envelopment Analysis (DEA)

William W. Cooper (1978): “Data envelopment analysis is a method for evaluating decision making units within an organization, by using imputed shadow prices. These prices are computed using a fractional program that is solved by reducing it to a linear program.”It concerned with evaluations of performance and it is especially concerned with evaluating the activities of organizations such as business firms, government agencies, hospitals, educational institutions. DEA assigns weights to the inputs and outputs of a DMU that give it the best possible efficiency. It thus arrives at a weighting of the relative importance of the input and output variables that reflects the emphasis that appears to have been placed on them for that DMU.

The main advantage to this method is its ability to accommodate a multiplicity of inputs and outputs. It doesn't require an assumption of a functional form relating inputs to outputs. DMUs are directly compared against a peer or combination of peers. The analyzed data sets vary in size. Some analysts work on problems with as few as 15 or 20 DMUs while others are tackling problems with over 10,00 DMUs.

The objective of data envelopment analysis is to find the efficiency of the various DMU’s to arrange or selection the best DMU. The objective of any selection procedure is to identify appropriate selection criteria, and obtain the most appropriate combination of criteria in conjunction with the real requirement. The DEA is also used to find the most desirable alternatives from a set of available alternatives based on the selected criteria. In DEA, alternatives are ranked from best to worst based on their efficiency. Selection criterions are often called as attributes and they are either given by industry or taken from literature.

4. PROBLEM STATEMENT

Consider a two-stage supply chain, for example, supplier-manufacturer supply chain asshown in Figure 1.

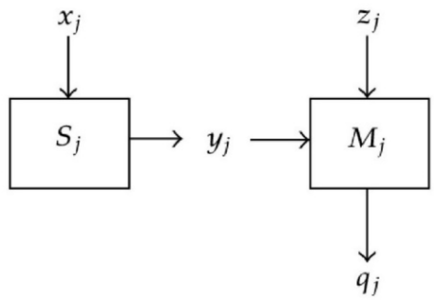

Figure 1. Supplier-manufacturer supply chain

It is assumed that each supplier Sj in DMUj : j = 1,...,n has m inputs xij : i = 1,...,m and s outputs yrj : r = 1,..., s. These outputs can become the inputs to the manufacturer Mj. The manufacturer Mj has its own inputs Zdj : d = 1,...,D. The final outputs from manufacturer are qlj : l = 1,..., L.

4.1 Proposed Model

Consider a buyer-seller supply chain as described in Fig. 1, where $X_A$is the input vector of the seller, and $Y_A$is the seller's output vector. $Y_A$is also an input vector of the buyer, along with X_B, with $Y_B$being the buyer's output vector.Suppose there are *n*such supply chains or observations on one supply chain.

$$\text{Max } \frac{U^T Y_{B0}}{V^T(X_{A0}, X_{B0})}$$

$$\text{s.t } \frac{U^T Y_{Bj}}{V^T(X_{Aj}, X_{Bj})} \leq 1 \quad j = 1, 2\ldots\ldots\ldots, n \qquad (1)$$

$$U^T,\ V^T \geq 0$$

Zhu (2003) shows that DEA model (1) fails to correctly characterize the performance of supply chains, because it only considers the inputs and outputs of the supply chain system and ignores measures $Y_A$associated with supply chain members. Zhu (2003) also shows that if $Y_A$are treated as both input and output measures in model (1), all supply chains become efficientZhu (2003) further shows that an efficient performance indicated by model (1) does not necessarily indicate efficient performance in individual supply chain members. Consequently, improvement to the best-practice can be distorted. i.e., the performance improvement of one supply chain member affects the efficiency status of the other, because of the presence of intermediate measures.

