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A DEA-like Model for Multiple Criteria Supplier Selection Problem

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Abstract. In today's highly competitive environment, an effective supplier selection process is very important to the success of any manufacturing organization. In this context, supplier selection represents one of the most important functions to be performed by the purchasing department. Supplier selection is a multi-criterion problem which includes both qualitative and quantitative factors (criteria). A trade-off between these tangible and intangible factors is essential in selecting the best supplier. A number of models and techniques have been developed to deal with selecting and evaluating suppliers. In this paper a simple weighted linear optimization model is proposed for multiple criteria supplier selection problem. The proposed model ranks the suppliers without solving the model n times (one linear programming (LP) for each supplier) and therefore allows the manager to get faster results.

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1. Introduction

Supplier selection and evaluation have become one of the major topics in production and operations management literature, especially in advanced manufacturing technologies and environment. The main objective of supplier selection process is

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to reduce purchase risk, maximize overall value to the purchaser, and develop closeness and long-term relationships between buyers and suppliers. Choosing the right method for supplier selection effectively leads to a reduction in purchase risk.
Supplier selection is a multiple criteria decision-making (MCDM) problem which is affected by several conflicting factors. Consequently, a purchasing manager must analyze the trade-off between the several criteria. MCDM techniques support the decision-makers (DMs) in evaluating a set of alternatives [2]. Supplier selection problem has become one of the most important issues for establishing an effective supply chain system. The supplier selection problem in a supply chain system is a group decision according to multiple criteria from which a number of criteria have been considered for supplier selection in previous and present decision models. The purchasing manager must know a suitable method, then use the best method from the different types of methods to select the right supplier.
There are at least three journal articles reviewing the literature regarding supplier evaluation and selection models [18, 19, 59]. Since these articles review the literature up to 2000, therefore Table 1 of this paper shows a survey of the multi-criteria supplier evaluation and selection approaches through a literature review from 2000 to 2008.The remainder of this paper is organized as follows.We present our new model in section 2. In section 3 we present a non-parametric statistical method that utilizes ranks of suppliers in identifying homogenous groups of suppliers. In section 4 we apply proposed model to a numerical example. Section 5 is devoted to implementation of the proposed model to a real case study. Section 6 concludes the paper.

2. The model

One of the most important methods which used for supplier selection is weighted linear optimization. The weighted linear optimization approach does not require the decision maker to pre-define the weights. Weights are endogenously determined when solving a linear model. Weighted linear optimization can automatically derive optimal weights of criteria with the performance score of the suppliers. In weighted linear optimization models applied to supplier selection problems, decision makers cannot have any involvement or control for the importance of the criteria. 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. In a recent paper [41] 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 weighted linear optimization 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 do 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 section is to present a new weighted linear model which overcome shortcoming mentioned above.

2.1 *Ng-model*

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

Table 1. Taxonomy of approaches of supplier evaluation.

Category	Approach	Proposed by
DEA	A DEA model about nine factors	[8]
	A DEA model with 3 inputs and 2 outputs	[35]
	DEA to measure the comparative-efficiencies of suppliers	[23]
	A DEA model about eleven factors	[39]
	A three-phase approach	[52]
	A DEA model	[47]
	A DEA model with use of cluster-analysis and statistical methods	[54]
	DEA integrated by TCO	[24]
	Integrated DEA and sensitivity analyses	[44]
	A DEA model with respect to 3 factors	[45]
	DEA without input	[50]
	Chance-constrained DEA approach	[57]
	Augmented imprecise DEA approach	[61]
Linear programming	LP model	[53]
Integer linear (nonlinear) programming	Binary integer linear programming	[51]
	Mixed integer-linear programming	[28]
	Mixed integer-nonlinear programming	[26]
Multi objective programming	Multi objective programming with derived weights of criteria in advance	[40]
		[47]
	Multi-objective programming problem with three objective functions	[58]
Analytic hierarchy (network) process	Web-based AHP system	[1]
	Five-step AHP-based model	[38]
	Interactive selection model with AHP	[10]
	AHP based on the customer requirements	[11]
	Integrated AHP and Noguchis voting and ranking method	[36]
	AHP-based decision support system in a mass customization environment	[29]
	ANP with respect to organizational factors and strategic performance metrics	[47]
	ANP with ten evaluating criteria as a controlling factor	[5]
	Criteria,ANP with criteria which were classified into three clusters	[25]
Fuzzy set theory(FST)	Hierarchy model based on FST	[12]
	A fuzzy set approach, by emphasizing Performance and capability factors	[46]
	Two-tuple fuzzy linguistic model	[22]
SMART	A five-step approach based on SMART	[4]
	Selecting some of the relevant criteria and metrics for the selection process	[30]
Genetic algorithm (GA)	GA based optimization methodology with providing possible configurations of the selected suppliers	[21]
Integrated AHP approaches	Integrated AHP and a multi-attribute negotiation mechanism	[13]
	Integrated TCO, AHP and DEA	[43]
	An integrated AHP-DEA	[48]
	An integrated AHP, DEA and ANN	[27]
	An integrated AHP-GP	[9]
	An integrated AHP-GP	[42]
	A three-phase integrated AHP-GP	[37]
Integrated fuzzy approaches	Fuzzy AHP	[32]
	Integrated cluster analysis, AHP and Fuzzy logic	[7]
	Fuzzy based approach and GA	[31]
	Fuzzy multi-objective LP	[2]
	Fuzzy QFD	[6]
	Fuzzy SMART	[33]
	Fuzzy SMART with sensitivity analysis	[14]
Other approaches	Integrated ANN and CBR	[15, 16]
	Integrated ANN and GA	[34]
	Integrated ANP and multi-objective mixed integer LP	[20]
	Integrated multi-objective programming and DEA	[60]
	Integrated SMART and DEA	[49]

