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Developing a DEA Model to Measure the Performance of Supply Chains

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ABSTRACT

Supplier selection is a process by which firms identify, evaluate, and contract with suppliers and plays a vital role in the management of a supply chain. Hence, the goal of the current paper is to propose a simple non-parametric model for the multiple criteria supplier selection problem. The suggested model provides non-zero weights for all criteria and allows the manager to get faster results by ranking the suppliers without solving the model n times.

1 Introduction

Supplier selection and evaluation is one of the most vital actions of companies in a supply chain. Selecting the wrong supplier could be enough to deteriorate the whole supply chain's financial and operational position. In today's highly competitive, global operating environment, it is impossible to produce low cost, high quality products successfully without satisfactory suppliers [1,22]. The success of a supply chain is highly dependent on selection of good suppliers. Supplier selection and evaluation is the process of finding the appropriate suppliers who are able to provide the buyer with the right quality products and/or services at the right price, in the right quantities and at the right time [15,27]. Toloo and Nalchigar [21] proposed an integrated data envelopment analysis model which was able to identify most efficient supplier in presence of both cardinal and ordinal data. Hadi-Vencheh [5] proposed a weighted nonlinear model to solve the multiple criteria supplier-selection problem. Hadi-Vencheh and Niazi-Motlagh [6] presented an extended voting analytic hierarchy process method for selecting suppliers. Karsak and Dursun [12] proposed a novel fuzzy multi-criteria group decision making framework for supplier selection integrating quality function deployment and data envelopment analysis. Izadikhah and Farzipoor Saen [9] present a new two-stage DEA model considering negative input-intermediate-output data to evaluate 29 Iranian supply chains producing equipment of expendable medical devices. Izadikhah and Farzipoor Saen [10] developed a method for solving the voting system by data envelopment analysis for selecting the most sustainable suppliers that supply self-supporting cable for a power distribution company. Dobos and Vörösmarty [3] developed a data envelopment analysis supplier selection method, where green factors served as the output variables of a DEA model, and management variables were the inputs. Tavassoli et al. [20] presented four types of supplier selection models in supply chains and provided a decision-making scheme for selecting an appropriate model for supplier selection by means of DEA models. Davoudabadi et al. [2] developed a new integrated efficiency measurement model combining statistical techniques, decision making, and mathematical programming for resilient supplier analysis.

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Yazdani et al. [20] provided a sustainable supplier evaluation structure under multiple criteria and interval valued fuzzy neutrosophic model. Sivanagaraju Pitchaiah et al. [18] reviewed the literature of multi-criteria dynamic methodologies for supplier assessment and choice. Kaur and Prakash Singh [13] proposed a multi-stage hybrid model for integrated supplier segmentation, selection, and order allocation considering risks and disruptions. Izadikhah et al. [8] proposed a novel fuzzy chance-constrained two-stage data envelopment analysis model as an advanced and rigorous approach in the performance evaluation of sustainably the supply chains. Izadikhah and Farzipoor Saen [11] presented a new stochastic two-stage data envelopment analysis model for assessing the sustainability of supply chains. Hosseini et al. [7] presented a method for supplier selection and order allocation under uncertainties for a multi-item, multi-period setting, where each supplier has its own pricing policy. Saputro et al. [17] formulated a framework that provides guidance on how supplier selection should be formulated and approached for different types of items segmented in Kraljic's portfolio matrix and production policies. Indeed supplier selection is a multiple criteria decision-making (MCDM) problem affected by several conflicting factors such as price, quality and delivery [4]. Over the years, several techniques have been developed to solve the problem efficiently. Among the methods the non-parametric models appears to be the easiest for practical implementation. The non-parametric approach does not require the decision maker to pre-define the weights. Weights are endogenously determined when solving a non-parametric model. Non-parametric models can automatically derive optimal weights of criteria with the performance score of the suppliers. In non-parametric models applied to supplier selection problems, decision makers can not have any involvement or control for the importance of the criteria [14,16,19,23,24,25]. The decision makers may not have enough knowledge to assign exact weight values but they can rank the importance by their expertise or experience. In this kind of decision making environment, the two above mentioned streams of approaches (weights determined exogenously and weights determined endogenously) may not be applicable [16]. In a recent paper Ng [16] proposed a weighted linear optimization model for multi-criteria supplier selection problem. The proposed model hereafter called the "Ng-model" retains the advantage of the non-parametric approach, that requires no pre-define weight values. At the same time it allows involvement of the decision maker in ranking the relativity of importance of criteria. The Ng-model is simple and easy to understand. Despite its many advantages, the Ng-model leads to a situation where the weight of a certain criterion becomes zero. That is, this criterion does not have any role for determining total score of the related supplier. This may lead to a situation where a supplier is inappropriately ranked. This may not reflect the real position of this supplier. The purpose of this paper is to present a new non-parametric model which overcome shortcoming mentioned above.

