Industry Supply Chain Performance Evaluation Using Data Envelopment Analysis (DEA)

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ABSTRACT

This study provides a realistic framework in the study of supply chain performance and determines the efficiency of the supply chain concept in direct contact with suppliers and customers. In other words, only two levels of the supply chain are considered. This paper measures supply chain performance using DEA technique models by integrating all activities of the value chain. Also provides a useful guide to the use of this technique as a classification tool in measuring supply chain efficiency.

INTRODUCTION

Supply chain management is one of the most discussed topics in the business literature. According to Simichi - Levi supply chain management is a set of approaches that is used for the overall efficiency of raw material suppliers, manufacturers, warehouses and stores, so that the proper amount of goods, in the right place at the right time with the minimum cost of producing and distributing goods and services and the needs are satisfied (Simchi-Levi, et al., 2003).

Supply chain as a hybrid system that consists of four processes, namely, planning, sourcing, production and delivery links the various parts, including suppliers of materials, manufacturing facilities, distribution services and customers through streams of material, financial and information (Christopher, 1998). Effectiveness of supply chain management in an organization is proved when the organization is able to make an effective mechanism to provide a fast and reliable quality goods and services with minimum cost that is fundamental for an organization to achieve a sustainable competitive advantage. Supply chain performance evaluation is generally necessary to achieve an effective supply chain. Assessment and management of total supply chain performance efficacy applies a combination of multiple tools to measure the functions associated with supply chain which aims to integrate and coordinate the function components in the chain.

Manage the total supply chain performance efficacy is very difficult and challenging task. Ross also noted that even large companies like Sears and GM with extensive supply chains; do not have total supply chain performance efficacy measurement systems (Ross, 1998).

This paper aims to provide a realistic framework for the study of supply chain performance and examines DEA technique application.

In this paper, the concept of supply chain efficiency in direct contact with suppliers and customers is determined. In other words, only two tiers of the supply chain are considered. This study develops an instrument to measure the supply chain by using data envelopment analysis (DEA). DEA is a nonparametric method for evaluating the performance of the units based on linear programming techniques.

DEA can measure multiple inputs and outputs and evaluate them quantitatively and qualitatively. Therefore, managers will be able to make reasonable judgments about the effectiveness of the analysis units. Here we pose a DEA model for supply chain efficiency evaluation of different companies. The model also helps managers for identifying inefficient operations and provides a pattern and strategy in supply chain performance development. This paper is organized as follows: First, we pointed out some traditional supply chain performance
measurement methods and problems associated with introduce DEA and its applications in supply chain process. Then describe and identify the developed DEA model for measuring supply chain efficiency. This is pursued by model application in 22 industries supply chain. The results will be discussed, reach to perfection with managerial implications and end.

**Measuring supply chain efficiency:**

Today, looking at the business is based on the network business and supply chain approaches and their management has started with the same attitude into the realm of existence. Traditionally, the companies have pursued performance based on accounting and finance. But the parallel to evolution of the solitary approach to the network approach and supply chain performance measurement systems are also welcome evolution towards network performance measurement and supply chain.

In recent years, a new stream is created in order to measure efficacy, to measure supply chain efficiency is somewhat difficult because clients exert a lot of pressure on manufacturers to speed up the construction and deliveries (Stewart, 1997). In addition, to measure supply chain efficiency, other specific measures in addition to financial measures for evaluating the tardiness, the rate of delivery orders and ... are required. These criteria are even more complex due to the influence of productive capacity and other imposed activities. In this regard, the creation of multiple performance measures, work ⇒ easier to evaluate the performance (Rao, 2006). These pro tools are not only the logical reasons for quantity but also provide some insight for managers of qualitative perspective on strategic decisions making.

**Traditional methods of measuring supply chain efficiency:**

Radar diagram and chart Z are among the first measurement tools of supply chain efficiency. These tools are based on Gap Analysis techniques with graphical nature. Though graphical approach understanding is easier, when the goal is multiple element, input and output analysis the use of this technique is virtually impossible.

Other popular method is the use of ratios. In this way the efficiency is calculated by output divided by the input product that is and easy calculation. But even when we have multiple inputs and outputs this approach would not be appropriate because the use of these inputs and outputs different ratios can be achieved without a comprehensive combined set of ratios for judgment.