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

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

Ng converts all measurements in a 0-1 scale for all items. 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 $w_{i1} \geqslant w_{i2} \geqslant \cdots \geqslant w_{im}$ 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 [41] for aggregation purposes is as follows:

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

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) is converted to the following for all suppliers:

$$\begin{aligned} \max \quad & S_i = \sum_{j=1}^{m} a_{ij} u_{ij} \\ s.t. & \sum_{j=1}^{m} j u_{ij} = 1, \\ & u_{ij} \geqslant 0, \qquad j = 1, 2, \ldots, m \end{aligned} \tag{3}$$

Now the maximal scores S_i can be obtained by the dual of the model (3). That is, the score S_i of the ith supplier can be easily obtained as $max_{j=1,2,\ldots,m}(\frac{1}{j}\sum_{k=1}^{j} y_{ik})$.

2.2 *Issues on Ng-model*

In what follows we express shortcomings of the Ng-model. *Firstly*, the Ng-model leads to a situation where the weight of a certain criterion becomes zero. That is, this criterion do not have any role for determining total score of the related suppliers. This may not reflect the real position of a supplier. For more explantation, consider a situation where three criteria, including supply variety, distance and quality are under consideration by a company and there are 5 suppliers available. The measure of each supplier under the criteria are listed in Table 2.

Table 2. Measures of suppliers under criteria.

Supplier	Supply variety	Distance	Quality
1	19	567	90
2	12	967	90
3	33	635	95
4	2	795	90
5	34	689	95

We take a reciprocal transformation of distance 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 3 shows the transformed and normalized measures of all suppliers.

Table 3. Transformed and normalized measures.

Supplier	Supply variety	Distance	Quality
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

Now we solve this supplier selection problem using the Ng-model (the model (2)). Table 4 shows the score of each supplier and optimal weights for each criterion.

Table 4. Weights and score of suppliers.

Supplier	w_{i1}	w_{i2}	w_{i3}	S_i
1	0.5	0.5	0	0.76565
2	1	0	0	0.3125
3	1	0	0	0.9688
4	0.5	0.5	0	0.28595
5	1	0	0	1

As for the third criterion for all suppliers the weights is zero, which means that the third criterion, quality, does not have any meaning. Besides, the Ng-Model only considers the first criterion, supply variety, for suppliers 2, 3 and 5.
Secondly, however the Ng-model can obtain the scores of suppliers without a linear optimizer, but the score of each supplier is obtained as the maximum of the partial averages, $\frac{1}{j}\sum_{k=1}^{j} y_{ik},\ j = 1, 2, ..., m$. That is, for each supplier we have to compute m partial averages and hence for n suppliers we must calculate mn partial averages and this is time consuming.

2.3 *Proposed model*

In virtue of its weighted linear feature, the Ng-model avoids subjectiveness in determining weights and provides an objective way for multi-criteria supplier selection problem. However, as we saw 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 ($j = 1, 2, \ldots, m$). The proposed model is as follows:

$$
\begin{aligned}
&\max\ \alpha + w_m \\
&s.t.\ \alpha \leqslant S_i = \sum_{j=1}^{m} y_{ij} w_j, \qquad i = 1, 2, ..., n \\
&\quad w_1 \geqslant w_2 \geqslant \cdots \geqslant w_m \geqslant 0, \\
&\quad \sum_{j=1}^{m} w_j = 1.
\end{aligned}
\tag{4}
$$

The above model maximize the minimum of the total scores of the n suppliers and determine a common set of weights for all the suppliers. In fact, the model (4) maximizes α (minimum of the total scores) and the minimum weight w_m at the same time and determines the most favorable weight for all suppliers. Indeed, w_m is added as a component of the objective function to force w_m not to equal to 0.
In the next section we present a statistical method that utilizes the scores of suppliers in identifying homogenous groups of vendors. Since the scores do not lend

themselves to the assumption of normality, we utilize a non-parametric procedure.