The remainder of this paper is organized as follows. The Ng-model is illustrated in Section 2. Shortcomings of the Ng-model are presented in Section 3. We present our model in Section 4. In Section 5 we apply proposed model to a numerical example. Section 6 concludes.

2 Ng-model [16]

Assume that n suppliers are available for a company. The purchasing manager would like to evaluate these suppliers based on m criteria. In particular, let the performance of ith supplier in terms of each of the criteria j, be denote as x_{ij}. For simplicity, further assume all measures are positively related to the score of a supplier. If there is a negatively related criterion, transformation of negativity or taking reciprocal can be applied for conversions. The purpose is to aggregate multiple performance scores of a supplier with respect to different criteria into a single score S_i. In the Ng-model, the author firstly transforms all measures to comparable base using linear transformation

$$y_{ij} = \frac{x_{ij} - min_{i=1,2,\dots,n}\{x_{ij}\}}{max_{i=1,2,\dots,n}\{x_{ij}\} - min_{i=1,2,\dots,n}\{x_{x_{ij}}\}} \tag{2.1}$$

Ng converts all measurements in a 0-1 scale for all suppliers. To facilitate the supplier selection under multiple criteria, Ng defines a non-negative weight w_{ij} which is the weight of contribution of performance of the ith supplier under the jth criteria to the score of the supplier. It is assumed the weights are ranked in a descending order such that $w_{i1} \geq w_{i2} \geq \cdots \geq w_{im}$ for all supplier i. The purpose is to aggregate multiple performance scores of a supplier with respect to different criteria into a single score. The proposed model by Ng [16] for aggregation purposes is as follows:

$$\begin{aligned} max \quad & S_i = \sum_{j=1}^{m} y_{ij} w_{ij} \\ s.t. \quad & \sum_{j=1}^{m} w_{ij} = 1, \\ & w_{ij} \geq w_{i(j+1)} \geq 0, \quad j = 1, 2, \dots, m-1 \\ & w_{ij} \geq 0, \qquad\qquad\quad j = 1, 2, \dots, m. \end{aligned} \tag{2.2}$$

Based on the transformations $u_{ij} = w_{ij} - w_{i(j+1)}$, $u_{im} = w_{im}$ and $a_{ij} = \sum_{k=1}^{j} y_{ik}$, the model (2.2) is converted to the following for all suppliers:

$$\begin{aligned} max \quad & S_i = \sum_{j=1}^{m} a_{ij} u_{ij} \\ s.t. \quad & \sum_{j=1}^{m} j u_{ij} = 1, \\ & u_{ij} \geq 0, \qquad\qquad j = 1, 2, \dots, m \end{aligned} \tag{2.3}$$

Now the maximal scores S_i can be obtained by the dual of (2.3). That is, the score S_i of the ith supplier can be easily obtained as $max_{j=1,2,\dots,n}(\frac{1}{j}\sum_{k=1}^{j} y_{ik})$.

3 Issues on Ng-model

In what follows we express Ng-model's shortcomings. *Firstly*, the Ng-model leads to a situation where the weight of a certain criterion becomes zero. That is, this criterion does not have any role for determining total score of the related supplier. This may not reflect the real position of a supplier. For more explantation, consider a situation where three criteria are under consideration by a company and there are 5 suppliers available. The measure of each supplier under the criteria are listed in Table 1.

Supplier	Firs criterion	Second criterion	Third criterion
1	19	567	90
2	12	967	90
3	33	635	95
4	2	795	90
5	34	689	95

Table 1: Measures of suppliers under criteria.

We take a reciprocal transformation of the second criterion so that the transformed values are positively related to the desired scores. Normalization is then performed to scale all measures within a 0-1 range. Table 2 shows the transformed and normalized measures of all suppliers.

Supplier	Firs criterion	Second criterion	Third criterion
1	0.5313	1	0
2	0.3125	0	0
3	0.9688	0.7411	1
4	0	0.3067	0
5	1	0.5719	1

Table 2: Transformed and normalized measures

Now we solve this supplier selection problem using the Ng-model (the model (2.2)).Table 3 shows the score of each supplier and optimal weights for each criterion.