Performance evaluation of supply chain should be considered as a multi-dimensional structure. Evaluation is important in the implementation of changes to current operations and creation of new strategies to stop competitors. Financial ratios such as return on sales and return on investment may not be sufficient as a marker to draw the overall supply chain efficiency. So the traditional tools cannot be taken into account multiple structures as suitable tool for evaluating supply chain performance. Hence, supply chain efficiency is a complex problem that requires more than one measure. A series of studies have also suggested that performance measurement multi-agent model can be effective to evaluate the supply chain performance (Measurement model). These models are capable to reflect duty unit’s efficiency and technological tools in a supply chain.

**DEA review and its applications in the supply chain:**

DEA first was introduced by Charnes and Cooper (1987) as a linear programming (LP) and a method for Decision Making Units (DMUs) performance analysis.

DEA Technique enables managers use data effectively in all scales without having to find the relation between them (Zhu, 2000). These techniques compared to other means of MCDM, such as Analytical Hierarchy Process (AHP) is capable to measure multiple inputs and outputs separately, and operate as a multiple criteria decision-making tool. The DEA does not need to determine numerical index weights or priorities modelling for analysis, although if necessary or desired could be included in it that it makes to avoid discrimination in the criteria used due to different approaches. Therefore, the advantage of DEA Compared to MCDM methods is that requires less information in decision-making and analysis. In this technique allows assessing strategies that can be useful in decision-making. A comparative analysis of DEA as a separate method of MCDM has been suggested by Sarkis (Farrell, 1957).

DEA literature has shown that this technique is widely used in measuring efficiency especially in benchmarking issues. Collier and Storbeck used standard DEA approach that measures technical efficiency to determine benchmarks. Morey and Bell used DEA to determine benchmarks by finding a much more cost-effective resource. Also, DEA is used for benchmarking in banking and finance industry and grocery stores, as well (Collier and Storbeck, 1993). In addition, Richards has shown the importance of using DEA in conjunction with the balance score cards assessment and noted that reliance on this tool for position preservation, as a strategic tool is increasing (Bell and Morey, 1995).

In this paper we do not intent to offer a long history of DEA, but we widely use of DEA in internal and external benchmarking in the literature clearly demonstrates DEA is used by managers as an excuse tool for a performance measurement that show the performance comparison is derived from the principles of performance...
measurement. Benchmarking process techniques starts with efficacy measurement and then proceeds to classify and compare efficacy.

Although DEA models are widely based on the literature and so far study or search was not able to gather reports on supply chain performance measurement. The traditional DEA model value has led to its expansion in supply chain management. Wong explained that motivation behind the use of DEA as a tool for supply chain performance measurement is based on extant supportive literature and logic to use the techniques as a tool for decision making in supply chain management (Richards, 2003).

Data envelopment analysis:

This study method is DEA. Two models of DEA are developed to measure the efficiency of the supply chain. DEA model is suitable for evaluating the efficiency of the supply chain because this technique can target multiple inputs and outputs without any unrealistic presumption about variables that typically exist in the optimal supply chain model.

Methodology first shows DEA approach cornerstone. The will follow the development of models to measure supply chain efficacy. Then, the model will be applied on 22 industries.

DEA cornerstone and model structure:

DEA is a mathematical programming technique that measures relative efficacy of decision making units based on multiple inputs and outputs compared to other units. Efficiency score is defined based on the weighted sum of output divided by weighted sum of input while the weight should be determined. DEA models determines that Highest possible efficiency score related to a unit of decisions making, and while assuming the units efficacy scores less than or equal to 1 calculates efficacy score. A fraction of a DEA in a mathematical programming model is shown below:

$$\text{maximize} \quad h_0 = \frac{\sum_{i=1}^{n} u_i y_{ij}}{\sum_{i=1}^{m} v_i x_{ij}}$$  

$$\sum_{i=1}^{m} u_i y_{ij} \leq 1, \quad j = 1, \ldots, n$$  
$$\sum_{i=1}^{m} v_i x_{ij}$$  

$$u_r \leq \epsilon, \quad r = 1, \ldots, t \quad v_r \leq \epsilon \quad i = 1, \ldots, m$$  

(1)

When Ur is output weight of the rth, Vi input weight of ith , yij is rth output unit of jth decision making unit, xij is ith input of jth decision making unit, t is the total outputs, I have the same decision-making input j I can be. t the total number of outputs, m the total number of inputs, n the number of decision-making units, and \(\epsilon\) is a very small amount. Objective function of equation (1) means to maximize the efficiency of decision making unit j0 by choosing a set of weights for inputs and outputs. The first set of constraints corresponding to equation (1) is to ensure that the by choice of weights, scores of all m decision making units efficacies is not more than 1. The second and third set of constraints, equation (1), is related to inputs and outputs weights which are to ensure that no weights are not zero.

