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Supply Chain Performance Evaluation With Rough Data Envelopment Analysis

Case Study: Food Industry (Ramak Co.)

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Abstract—**In this article after reviewing different tools for evaluating the performance of supply chain performance, a new approach based on RDEA has been generated. By the mean of this approach some elements that are not deterministic in nature can be evaluated more precisely. In the other words for each rough data an interval can be calculated, that the upper and lower boundaries of it shows the probable maximum and minimum values of the element and obviously it can takes any value in this interval. Then based of these values,the efficiency of each DMU can be calculated.**

Keywords- Supply Chain Management, Rough Data Envelopment Analysis, Performance Evaluation

I. INTRODUCTION

Market globalization has made supply chain management one of the interesting topics to be discussed. An efficient supply chain can cause a range of benefits, including reduced cost, increased market share and sales, and sustainable customer relationship. (Fergusen, 2000) also it has been cited that measuring supply chain performance can improve the overall performance. (Chen and Paulraj, 2004) .efficiency of supply chain encountered an integration of performance of all members. As such managing the overall supply chain efficiency is a challenging task.

"Performance" implies predetermined parameters and "measurement" implies on ability to monitor events and activities in a meaningful way. Performance measurement can be defined as the process of quantifying the effectiveness and efficiency of action (Neely et al, 1995). A number of approaches for measuring performance are: balanced scorecard (Kaplan and Norton, 1992), the performance measurement matrix (Keegan et al, 1989) performance measurement questionnaire (Dixon et al, 1990), criteria for measurement system design (Globerson, 1985) and computer aided manufacturing approaches. However utilizing them highlights a range of limitations including, lack of strategic focus, forcing managers to encourage local optimization rather than seeking the continuous improvement and also they are disable to provide adequate information about competitors.

In 1900, founder of General Motors, William Durant, claimed that profit is outcome of a cost stream that spread throughout the supply chain, not result of an accounting exercise. Since then, the principle of identifying profit and controlling cash flow has been used to dominate organizational performance measurement. Generally the efficiency of supply chain which is usually managed as a series of simple business functions is measured by taking the ratio of revenue over the total supply chain operational cost. However, since increasing demands for quick order fulfillment and fast delivery, new trends have emerged. As such, in addition to usual financial measures, other specific indicators such as customer's satisfaction should be considered. Emerge of multiple performance measures has made the efficiency measurement task, difficult and sophisticated. Also the toll utilizing to measure the performance should not only provide quantitative reasoning but should also provide qualitative perspective to remain aligned with strategic goals of the organization.

The primary objective is this paper is to provide a realistic application of DEA to study supply chain performance. DEA is a non parametric method to analyze efficiency and was proposed by Charnes et al (1978) to produce the efficiency frontier based on the concept of Pareto optimum. DEA is a powerful tool in evaluating organizations with multiple inputs and can consider qualitative and quantitative measures. In general this paper is organized as follow: first a brief description on some traditional tools of measuring supply chain performance, and then a review on DEA and its applications and concepts associated with supply chain. This is followed by the explanation of methodology and DEA models developed to measure supply chain efficiency and application of them in an organization. And the last chapter provides some conclusions about the research.

II. LITREATURE REVIEW

A. Traditional Methods to Masure Supply Chain Efficiency

In the process of evaluating the performance, choosing the performance measures is an important task, because via them, actions of management and solutions for improvement would be derived. Obviously these measures vary from field to field.

Reviewing literature shows focuses on cost-based performance measures. Because the metric of cost has conveniences in understanding and that's why managers used to welcome it more. (Ellram, 2002, Ballou et al. 2000). But inflexibility and lack of integration with strategic focus, made researchers, looking for better measures, that contains quantitative as well as qualitative measures in supply chain. Beamon (1999) identified three types of measures, namely resources, output and flexibility. Extending these measures leads to provide a new framework for supply chain evaluation that measures strategic, tactical and operational level of performance.