Supplier(i)	w_{i1}	w_{i2}	w_{i3}	S_i
1	0.5	0.5	0	0.7656
2	1	0	0	0.3125
3	1	0	0	0.9688
4	0.5	0	0	0.2860
5	1	0	0	1

Table 3: Weights and score of suppliers

As we see the weight of third criterion for all suppliers is zero,which means that this criterion does not have any meaning. Indeed, the Ng-model ignores this criteria. In actual applications, making the weight of a certain criterion zero means that we throw away the corresponding part of the obtained data.
Secondly, as we will see in section 5 the Ng-model could not provide a robust ranking for all the suppliers. That is, in the Ng-model it is possible that the score of two supplier i and j is equal, $S_i = S_j$, and hence we can not determine which one of these two suppliers is better.

4 The model

By virtue of its Data Envelopment Analysis feature, the Ng-model avoids subjectiveness in determining weights and provides an objective way for multi-criteria supplier selection problem. However, as we saw in the preceding section there are two drawbacks for the Ng-model. To address these issues, we propose a similar weighted optimization model which determine score of all suppliers. Let w_j be the relative importance weight attached to the jth criterion $(j = 1, 2, \ldots, m)$ and y_{ij} be defined as before. The total score of each supplier is defined as $S_i = \sum_{j=1}^{m} y_{ij} w_j,\ i = 1, 2, ..., n$, which is a linear function of the relative importance weights. Once the weights are given or determined, suppliers can be ranked in terms of their total scores. To determine the relative importance weights,we propose the following model:

$$
\begin{aligned}
& max\ \ \alpha \\
s.t.\quad & \alpha \le S_i = \sum_{j=1}^{m} y_{ij} w_j \le 1, \quad i = 1, 2, ..., n \\
& w_1 \ge w_2 \ge \cdots \ge w_m, \\
& w_m \ge \varepsilon.
\end{aligned}
\tag{4.1}
$$

The above LP model maximizes the minimum of the total scores of the n suppliers and determine a common set of weights for all suppliers. As a theoretical construct, ε provides a lower bound for scoring of grades to keep them away from zero. Hence, the following LP is proposed to determine the ε.

$$
\begin{aligned}
& \varepsilon^* = max\ \varepsilon \\
s.t.\quad & \sum_{j=1}^{m} y_{ij} w_j \le 1, \qquad\qquad i = 1, 2, ..., n \\
& w_1 \ge w_2 \ge \cdots \ge w_m, \\
& w_m - \varepsilon \ge 0.
\end{aligned}
\tag{4.2}
$$

In what follows we prove that the optimal value of model (4.2) is greater than zero. Besides, it clear that it is bounded, hence $0 < \varepsilon^* < \infty$. Therefore the optimal weights in model (4.2) are not zero, that is $w_j > 0$ for all $j = 1, 2, \ldots, m$.

Lemma 4.1. *The optimal value of model (4.2) is greater than zero, that is* $\varepsilon^* > 0$.

Proof. The dual of model (4.2) is as follows:

$$
\begin{aligned}
& min \quad \sum_{i=1}^{n} \theta_i \\
s.t.\quad & \sum_{i=1}^{n} v_{i1} \theta_i - \delta_1 = 0 \\
& \sum_{i=1}^{n} v_{ij} \theta_i + j\delta_{j-1} - j\delta_j = 0, \quad j = 2, ..., m-1 \\
& \sum_{i=1}^{n} v_{im} \theta_i + m\delta_{m-1} - \delta_m = 0 \\
& \delta_m = 1 \\
& \theta_i, \delta_j \ge 0,\ i = 1, ..., n;\ j = 1, ..., m
\end{aligned}
\tag{4.3}
$$

By contradiction assume that $\varepsilon^* = 0$. Hence, $\theta^* = \sum_{i=1}^{n} \theta_i^* = 0$. Therefore according to the constraints of model (4.3), for all $j = 1, ..., m$, we have $\delta_j = 0$ which contradicts to the last constraint of Model (4.3), So $\varepsilon^* = \theta^* > 0$. $\square$