With the constant denominator of the objective function and placing it in equation (1) restrictions and maximizing the numerator in the objective function, the problem could be in the form of a linear programming problem as follows.

$$\text{maximize} \quad h_0 = \sum_{i=1}^{n} u_i y_{ij} \quad \sum_{r=1}^{t} v_r x_{ij} = 1$$  

$$\sum_{i=1}^{n} u_i y_{ij} - \sum_{j=1}^{n} v_j x_{ij} \leq 0, \quad j = 1, \ldots, n$$  
$$u_r \leq \epsilon, \quad r = 1, \ldots, t \quad v_r \leq \epsilon \quad i = 1, \ldots, m$$  

(2)

Equation (2) secondary model can be as follows, equivalent to:
\[ \min_{i} \theta - \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{j=1}^{l} s_j^+ \right) \]

\[ \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{jo}, \quad i = 1, \ldots, m \]

\[ \sum_{j=1}^{n} \lambda_j y_{ij} + s_j^+ = y_{jo}, \quad i = 1, \ldots, m \]

\[ \lambda_j, s_i^-, s_j^+ \geq 0 \] (3)

Where \( s_r, s_i, \lambda \) are the secondary variables, \( \theta \) Variable is a "technical efficiency" score that we want to calculate and \( s_r, s_i \) are auxiliary input and output auxiliary variables represent the rate of the shortfall in output, while an input auxiliary variables represent the rate of additions to the inputs. Lack and efficacy variables, which are closely related to each other, help us in the future decision making as in the past will.

Based on equation (3) a DMU\(_{j0}\) is efficient if and only if is the optimal answer of the secondary model \( s_j = s_i = 0, \theta = 1 \), for all \( i \) and \( r \) (s). Here the asterisk denotes ultimate answer of the model is that is equal to 1 for both equations (2) and (3). For a deficient DMU\(_{j0}(\theta \neq 1)_j \) appropriate adjustments can be done for inputs and outputs to improve performance and therefore efficiency. These adjustments are shown in equation (4) and (5).

\[ x_{ij0}' = \theta x_{ij0} - s_i^- \], \quad i = 1, \ldots, m. \] (4)

\[ y_{ij0}' = y_{ij0} + s_j^+ \], \quad r = 1, \ldots, l. \] (5)

According to the secondary theory (dual) in linear programming, for an efficient DMU\(_{j0}\) in the final answer should have \( \lambda > 0 \). Also we know that every single decision making (DMU) of a peer group unit equals to 1. A peer group consists of an inefficient DMU\(_{j0}\) and a series of efficient DMU (efficiency score: 1). improved inputs and outputs is obtained from the secondary model in equations (4) and (5). This is because equation (3) constrains links each DMU\(_{j0}\) output and input levels to output and input level of a DMU of a peer group. In data oriented model that emphasizes on reduced inputs for efficiency, inputs adjustment are applied while in output-oriented models take advantage of outputs adjustment. Data oriented models are most commonly used by managers because they have more control on input than outputs.

Secondary model (3) is known as a cover model. The advantage of DEA model solution via the dual is that in DEA models the number of DMU is mainly more than that of inputs and outputs with the reduced number of constraints in the dual. In addition, the secondary variables directly will show improvements in data and outputs for each DMU to achieve efficiency 1 in output. DEA model solution via the dual method is common. If the convexity constraint \( \sum_{i=1}^{n} \gamma_i = 1 \) is added equation (3), the model will only show technical efficiency (TE) (Envelopment analysis). Above model (Equation 3) is used to calculate the technical efficiencies. Then we need to enter the cost information in the model and rewrite the model to minimize the cost. With this new model, we can measure cost efficiency and allocative efficiency. Input financial information is needed to measure cost efficiency and allocative efficiency.