$$\text{Max } \frac{1}{2}\left[\frac{U_A^T Y_{A0}}{V_A^T X_{A0}} + \frac{U_B^T Y_{B0}}{V_B^T(X_{B0}, Y_{A0})}\right]$$

$$\text{s.t } \frac{U_A^T Y_{Aj}}{V_A^T X_{Aj}} \leq 1 \quad j = 1, 2\ldots\ldots. n \qquad (2)$$

$$\frac{U_B^T Y_{Bj}}{V_B^T(X_{Bj}, Y_{Aj})} \leq 1 \quad j = 1, 2\ldots\ldots n$$

$$U_A^T, V_A^T, U_B^T, V_B^T \geq 0$$

Although model (2) considers Y_A, it does not reflect the relationship between the buyer and the seller. The weights of Y_A as inputs of the buyer may not be equal to the weights of Y_A as outputs of the seller. Model (2) treats the seller and the buyer as two independent units. This does not reflect an ideal supply chain operation.Based upon Li, Huang and Ashley (1995), we suppose the seller-buyer interaction is viewed as a two-stage noncooperative game with the seller as the leader and the buyer as the follower. For example, in the case of non-cooperative advertising between the manufacture (seller) and the retailer (buyer), Toyota automobile company decides that it wants to promote sales of a particular model and directs and subsidizes its local dealers. The local dealers then react to Toyota's strategy by adjusting the amount they spend on advertising and promotion. First, we use the CCR model to evaluate the efficiency of the seller, as the leader.

$$\text{Max } \frac{U_A^T Y_{A0}}{V_A^T X_{A0}} = E_{AA}$$
$$\text{s.t.} \frac{U_A^T Y_{Aj}}{V_A^T X_{Aj}} \leq 1 \quad j = 1, 2\ldots\ldots n \quad (3)$$
$$U_A^T, V_A^T \geq 0$$

This model is equivalent to the following standard DEA multiplier model:

$$\text{Max } \mu_A^T Y_{A0} = E_{AA}$$
$$\text{s.t.} \omega_A^T X_{Aj} - \mu_A^T Y_{Aj} \geq 0 \quad j=1, 2\ldots\ldots n \quad (4)$$
$$\omega_A^T X_{A0} = 1$$
$$\omega_A^T, \mu_A^T \geq 0$$

Suppose we have an optimal solution of model (4) $\omega_A^{T*}, \mu_A^{T*}$,and E_{AA}^* and denote the seller's efficiency as E_{AA}^*. We then use the following model to evaluate the buyer's efficiency:

$$\text{Max } \frac{U_B^T Y_{B0}}{V_B^T X_{B0} + D \times \mu_A^T Y_{A0}} = E_{AB}$$
$$\text{s.t.} \frac{U_B^T Y_{Bj}}{V_B^T X_{Bj} + D \times \mu_A^T Y_{Aj}} \leq 1 \quad j = 1, 2\ldots\ldots n \quad (5)$$
$$\mu_A^T Y_{A0} = E_{AA}^*$$
$$\omega_A^T X_{Aj} - \mu_A^T Y_{Aj} \geq 0 \quad j = 1, 2\ldots\ldots n$$
$$\omega_A^T X_{A0} = 1$$
$$\omega_A^T, \mu_A^T, U_B^T, V_B^T, D \geq 0$$

Note that in model (5), we try to determine the buyer's efficiency given that the seller's efficiency remains at E_{AA}^*. Model (5) is equivalent to the following non-linear model:

$$\text{Max } \mu_B^T Y_{B0} = E_{AB}$$
$$\text{s.t.} \omega_B^T X_{Bj} + d\mu_A^T Y_{Aj} - \mu_B^T Y_{Bj} \geq 0 \quad j = 1, 2\ldots\ldots n \quad (6)$$
$$\omega_B^T X_{B0} + d\mu_A^T Y_{A0} = 1$$
$$\mu_A^T Y_{A0} = E_{AA}^*$$
$$\omega_A^T X_{Aj} + \mu_A^T Y_{Aj} \geq 0 \quad j = 1, 2\ldots\ldots n$$
$$\omega_A^T X_{A0} = 1$$
$$\omega_A^T, \mu_A^T, \omega_B^T, \mu_B^T, d \geq 0$$