3. Kruskall-Wallis test

A non-parametric statistical procedure referred to as the Kruskall-Wallis (KW) test is utilized in testing our hypotheses that at least one of the vendors tends to yield larger efficiency scores than at least one other vendor. The KW test, which is based on ranks, is utilized to analyze the differences in two or more independent samples. It is an extension to the Mann-Whitney test, which examines two samples. It is suitable to use this test in situations where the sample sizes are even less than 5. For more information see Conover (1980). The generic null and the alternate hypothesis for the test are:

H_0: All of the k population distribution functions are identical.
H_1: At least one of the populations tends to yield larger observations that at least one of the other populations

Test statistic: $T = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1)$, where N is the total number of observations; k is the number of groups; n_i is the number of observations in ith group, where $i = 1, ..., k$; and R_i is the sum of the ranks of observations in each group. In this test if $T > \chi^2(k-1, 1-\alpha)$ then reject H_0, otherwise fail to reject H_0, where α is the probability of making a type I error.
To identify differences among groups multiple comparisons can be conducted. The groups i and j are different if the following inequality is satisfied:

$$\left|\frac{R_i}{n_i} - \frac{R_j}{n_j}\right| > t_{1-(\frac{\alpha}{2})} \left(S^2 \frac{N-1-T}{N-K}\right)^{\frac{1}{2}} \left(\frac{1}{n_i} + \frac{1}{n_j}\right)^{\frac{1}{2}},$$

where $S^2 = \frac{1}{N-1}\left(\sum R(x_{ij})^2 - N\frac{(N+1)^2}{4}\right)$, $R(x_{ij})$ is the rank assigned to observation j in ith group; t value is the $(1-\frac{\alpha}{2})$ quantile of t distribution with $N-k$ degrees of freedom. The α value used is the same as in the KW test.

4. Numerical illustration

We illustrate implementation of our proposed model with a multi-criteria supplier selection problem as in the literature [35, 41]. Five criteria, including price, supply variety, quality, distance, and delivery are under consideration by a firm manufacturing agricultural and construction equipment. 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. 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. There are 18 supplier available. The measure of each supplier under the five criteria are listed in Table 5. 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. Here, the transformation formula that we used is $y_{ij} = \frac{x_{ij}}{max_i\{x_{ij}\}}$. Table 6 shows the transformed and normalized measures of all suppliers.

Using the Ng-model, Table 7 shows the obtained weights for each supplier and its score (rank). As we see, the Ng-model does not consider the two last criteria for all suppliers except supplier 5 and supplier 6. Besides, the second and third criteria are considered only for three suppliers (suppliers 5, 6 and 10). As a matter of fact, only the first criterion is considered for all suppliers. Moreover, the Ng-model could not assist the manager in obtaining a preferable and robust ranking result for suppliers (two of them have rank 1 and thirteen of tham have rank 5).

We used the data of Table 6 to find the weights of five criteria by proposed model (4). After solving we obtained the weight for Reciprocal of Price index, Supply variety, Quality, Reciprocal of Distance and Delivery are 0.467, 0.230, 0.190, 0.080, 0.033, respectively, and $\alpha^* = 0.798$. Table 8 shows the rank of each supplier using the proposed model. This table shows the rank of each supplier in the proposed model, Ng-model and DEA model [35] as well.

For comparison purpose, we consider the best 5 suppliers as there were 5 efficient suppliers identified by the Ng-model in [41], using the same data set. The top 5 suppliers identified are suppliers 15, 17, 6, 10 and 5. These suppliers are good suppliers in the Ng-model as well, but with difference ranking. In the Ng-model the top 5 suppliers are 15, 17, 10, 6, and 5. As we see, suppliers 15 and 5 have the same rank in both Ng-model and the proposed model. It can be seen from Table 8 that supplier 15 has the first rank in the proposed model whereas suppliers 15 and 17 have first rank in the Ng-model; And the Ng-model could not recognized which one of these two supplier is better. Now consider supplier 10. This supplier has the second rank in the Ng-model while the rank of this supplier in the proposed model is 4. To explain this difference note that according to Table 7 the Ng-model only considers the three criteria (w_1, w_2 and w_3 are not zero) and ignores the other two criteria ($w_4 = w_5 = 0$); while our method considers all of the criteria.