Efficacy model by entering costs is shown below.

\[ \min_{i} \sum_{j=1}^{m} c_{j0} x_{ij} \]

\[ x_{ij} \geq \sum_{j=1}^{n} x_{ij} \lambda_j \], \quad i = 1, \ldots, m \]

\[ y_{ij0} \leq \sum_{j=1}^{n} y_{ij0} \lambda_j \], \quad r = 1, \ldots, l \]

\[ \lambda_j \geq 0 \] (6)
Where $c_{ij}$ the cost per unit of input $i$ of DMU $j$, that can vary from one DMU to another. Cost efficiency (CE) of every single decision making unit is calculated as follows:

$$CE = \frac{c'_{ij}x'_{ij}}{c'_{ij}x_{ij}}$$  \hspace{1cm} (7)

This ratio is equal to the least cost to the actual observed cost. Similarly, the allocative efficiency (AE), also is obtained by division of cost efficiency (CE) to technical efficiency (TE). Technical efficiency is obtained by equation (3) as:

$$AE = \frac{CE}{TE}$$  \hspace{1cm} (8)

Allocative efficiency measure reflects a combination of insufficient inputs. These data are important to all managers with calculation of the opportunity cost, because the managers make use of this information as the basis for decision-making, resource allocation, and strategic planning for ongoing improvement (Wong and Wong, 2006).

Models application infrastructure:

Both DEA models are formed to be used in supply chain performance measurement. We’ll talk later about the core concepts of each model and how each model will show the solution to the director. As already mentioned, the model of technical efficiency will provide us with TE and model of cost efficiency also provide us with CE. Allocative efficiency (AE) can also be obtained after identifying cost- efficiency and technical efficiency. Technical efficiency emphasizes on the ability of a firm to obtain maximal output from a specified data and allocative efficiency emphasizes on the ability of a firm to use the data optimally regarding the price. In sum this article attempts to develop a framework for supply chain performance measurement.

There are four overall levels of supply chain management in Supply Chain Operations Reference model (SCOR) (Stewart, 1997):

The first level consists of main processes of plan, source, make, delivery and return. Second level categorizes policy and strategic activities for the firm in the production and service delivery. The third level consists of information that is used by a firm for a successful supply chain planning and goal setting. At this level, the process elements, the successful benchmarks and best practices of every industry and capacity necessary to achieve the continuous improvement of the supply chain can be defined. And finally, the fourth level is the functional level where supply chain management activities is defined to adapt to changing conditions in any organization.

The study also is used presented variables in the model. Conceptual model is shown in Figure 1. The purpose of this paper is to provide an analytical framework to measure the internal supply chain efficiency in manufacturing companies and comprises all activities related to the internal supply chain within an organization to manufacture products. Thus measures levels efficacies using levels 2 and 3 indices, though the levels efficacy may represent the supply chain of the company’s overall efficacy at the macro level 1. The SCOR model metrics that have been used in this article include key financial metrics and operational criteria. The DEA is used as a tool for the analysis of these variables. Table 1 show the input and output variables of the model.

![Conceptual model for measuring internal supply chain efficiency](image-url)
Output variables:
1- Financial- revenue variables. This is a general criterion to assess the efficacy of profit organizations.
2- Operational criteria - Timely order delivery rate (ODR) is the general public performance of “the supply chain delivery capability”. This criterion refers supply chain performance in delivering the right product in the right place at the right time, in the right packaging in a reasonable amount, with proper documentation to appropriate client.

Table 1: Input and output variables used in the analysis of DEA models

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Output variables</th>
<th>Input variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Criteria</td>
<td>Income</td>
<td>Cost</td>
</tr>
<tr>
<td>Operational criteria for supply chain</td>
<td>In time order delivery rate (ODR)</td>
<td>Internal manufacturing capacity (IMC)</td>
</tr>
</tbody>
</table>

Input variables:
1- Financial - cost criteria. Demonstrate cost of supply chain performance. These costs are related to supply chain operations.
2- Operational criteria. Cycle time (CT) (time from start to completion in order to complete a production process) refers to the performance of supply chain responsibility and to the speed of the supply chain in providing products or services to customers.
3- The capability or manufacturing flexibility (internal manufacturing capability- IMC) refers to the performance of supply chain flexibility and supply chain agility in responding to market changes to gain or maintain competitive advantage.