Note that $\omega_B^T X_{B0} + d\mu_A^T Y_{A0} = 1$ and $\mu_A^T Y_{A0} = E_{AA}^*$. Thus, we have $0 \leq d \leq \frac{1}{\mu_A^T Y_{A0}} = \frac{1}{E_{AA}^*}$, i.e, we have the upper and lower bounds on d. Therefore, d can be treated as a parameter and model (6) can be solved as a linear program. In computation, we set the initial d value as the upper bound, namely, $d_0 = \frac{1}{E_{AA}^*}$, and solve the resulting linear program. We then start to decrease d according to $d_t = \frac{1}{E_{AA}^*} - \varepsilon \times t$ for each step t, where ε is a small positive number.

We solve each linear program of model (6) corresponding to $d_t$and denote the optimal objective value as $E^*_{BA}(d_t)$.Let E^*_{BA} = Max E^*_{BA}(d_t). Then we obtain a best heuristic search solution $E^*_{BA}$to model (6). This E^*_{BA}represents the buyer's efficiency when the seller is given the pre-emptive priority to achieve its best performance. The efficiency of the supply chain can then be defined as

$$e_{AB} = \frac{1}{2}(E^*_{AA} + E^*_{AB})$$

Similarly, one can develop a procedure for the situation when the buyer is the leader and the seller the follower. For example, in the October 6, 2003 issue of the Business Week, its cover story reports that Walmart dominates its suppliers and not only dictates delivery schedules and inventory levels, but also heavily influences product specifications.

We first evaluate the efficiency of the buyer using the standard CCR ratio model

$$\text{Max } \frac{U_B^T Y_{B0}}{V_B^T X_{B0} + V^T Y_{Aj}} = E_{BB}$$

$$\text{s.t.} \frac{U_B^T Y_{Bj}}{V_B^T X_{Bj} + V^T Y_{Aj}} \leq 1 \quad j = 1, 2 \ldots\ldots n \qquad (7)$$

$$U_B^T, V_B^T, V^T \geq 0$$

Model (7) is equivalent to the following standard CCR multiplier model

$$\text{Max } \mu_B^T Y_{B0} = E_{BB}$$

$$\text{s.t.} \omega_B^T X_{Bj} + \mu^T Y_{Aj} - \mu_B^T Y_{Bj} \geq 0 \quad j = 1, 2, \ldots\ldots, n \qquad (8)$$

$$\omega_B^T X_{B0} + \mu^T Y_{A0} = 1$$

$$\omega_B^T, \mu_B^T, \mu^T \geq 0$$

Let $\omega_B^{T*}, \mu_B^{T*}, \mu^{T*}, E^*_{BB}$ an optimal solution from model (8) where E^*_{BB}represents the buyer's efficiency score.

5.Estimating the efficiency of Company ABC Ltd.

We now illustrate the above DEA procedures with ten supply chain operations (DMUs) given in Table 1. The supplier has three inputs and two outputs. The manufacturer has three inputs and two outputs. The two output of supplier becomes input of the manufacturer.

Supplier

Input

X_1= labor cost (Lakh Rs)

X_2= operating cost (Lakh Rs)

X_3 = shipping cost (Lakh Rs)

Output

Y_1= number of product *A* shipped (Cast aluminum alloy) (Rs/Kg)

Y_2= number of product *B* shipped (Titanium) (Rs/Kg)

Manufacturer

Input

Y_1= number of product *A* shipped (Cast aluminum alloy) (Rs/Kg)

Y_2= number of product *B* shipped (Titanium) (Rs/Kg)

Z_1= labor cost (Lakh Rs)

Output

Q_1= sales (Lakh Rs)

Q_2= profit (Lakh Rs)