The above example has been solved (using DEA) in [35], too. For comparison purpose, we consider the best 5 suppliers as there were 5 efficient suppliers identified by the DEA model in [35]. The top 5 suppliers identified are suppliers 1, 10, 12, 15 and 17. Suppliers 10, 15 and 17 are good suppliers in both DEA and the proposed model. Suppliers 5 and 6 were not identified as good suppliers in the DEA model. On the other hand, suppliers 1 and 12 were identified as good suppliers in the DEA model but were not identified by our proposed model. The reason for this difference is due to the incorporation of the relative importance of the criteria. Suppliers 1 and 12 were efficient suppliers in DEA models. 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 6 with relatively low supply variety measures, 24 and 28 respectively, were rated high because of the advantage of relatively shorter distance. Finally note that similar to the Ng-model the DEA model proposed in [35] 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 DEA model.

Table 5. Measures of suppliers under criteria.

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

Table 6. Transformed and normalized measures of suppliers.

Supplier	Reciprocal of Price index	Supply variety	Quality	Reciprocal of Distance	Delivery
1	0.800	0.037	1.000	0.955	0.900
2	0.800	0.245	0.997	0.370	0.800
3	0.800	0.056	1.000	0.333	0.900
4	0.800	0.056	1.000	0.131	0.900
5	0.800	0.452	0.998	1.000	0.900
6	0.800	0.528	0.965	0.987	0.900
7	0.800	0.018	1.000	0.169	0.850
8	0.800	0.452	1.000	0.241	0.970
9	0.800	0.207	0.999	0.371	0.900
10	0.800	1.000	0.975	0.404	1.000
11	0.800	0.188	0.999	0.987	0.950
12	0.800	0.132	0.998	0.419	0.980
13	0.800	0.358	0.999	0.419	0.900
14	0.800	0.226	0.918	0.246	0.900
15	1.000	0.622	0.999	0.374	0.950
16	0.800	0.037	1.000	0.299	0.950
17	1.000	0.641	0.999	0.345	0.950
18	0.800	0.169	0.993	0.260	0.850

Table 7. Obtained results using theNg-model.

Supplier (i)	w_{i1}	w_{i2}	w_{i3}	w_{i4}	w_{i5}	Score	Rank
1	1.000	0.000	0.000	0.000	0.000	0.800	5
2	1.000	0.000	0.000	0.000	0.000	0.800	5
3	1.000	0.000	0.000	0.000	0.000	0.800	5
4	1.000	0.000	0.000	0.000	0.000	0.800	5
5	0.200	0.200	0.200	0.200	0.200	0.830	4
6	0.200	0.200	0.200	0.200	0.200	0.836	3
7	1.000	0.000	0.000	0.000	0.000	0.800	5
8	1.000	0.000	0.000	0.000	0.000	0.800	5
9	1.000	0.000	0.000	0.000	0.000	0.800	5
10	0.333	0.333	0.333	0.000	0.000	0.925	2
11	1.000	0.000	0.000	0.000	0.000	0.800	5
12	1.000	0.000	0.000	0.000	0.000	0.800	5
13	1.000	0.000	0.000	0.000	0.000	0.800	8
14	1.000	0.000	0.000	0.000	0.000	0.800	5
15	1.000	0.000	0.000	0.000	0.000	1.000	1
16	1.000	0.000	0.000	0.000	0.000	0.800	5
17	1.000	0.000	0.000	0.000	0.000	1.000	1
18	1.000	0.000	0.000	0.000	0.000	0.800	5

Table 8. Ranking using proposed model and a comparison of our model, Ng-model and DEA.

Supplier	Ranking		
	Proposed model	Ng-model	DEA
1	7	5	1
2	12	5	13
3	14	5	8
4	17	5	8
5	5	4	7
6	3	3	9
7	18	5	10
8	9	5	2
9	11	5	6
10	4	2	1
11	6	5	3
12	10	5	1
13	8	5	5
14	13	5	12
15	1	1	1
16	15	5	4
17	2	1	1
18	16	5	11

5. Case study

A set of seven suppliers is considered in the evaluation process. The case study is related to the supplier selection of an Energy Company (EC) which concentrates on producing solar boiler and solar water refiners in Iran. This company, to produce its products, is required to purchase solar panels with different sizes and voltages.