Pittiglio, Rabin, Todd, and Mc. Grath generated the first universal performance measures which are known as PRTM. This is the first comprehensive method that provides a world class supply chain measurement. In PRTM, the keys for excellence of supply chain are identified as: delivery performance, flexibility and responsiveness, logistics and cost, and asset management. The concept of PRTM extended and supply chain council proposed the supply chain operations reference (SCOR) model. (Stewart, 1997) which became the first cross-industry framework for evaluating supply chain performance. SCOR is structured in 4 levels based on a plan, source, make, and deliver framework. The metrics used in SCOR include a broad range such as delivery performance, order fulfillment, production flexibility, and cash-to-cash cycle time.

Although the study of performance measurement was enriched by different researchers and findings, still some gaps exist in certain aspects. Lack of valid measurement criteria and adequate methodologies to aggregate individual performance measures into a single index of performance was one of them. Most methodologies were unable to consider relative importance of measures, which varies among the firms. In addition there was no aggregate measure of overall supply chain performance that could be utilized to compare performance with other industry members.

Although numerous advantages of SCOR, in 2004, Samuel et al. showed that utilization of SCOR seems to be rather rigid and needs further enhancement. Since networks of supply chain are becoming more complex, the SCOR model needs to be more dynamic and should be able to provide an adequate platform to measure these complex features. For example "bullwhip" effect is one of the phenomena that can affect the supply chain as a whole. Sometimes control of this phenomenon is out of the territory of managers. However SCOR provides deterministic performance metrics that are controllable by managers and administrators. As a result SCOR should be more dynamic to be able to synchronize different elements. Also by the review of literature, it can be drawn that past work had failed to address the collaborative relationship in the area, that involves joint decision making.

B. Tools used in Supply Chain Evaluation

Basically there are 2 types of measurement, parametric and non-parametric. These two categories utilize different tools to evaluate. In parametric analysis usually gap-based techniques are used for performance measurement. Some of them are "SPIDER" and "RADAR" diagram and the "Z" chart. These tools are very graphical in nature and this feature makes them easy to understand. However they are not useful when analyst needs to integrate different elements into one complete picture.

Another parametric method which has been used in different areas is the ratio. It is easy to compute and calculates the relative efficiency of output versus input. However different ratios provide different interpretations and it is difficult to combine the entire set of ratios into a single judgment.

Analytical hierarchy process is also used to analyze data in performance measurement. It utilizes personal views of experts to convert various weighted scores into a single score. Though this method provides managerial insights in quantifying measures, it is subjugated to high degree of subjectivity.

Statistical methods such as regression are also useful tools to some extent. They are kind of the parametric measures which are able to provide meaningful relationships for decision makers. However regression can only analyze one single output at a time. By adding another criterion, the approach has to be repeated. Also it can only consider average values which probably do not occur in the real world. On the other hand considers that all the firms have the same performance in combining their input factors.

One of the commonly used tools in non-parametric which can provide a comprehensive framework in performance measurement is balanced scorecard (BSC). (Kaplan and Norton, 1993) Some critical areas that BSC considers are product, process, customer, and market development. It has four main perspectives which are traditional financial indicators, customers, internal business processes, and innovation and learning. BSC can link strategic objectives of a firm to a comprehensive set of measures. This feature specifies BSC from other tools. However BSC cannot provide any mathematical logic for relationships among different criteria. Hence utilizing BSC makes some difficulties in comparing internal and intra performance of the firm. That’s why in order to evaluation, utilizing BSC is not enough and to arrive to some judgments, utilizing parametric methods is proposed.