Table 1: Data Sheet

DMUs	X_1	X_2	X_3	Y_1	Y_2	Z_1	q_1	q_2
DMU-1	9	50	1	200	1000	8	1000	250
DMU-2	10	18	10	100	1500	10	700	200
DMU-3	9	30	3	80	2000	8	960	300
DMU-4	8	25	1	200	2000	10	800	200
DMU-5	10	40	5	150	2000	15	850	150
DMU-6	7	35	2	350	1000	5	900	350
DMU-7	7	30	3	100	2500	10	1000	300
DMU-8	12	40	4	200	2500	8	1200	100
DMU-9	9	25	2	100	1000	15	1100	150
DMU-10	10	50	1	200	1500	10	800	200

5.1 DEA-frontier Software

For evaluating the efficiency of supply chain networks, we used a DEA-frontier software. DEA-frontier software works along with the Microsoft Excel, before we run the DEA-frontier software some arrangement and setting had to be done in Microsoft Excel.

5.2 Result and Discussion

It should be noted here that the higher the efficiency is the more efficient the supply chain. From Table 1 and Fig. 2, the following conclusions can be drawn. Firstly, suppliers (1, 2, 4, 6, 7 and 10) and manufacturers (1, 3, 6, 8 and 9) performed well. Their efficiencies are all equal to 1, i.e. they are all efficient. Secondly, supplier-9 and manufactures-5 performs the worst, its efficiencies are 0.50000 and 0.59759 which is the smallest among all the DMUs. Thirdly, most of the suppliers and manufactures perform well. Except supplier-9 average efficiencies that

have exceeded 0.5

Table 1 Supplier Efficiency and Manufacturer Efficiency

DMUs	Supplier	Manufacturer
1	1.00000	1.00000
2	1.00000	0.80543
3	0.80000	1.00000
4	1.00000	0.62786
5	0.67595	0.59759
6	1.00000	1.00000
7	1.00000	0.83333
8	0.77042	1.00000
9	0.50000	1.00000
10	1.00000	0.66813

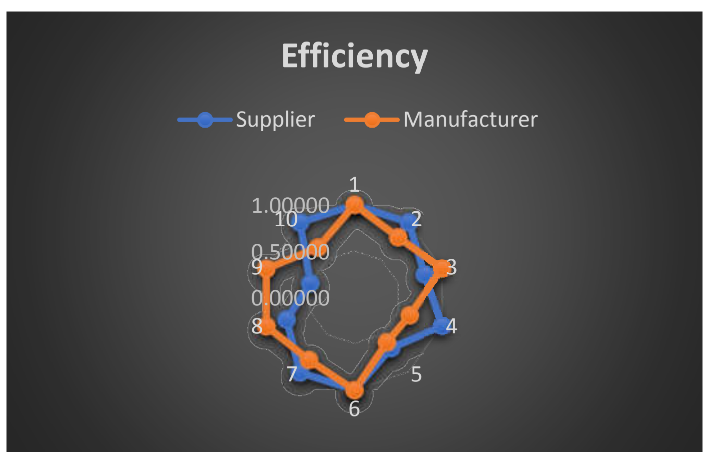

Figure 2. Efficiency of Supplier and Manufacturer

The figure clearly shows the most effective and efficient decision making unit which have an efficiency value equal to 1. We see in the figure that only decision making unit number 1 and decision making unit number 6 having a common point and also attain maximum efficiency. Supplier-1 having efficiency level 1 and Manufacturer-1 also having efficiency level 1, it's means DMU-1 is a most effective.Supplier-10 having efficiency level 1 and Manufacturer-10 having efficiency level 0.66813 which means they were also not perfect for developing a network.Supplier-2 having efficiency level1 and Manufacturer-2 having efficiency level 0.80543 which means manufacturer is not efficient. Supplier-5 having efficiency level 0.67595 and Manufacturer-5 having efficiency level 0.59759, they both were performed worst. Here we find only two decision making unit which have an efficiency level equal to 1, the DMU's are 1 and 6 so we chose one of them for developing a supply chain network which develop a most efficient and effective network.