5 Numerical illustration

For illustration purpose, we apply our method to a multi-criteria supplier selection problem as in the literature [5-15]. Five criteria, including supply variety, quality, distance, delivery, and price are under consideration by a firm manufacturing agricultural and construction equipment. Supply variety is the number of parts supplied by the suppliers. It is considered first as the company would like to reduce the number of suppliers. The quality of supplied parts is also an important criterion for a company in supplier evaluation. The distance is related to delivery efficiency. A longer distance will affect the delivery service of the supplier due to a longer lead time or restricted delivery time windows. The criterion "Delivery" measures the percentage of on-time delivery. Lastly, the price index indicates the estimated price level offered by a supplier as compared to the average market price. If the price level offered is higher than the average price, the price index will be of a value higher than 100% and vice versa. There are 18 supplier available. The measure of each supplier under the five criteria are listed in Table 4. We take a reciprocal transformation of price and distance measures so that the transformed values are positively related to the desired scores. Normalization is then performed to scale all measures within 0-1 range. Table 5 shows the transformed and normalized measures of all suppliers. Using the Ng-model, Table 6 shows the obtained weights for each supplier and its score (rank). As we see, the Ng-model does not consider the last criterion for all suppliers and the fourth criterion is considered only for three suppliers. Besides, the Ng-model could not assist the manager in obtaining a preferable and robust ranking result for suppliers (see the score of suppliers 3 and 4).

Supplier	Supply variety (Unit)	Quality(%)	Distance (Mile)	Delivery (%)	Price index (%)
1	2	100	249	90	100
2	13	99.79	643	80	100
3	3	100	714	90	100
4	3	100	1809	90	100
5	24	99.83	238	90	100
6	28	96.59	241	90	100
7	1	100	1404	85	100
8	24	100	984	97	100
9	11	99.91	641	90	100
10	53	97.54	588	100	100
11	10	99.95	241	95	100
12	7	99.85	567	98	100
13	19	99.97	567	90	100
14	12	91.89	967	90	100
15	33	99.99	635	95	80
16	2	100	795	95	100
17	34	99.99	689	95	80
18	9	99.36	913	85	100

Table 4: Measures of suppliers under criteria

Supplier	Supply variety	Quality	Reciprocal of Distance	Delivery	Reciprocal of Price index
1	0.02	1.00	0.95	0.50	0.00
2	0.23	0.97	0.27	0.00	0.00
3	0.04	1.00	0.23	0.50	0.00
4	0.04	1.00	0.00	0.50	0.00
5	0.44	0.98	1.00	0.50	0.00
6	0.52	0.58	0.99	0.50	0.00
7	0.00	1.00	0.04	0.25	0.00
8	0.44	1.00	0.13	0.85	0.00
9	0.19	0.99	0.28	0.50	0.00
10	1.00	0.70	0.31	1.00	0.00
11	0.17	0.99	0.99	0.75	0.00
12	0.12	0.98	0.33	0.90	0.00
13	0.35	1.00	0.33	0.50	0.00
14	0.21	0.00	0.13	0.50	0.00
15	0.62	1.00	0.28	0.75	1.00
16	0.02	1.00	0.19	0.75	0.00
17	0.63	1.00	0.25	0.75	1.00
18	0.15	0.92	0.15	0.25	0.00

Table 5: Transformed and normalized measures of suppliers

Supplier	w_1	w_2	w_3	w_4	w_5	Score	Rank
1	0.333	0.333	0.333	0.000	0.000	0.656	9
2	0.500	0.500	0.000	0.000	0.000	0.600	10
3	0.500	0.500	0.000	0.000	0.000	0.520	14
4	0.500	0.500	0.000	0.000	0.000	0.520	14
5	0.333	0.333	0.333	0.000	0.000	0.806	4
6	0.333	0.333	0.333	0.000	0.000	0.696	7
7	0.500	0.500	0.000	0.000	0.000	0.500	16
8	0.500	0.500	0.000	0.000	0.000	0.720	6
9	0.500	0.500	0.000	0.000	0.000	0.590	11
10	1.000	0.000	0.000	0.000	0.000	1.000	1
11	0.250	0.250	0.250	0.250	0.000	0.725	5
12	0.250	0.250	0.250	0.250	0.000	0.582	12
13	0.500	0.500	0.000	0.000	0.000	0.675	8
14	0.250	0.250	0.250	0.250	0.000	0.210	17
15	0.500	0.500	0.000	0.000	0.000	0.810	3
16	0.500	0.500	0.000	0.000	0.000	0.510	15
17	0.500	0.500	0.000	0.000	0.000	0.815	2
18	0.500	0.500	0.000	0.000	0.000	0.535	13