Hence, Energy Company buys its solar panels from different suppliers with respect to its type of home and industrial customers. At present seven potential suppliers have been identified, all with strong reputations in at least one area. Energy Company has identified the five criteria as fundamental criteria for selecting suppliers. Based upon past dealings with these seven firms, as well as reliable documentation from those firms, EC has calculated the average price per unit for items in the commodity group for each of the suppliers. EC has also examined responsiveness of those firms and has noted the typical lead time for each. No particular objective measures were available for evaluating the firms according to the other criteria, but subjective evaluation is possible based upon the documentation provided by the firms. As a result, the procurement manager has been able to study the documentation and rate each firm according to a seven point Likert-type scale on each of the subjective criteria. More typically this type of subjective evaluation would be the result of the work of a cross-enterprise commodity team. In such cases, each member of the team would perform the subjective rating task and the evaluations of each member would be averaged for each criterion. These averages would then be used in place of the managers assessments. Either way, a set of raw scores could be assembled for each of the vendors being considered.
Table 9 summarizes the raw score data for the seven firms being considered. Values indicated for price are given as average cost per unit for the items being considered. For lead time, the values given are in days. Thus, for both price and lead time, small data values are preferable. The subjective ratings for the other criteria are such that a value of 7 indicates the best performance that might be expected and a value of 1 indicates the worst conceivable performance. Table 10 shows the rank of each supplier using the proposed model as well as Ng-model. Using the Ng-model the best two suppliers are suppliers 4 and 7. While according to the proposed model the best two suppliers are 1 and 6. As we see the obtained results are completely different.
The rank corresponding to each supplier is utilized in performing the KW test. The null hypotheses for the test is rejected at an α value of 0.1 indicating that at least one of the suppliers tends to yield larger score that at least one of the other suppliers. We have conducted multiple comparisons and the results are depicted in Table 11. It is evident from Table 11 that group 1 suppliers, namely, suppliers 1 and 6 are the best performers followed by groups 2, 3, and 4. Based on the KW test there is no significant difference in performance among the suppliers within a group. The buyer can utilize this information in an effective manner for supplier selection decisions. For example, if the buyer is interested in selecting a single supplier then the optimal set from which to choose are suppliers 1 and 6. Thus, our approach provides the buyer with flexibility in the final selection process thereby allowing the buyer to base the decision on other intangible factors that cannot easily be quantified. Some examples of such factors include trust, credibility and credence, and effectiveness of communication.

Table 9. Data for seven suppliers.

Supplier	Price ($)	Quality	Lead time	Quantity	Delivery
1	8.75	7	3	6	6
2	11.20	7	2	4	3
3	11.73	7	1	4	6
4	6.00	3	4	5	4
5	9.77	5	2	7	1
6	8.91	5	3	7	7
7	7.25	2	2	4	4

Table 10. Suppliers ranks.

Supplier	1	2	3	4	5	6	7
Our model	1	6	3	4	5	2	7
Ng-model	3	7	5	1	6	4	2

Table 11. Homogenous groups of suppliers.

Supplier	Group 1	Group 2	Group 3	Group 4
1	✓			
2				✓
3		✓		
4		✓	✓	
5			✓	✓
6	✓			
7				✓

Table 11 also clearly demonstrates that supplier 3 is significantly better than suppliers 2, 5 and 7, and supplier 4 is significantly better than suppliers 2 and 7. This has important implications if the buyer is selecting multiple suppliers.

6. Conclusion

The issue of supplier selection have attracted the interest of researchers and research studies in this area have increased. In this paper a new weighted linear optimization model proposed and illustrated for suppliers selection problem in the presence of multiple criteria. The proposed model not only incorporates multiple criteria, but also maintains the effects of weights in the final solution. Limitations of the proposed model are as follows:

1. Being a deterministic rather than statistical technique, the proposed model produces results that are particularly sensitive to measurement errors.
2. Although some articles are on supply chain management environment, little attention has been paid on the influences on the whole supply chain if a certain supplier is selected. Some new criteria to reflect the whole supply chain performance should be developed in the process of supplier selection. The method mentioned in this study has shortcomings in dealing with the selection problem.

This paper has provided a simple weighted linear model for ranking suppliers. The problem considered in this study is at initial stage of investigation and further research can be done based on the results of this paper. Some of them are as follows: similar research can be repeated for determining the optimal weights especially in the presence of weight restrictions. Other potential extension to the methodology includes the integration of the proposed model with MCDM models like AHP or TOPSIS. Another future work is to extend the proposed model in the presence of cardinal and ordinal data. Finally, this study used the proposed model for supplier selection. It seems that more fields (e.g. technology selection, personnel selection, etc.) can be applied.

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