Another non-parametric tool in evaluation is data envelopment analysis (DEA). DEA can consider qualitative as well as quantitative measures, hence enables managers to provide reasonable judgments on efficiency of the resource usage. It uses the concept of efficient frontier which was suggested by Farrel (1957). DEA can also compute efficiency for multiple inputs and outputs by dividing weighted sum of outputs by a weighted sum of inputs. All the efficiencies would lay between 0 and 1, in which "1" shows the most efficient DMU. Although DEA can cover some shortages of other tools, it has some limitations too:

- Availability of data in order to make DEA results meaningful is really vital. All inputs and outputs of a DMU is needed to reach reasonable findings, however sometimes it is hard to find some of these data and sometimes firms are not interested in sharing data.
- Number of DMUs being compared cannot exceed a certain upper and lower limit. If so, number of efficient DMUs would increase.
- DEA assumes that all of DMUs in the firm have the same strategic goals and objectives. Hence DMUs

which are different in these aspects cannot be comparable by DEA.

- Interpretation of the results of DEA is so critical. Although DEA provides reasonable rankings for efficient DMUs, it seldom addresses the reasons of inefficiencies or solutions to reduce or eliminate it.

The set of profits and shortages of each tool makes it difficult to select the appropriate one. But DEA has some advantages that make it distinguished. Next section provides these features to justify its utilization as an efficient tool for supply chain performance measurement.

Data envelopment analysis

DEA is a linear programming based methodology that can evaluate DMUs qualitatively as well as quantitatively and also calculates multiple inputs and outputs. The term DMU stands for decision making unit and can be used either for comparing different firms or evaluating efficiency of one firm over time.

DEA was first proposed by Charnes, Cooper and Rhodes (CCR) in 1978. In 1984 Banker et al. suggested the evolutionary form of CCR model named BCC. In subsequent years, DEA received more concern and a large number of researchers studied about it and developed various models. In general these models differ in orientation, disposability, diversification and returns to scale, and types of measures.

The underlying concept of measuring efficiency in DEA is efficient frontier function. Then a set of efficient and inefficient units emerge. The analysis of inefficient units has two aspects. First it can show the maximum input level in order to attain a given amount of outputs. Secondly it can also show highest input level attained for a given amount of inputs. These approaches are called "minimal principle of efficiency" and "maximum principle of efficiency" respectively.

C. Motivations to use DEA in supply chain benchmarking

The tool which is used for evaluation should carry some characteristics in order to make it useful and suitable. Many researchers believe that simplicity and ease of use should be considered while selecting the tool (Maskell, 1991, Sheridan, 1993, DeToro, 1995, Blossom and Bradley, 1998). It must also be reliable and output results must be realistic enough to be helpful in making decisions.

DEA is a robust, standardized and transparent methodology that can fulfill all the requirements above. It also inherits some additional features which made it suitable to be selected as the supply chain benchmarking tool. Some of them are:

1) Ability in processing multiple elements

2) There is no need to specify the relationships among the performance measures.

3) The concept of efficient frontier which is used in DEA serves appropriately as an empirical standard of excellence.

4) DEA can analyze qualitative measures as well as quantitative measures simultaneously.

5) In the approach of utilizing DEA, there is no need to assume priori estimates. This feature increases the acceptability of its results.

III. Rough DEA

Although various applications of DEA in different fields, majority of these research assumes that the input and output parameters of the supply chain are deterministic. However in the real world problems, some factors such as demands, allocations, cost of shipment, and even locations of customers and facilities are usually changing. Hence uncertainty should be considered while evaluating supply chain performance. Since uncertainty has a great effect in supply chain, a number of researchers had studied about the concepts and applications of stochastic DEA and fuzzy DEA (Wu, 2009). For example Talluria et al. (2006) proposed a stochastic chance-constrained data envelopment analysis (CCDEA) approach in the presence of performance measures that are uncertain. Also Haung and Li (2001), Narasimhan et al. (2001), Cebi and Bayraktar (2003), Ohdar and Ray (2004), Amirteimoori et al. (2005) and Jahanshahloo et al (2006) showed various applications of encompassing uncertainty in DEA model to solve the supply chain performance evaluation.