Table 6: Obtained results using the Ng-model

Using the data of Table 5 we solved the linear programming model (4.2) and found that $\varepsilon^* = 0.2719$. Then, we employed this ε^* and solved the linear programming model (4.1). After solving the weight for Supply variety, Quality, Reciprocal of Distance, Delivery and Reciprocal of Price index is 0.2740, 0.2737, 0.2730, 0.2725, 0.2719 respectively, and $\alpha^* = 0.2301$. Table 7 shows the score and rank of each supplier using the proposed model, Ng-model and Liu-model [14] as well.

Supplier(i)	Score	Ranking		
		Proposed model	Ng-model	Liu-model
1	0.6767	7	9	1
2	0.4027	14	10	13
3	0.4849	12	14	8
4	0.4219	13	14	8
5	0.8000	4	4	6
6	0.7096	6	7	9
7	0.3534	15	16	10
8	0.6630	8	6	2
9	0.5370	11	11	7
10	0.8246	3	1	1
11	0.7945	5	5	3
12	0.6383	9	12	1
13	0.5973	10	8	5
14	0.2301	16	17	12
15	1.0000	1	3	1
16	0.5370	11	15	4
17	0.9945	2	2	1
18	0.4027	14	13	11

Table 7: Obtained results using proposed model and a comparison of our, Ng and Liu

For comparison purpose, we consider the best 5 suppliers as there were 5 efficient suppliers identified by the Ng-model in [16]. The top 5 suppliers identified are suppliers 15, 17, 10, 5 and 11. These suppliers are good suppliers in the Ng-model as well, but with difference ranking. In the Ng-model the top 5 suppliers are 10, 17, 15, 5, and 11. As we see, suppliers 17 and 11 have the same rank in both Ng-model and the proposed model. It can be seen from Table 7 that supplier 15 has the first rank in the proposed model whereas its rank in the Ng-model is 3. The reason is that our model considers all of the five criteria while the Ng-model considers only the first and second criteria, that is, the weight of the third, fourth and fifth criteria is zero in the Ng-model. Now consider supplier 10, this supplier has the first rank in the Ng-model while the rank of this supplier in the proposed model is 3. To explain this difference note that according to Table 6 the Ng-model only considers the first criterion $(w_1 = 1)$ and ignores the other criteria $(w_2 = w_3 = w_4 = w_5 = 0)$; while our method considers all of the criteria.

The above example has been solved by Liu et al (using DEA) in [14], too. For comparison purpose, we consider the best 5 suppliers as there were 5 efficient suppliers identified by the Liu-model in [14]. The top 5 suppliers identified are suppliers 1, 10, 12, 15, and 17. Suppliers 10, 15 and 17 are good suppliers in both Liu and the proposed model. Suppliers 5 and 11 were not identified as good suppliers in the Liu-model. On the other hand, suppliers 1 and 12 were identified as good suppliers in the Liu-model but were not identified by our proposed model. The reason for this difference are due to the incorporation of the relative importance of the criteria. Suppliers 1 and 12 were efficient suppliers in Liu-model. However, the supply varieties of these two suppliers are only 2 and 7, which are relatively low, compared to other suppliers. When the supply variety is considered relatively important criterion, these two suppliers are eliminated. Suppliers 5 and 11 with relatively low supply variety measures, 24 and 10 respectively, were rated high because of the advantage of relatively shorter distance. Finally note that similar to the Ng-model the Liu-model proposed in [14] could not rank the suppliers.

As we see our model therefore provides a more reasonable and encompassing index for supplier selection problem as compared to the Ng-model and Liu-model.

6 Conclusion

We discussed applicability of the multiple criteria supplier selection method proposed by Ng, and by using a non-parametric model, we determine the weights from data of each criterion. The Ng-model, gives rise to the case such that suppliers cannot be distinct, or the data of some criterion is ignored. Thus, we analyze the procedure to determine weights, and propose a simple non-parametric model for multiple criteria supplier selection problem. The advantages of our model are:

a) It is a very simple model that can be easily understood by managers.

b) The proposed model ranks the suppliers without solving the model n times (one linear LP for each supplier) and therefore allows the manager to get faster results.

c) Our model provides a method for supplier selection problem that not only incorporates multiple criteria, but also maintains the effects of weights in the final solution, an improvement over the model proposed by Ng.

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