- In the present work, we used DEA-frontier Software on a i5, 4Gbytes RAM, 2GHz PC.

6. CONCLUSIONS

The objective of this research was to develop a most efficient supply chain network and find out the efficiency of all DMUs which are very useful in the supply chain of an industry. These variables assume importance because on the basis of these variables the case company may decide the suppliers and manufacturing system because it affect the cost and quality of the finished product. Through careful examinations of the results obtained from DEA-frontier software, among the ten DMUs we have to choose only one which make supply chain network best. The work of a supply chain management is to construct a network (which start from raw material and end to the customer) which minimize the input cost and maximize the quality and profit. In this research, there are total 10 DMUs which are suitable for the manufacturer but the best choice for any supply chain will directly increase the profit of the company, so it has to choose only one DMU which construct a best supply chain network**.** As in the present work only suitable for choosing the best supply chain network and find out the all DMUs efficiency. So, it may be a challenge for the future research scholars to explore some new and different types of areas on which DEA technique will apply and that will be beneficial for the future data envelopment analysis system.

References

[1] Charnes, W. W. Cooper, and E. Rhodes, "Measuring the e□ciency of decision making units," *European Journal of Operational Research*, vol. 2, no. 6, pp. 429–444, 1978.
[2] A. Amirteimoori and A. Emrouznejad, "Flexible measures in production process: a DEA-based approach," *RAIRO Operations Research*, vol. 45, no. 1, pp. 63–74, 2011.
[3] A. Amirteimoori and S. Kordrostami, "Production planning: a DEA-based approach," *International Journal of Advanced Manufacturing Technology*, vol. 56, no. 1–4, pp. 369–376, 2011.
[4] A. Amirteimoori, "An extended transportation problem: a DEA-based approach," *Central European Journal of Operations Research*, vol. 19, no. 4, pp. 513–521, 2011.
[5] W. W. Cooper, L. M. Seiford, and J. Zhu, *Handbook of Data Envelopment Analysis*, Kluwer Academic Publishers, Norwell, Mass, USA, 2007.
[6] C. A. Weber and A. Desai, "Determination of paths to vendor market e□ciency using parallel coordinates representation: a negotiation tool for buyers," *European Journal of Operational Research*, vol. 90, no. 1, pp. 142–155, 1996.

[7] L. Easton, D. J. Murphy, and J. N. Pearson, "Purchasing performance evaluation: with data envelopment analysis," *European Journal of Purchasing and Supply Management*, vol. 8, no. 3, pp. 123– 134, 2002.

[8] S. Talluri and R. C. Baker, "A multi-phase mathematical programming approach for e□ective supply chain design," *European Journal of Operational Research*, vol. 141, no. 3, pp. 544–558, 2002.

[9] Y. Feng, D. Wu, L. Liang, G. Bi, and D. D. Wu, "Supply chain DEA: production possibility set and performance evaluation model," Annals of Operations Research, vol. 185, no. 1, pp. 195–211, 2011.

[10] Y. Chen, L. Liang, and F. Yang, "A DEA game model approach to supply chain efficiency," *Annals of Operations Research*, vol. 145, pp. 5–13, 2006.

[11] Y. J. Chen, "Structured methodology for supplier selection and evaluation in a supply chain," *Information Sciences*, vol. 181, no. 9, pp. 1651–1670, 2011.

[12] R. F¨are and S. Grosskopf, "Network DEA," *Socio-Economic Planning Sciences*, vol. 34, no. 1, pp. 35–49, 2000.

[13] Cvetkoska, V., 2011. Data Envelopment Analysis Approach and Its Application in Information and Communication Technologies. In HAICTA (pp. 421-430).