In a practical real world decision making we usually face the rough uncertain environment. To overcome this problem, rough set theory proposed by Pawlak and rough variable proposed by Liu (2004) can be employed. Reviewing the literature shows many researchers have studied in the field of stochastic DEA and fuzzy DEA. However researchers on rough DEA (RDEA) are still very few. Therefore the research on combining DEA with rough set theory is an attractive study field. In this paper a DEA model with rough set parameters and its applications to the real world supply chain performance evaluation problem has been proposed.

A rough set can be recognized by a couple of sets that identifies the approximation of upper and lower limits of it and can be denoted by $(\underline{X}, \overline{X})$. To face uncertainty, rough variables should be convertible to deterministic values. In this article we have utilized α-optimistic value α-pessimistic value operator to overcome this problem. As a result by identifying trust level of α for rough variables, CCR DEA model can be exchanged into a couple of maximum and minimum programming. For example consider $\xi = ([a, b], [c, d])$ as a rough variable in which $c \le a < b \le d$. Then the optimistic value for ξ can be calculated as:

$$\xi_{sup}(\alpha) = \begin{cases} (1-2\alpha)d + 2\alpha c & \text{if } \alpha \le ((d-b)/[2(d-c)]) \\ 2(1-\alpha)d + (2\alpha-1)c & \text{if } \alpha \ge ((2d-a-c)/[2(d-c)]) \\ \dfrac{d(b-a) + b(d-c) - 2\alpha(b-a)(d-c)}{(b-a)+(d-c)} & \text{otherwise} \end{cases}$$

And the pessimistic value for it can be calculated as:

$$\xi_{inf}(\alpha) = \begin{cases} (1-2\alpha)c + 2\alpha d & \text{if } \alpha \le ((a-c)/2(d-c)) \\ 2(1-\alpha)c + (2\alpha-1)d & \text{if } \alpha \ge ((b+d-2c)/2(d-c)) \\ \dfrac{c(b-a) + a(d-c) + 2\alpha(b-a)(d-c)}{(b-a)+(d-c)} & \text{otherwise} \end{cases}$$

Now considering these two values, the DEA model for a rough variable can be formulated as:

$$\text{Min}\,\theta$$
$$\text{s.t.}\begin{cases}\sum_{\substack{j=1\\j\neq j_0}}^{n}\lambda_j X_j^{\sup(\alpha)}+\lambda_{j_0}X_0^{\inf(\alpha)}\le \theta X_0^{\inf(\alpha)}\\ \sum_{\substack{j=1\\j\neq j_0}}^{n}\lambda_j Y_j^{\inf(\alpha)}+\lambda_{j_0}Y_0^{\sup(\alpha)}\ge Y_0^{\sup(\alpha)}\\ \lambda_j\ge 0 \quad ,j=1,2,3,\dots,n\end{cases}$$

And the upper limit for this variable is:

$$\text{Min}\,\theta$$
$$\text{s.t.}\begin{cases}\sum_{\substack{j=1\\j\neq j_0}}^{n}\lambda_j X_j^{\inf(\alpha)}+\lambda_{j_0}X_0^{\sup(\alpha)}\le \theta X_0^{\sup(\alpha)}\\ \sum_{\substack{j=1\\j\neq j_0}}^{n}\lambda_j Y_j^{\sup(\alpha)}+\lambda_{j_0}Y_0^{\inf(\alpha)}\ge Y_0^{\inf(\alpha)}\\ \lambda_j\ge 0 \quad ,j=1,2,3,\dots,n\end{cases}$$

Now for each of DMUs an interval that contains a lower and upper limit has been reached. For ranking DMUs we have utilized the meaning of maximum loss of efficiency. The maximum loss of efficiency the decision-maker might suffer is given by:

$$\text{Max}(r_i)=b-\theta_i^{\sup(\alpha)}=\text{Max}_{j\neq i}\left\{\theta_j^{\inf(\alpha)}\right\}-\theta_i^{\sup(\alpha)}$$

hus, the minimax regret criterion will choose the efficiency interval satisfying the following condition as the best efficiency interval:

$$\text{Min}\{\text{Max}(r_i)\}=\text{Min}\{\text{Max}\left[\text{Max}_{j\neq i}\left(\theta_j^{\inf(\alpha)}\right)-\theta_i^{\sup(\alpha)},0\right]\}$$

As a result, for ranking DMUs the maximum loss of efficiency for each interval is calculated and the DMU with the smallest maximum loss of efficiency is considered the most efficient one.