Studying data obtained from 16 selected companies in the cement sector, inputs and outputs have been analysed and technical, allocative and cost efficiency have been calculated. Table 2 shows the calculation results of DEA model.

Table 2:

<table>
<thead>
<tr>
<th>Allocative efficacy</th>
<th>Cost efficacy</th>
<th>Technical efficacy</th>
<th>Company</th>
<th>Tier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Iliam Cement</td>
<td>1</td>
</tr>
<tr>
<td>0.594</td>
<td>0.594</td>
<td>1.000</td>
<td>Urmia Cement</td>
<td>2</td>
</tr>
<tr>
<td>0.729</td>
<td>0.645</td>
<td>0.884</td>
<td>Shahroud Cement</td>
<td>3</td>
</tr>
<tr>
<td>0.772</td>
<td>0.608</td>
<td>0.843</td>
<td>Kerman Cement</td>
<td>4</td>
</tr>
<tr>
<td>0.864</td>
<td>0.859</td>
<td>0.994</td>
<td>Dashtestan Cement</td>
<td>5</td>
</tr>
<tr>
<td>0.764</td>
<td>0.727</td>
<td>0.952</td>
<td>Dorod Cement</td>
<td>6</td>
</tr>
<tr>
<td>0.710</td>
<td>0.635</td>
<td>0.894</td>
<td>Mazandaran Cement</td>
<td>7</td>
</tr>
<tr>
<td>0.719</td>
<td>0.719</td>
<td>1.000</td>
<td>Belbahan Cement</td>
<td>8</td>
</tr>
<tr>
<td>0.721</td>
<td>0.537</td>
<td>0.744</td>
<td>Fars Cement</td>
<td>9</td>
</tr>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Ghareh Cement</td>
<td>10</td>
</tr>
<tr>
<td>0.721</td>
<td>0.659</td>
<td>0.914</td>
<td>Bojnord Cement</td>
<td>11</td>
</tr>
<tr>
<td>0.732</td>
<td>0.590</td>
<td>0.807</td>
<td>Fars no Cement</td>
<td>12</td>
</tr>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Ghurb Cement</td>
<td>13</td>
</tr>
<tr>
<td>0.594</td>
<td>0.560</td>
<td>0.943</td>
<td>Salijan Cement</td>
<td>14</td>
</tr>
<tr>
<td>0.572</td>
<td>0.456</td>
<td>0.798</td>
<td>Khoraz Cement</td>
<td>15</td>
</tr>
<tr>
<td>0.696</td>
<td>0.638</td>
<td>0.903</td>
<td>Heymountan Cement</td>
<td>16</td>
</tr>
</tbody>
</table>

As the table demonstrates all companies that are technically efficient are not necessarily efficient in terms of allocative measures. This is consistent with effectiveness theoretical concepts that distinct clearly technical and cost efficiency models. In such a case, the results of the analysis performed support the validity of both models.

Conclusions:
Authors started this research due to the lack of appropriate tools to measure supply chain efficiency. DEA is reached development to the point that can be used as an efficient, flexible and reliable tool for measuring supply chain performance.

This paper examines two models of efficacy: the model of technical efficiency and cost efficiency models. Model of technical efficiency provides managers with technical efficiency and a cost efficiency model helps managers in cost and allocative efficiency. Information determined by this model help managers in determining inefficient operations and remedial action to seek continuous improvement.

In order to prove and show the usefulness of these two models, data was collected from 22 firms active in the countries cement sector. All companies that are technically efficient are not necessarily efficient in terms of allocative measures. This is consistent with effectiveness theoretical concepts that distinct clearly technical and cost efficiency models. In such a case, the results of the analysis performed support the validity of both models. Managers want to allocate resources effectively and efficiently. For managers equipped with right information and the right tool for decision making, the goal of maximizing efficiency and minimizing costs will be achievable. Opportunity costs arising from the model proves that these costs are very useful information for...
managers. This part of the information that is used as hybrid helps managers make better decisions in the field of resources design by the inputs combination allocative scenario analysis. The result in this paper provides a useful perspective on DEA applications as a modelling tool to support management decisions for measuring supply chain efficiency.

REFERENCES


Collier, D.A. and J.E. Storbeck, 1993. “A data envelopment approach to benchmarking in the telecommunication industry”, working paper, Ohio State Faculty of Management Science, Ohio State University, Columbus, OH.