IV. PERFORMANCE ENALUATION

The supply chain performance evaluation problem, considered in this paper is extracted from dairy industry. We assume one of the largest manufacturers that produce different kinds of ice-cream. Here the main aim is to evaluate the production of 6 different kinds of ice cream by utilizing RDEA. Each kind is produced under different conditions and by the use of different machines and labors.

There are many studies on the supply chain performance evaluation index system. In 1998, Lummus et al. suggested a four aspect index to measure supply chain performance. Mu (2000) proposed some statistical indices. As mentioned before, in 2000 PRTM was proposed and extending it put forward 11 indices in the supply chain operations reference (SCOR) model. In this study input and output variable are categorized according to SCOR. In addition the nature of dairy industry leads to consider some other measures. The overall results are shown in the table 1. It can be seen that the table includes both the input and output variables.

However lack of enough information makes some inconveniences in describing the parameters of the problem as known variables. For example there are many factors that can affect the transaction expense of the supply chain network. Some of them are: purchase expenses, marketing expenses, and information processing expenses. So usually our data cannot be precise enough. In the supply chain problem there are some approaches that can be used to deal with the imprecise information. One of them is fuzzy multi-objective programming that Wu et al (2009) proposed for supplier selection problem. In 2008 Xu and Liu utilized random fuzzy variable as a tool to describe supply chain operation cost in supply chain network design problem. Also Xu and Zhao (2008) used fuzzy rough variable for inventory problem with imprecise data. In this paper we have utilize rough variables to overcome uncertain parameters. In this paper we have utilize rough variables to overcome uncertain parameters. Also this study is based on 2 assumptions: The cost index is considered as a rough variable and; other indices are deterministic variables.

So rough variables are: direct costs, operation costs, and transaction expense. Other variables (i.e. time, human resource, flexibility, financial, service and capacity) are deterministic.

TABLE I. INPUT INDEX

Factor	Index	Measure	Unit
Input	Cost Time Human resource Capacity	Direct Cost Operation costs Transaction Expenses Order lead time Cycle time Total volume of employees Capacity of machines	Rial Rial Rial Rial Day Day Person Unit/Hour

TABLE II. INPUT INDEX

Factor	Index	Measure	Unit
Output	Service Financial	Frequency of delivery no. of product/ process/ technology developed and transferred to industry Sales volume Net profit vs. productivity ratio Cost reduced	number number Rial Rial Rial

In order to set up rough variables, we've developed an approach. As mentioned before, here we need 4 different data to adopt 2 intervals like ([a,b],(c,d]) in which $c\le a<b\le d$ .the upper approximation of a rough variable like direct cost can be assumed as the interval of a certain data in 2 different years, for example 2009 and 2010. And suppose

that direct cost is 2009 is less than direct cost in 2010 in the same season. Let p=(1/2)(a+b). then the lower approximation of rough variable can be considered as an interval nearby p, that can be denoted as [p-I,p+i] in which I is a variable on the distribution characteristics of direct cost data. Two other rough variables (i.e. operation costs and transaction expense) are structured by using the same technique. Calculations of this problem is available in the detailed paper of this article.

V. CONCLUSIONS

It is difficult for traditional DEA to deal with the SCM problem in the condition of uncertainty. Hence in order to make the results of two kinds of methods comparable, we employed the expected value theory of the rough variable to transfer the rough variable into deterministic variable. Then by utilizing the proposed methods, ranking order of DMUs determined. By comparing the results of ranking using DEA with RDEA it can be derived that the evaluation results by the RDEA method are more accurate and correspond to reality even more.

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