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Haibo Wang

Wei Wang

Yaquan Xu

Wei Sun

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Haibo Wang, Sanchez School of Business, Texas A&M International University, Laredo, Texas, USA.
E-mail: hwang@tamiu.edu

Wei Wang, Sanchez School of Business, Texas A&M International University, Laredo, Texas, USA.
Email: weiwang@dusty.tamiu.edu

Yaquan Xu
School of Business, Virginia State University, Petersburg, VA, USA
Email: yxu@vsu.edu

Wei Sun
Zhongyuan University of Technology, Zhengzhou, Henan, China
Email: sunwei2001@hotmail.com

Abstract

The selection of vendors is an important aspect of strategic management and operational decision making. The methods and process of vendor selection have undergone great changes during the past years, and the criteria and methods of vendor selection have changed and improved to a large extent. The single-item, multiple-vendor selection problem is well studied in the vendor selection literature. However, only a few papers in the literature discuss the multiple-item, multiple-vendor selection problem. This paper presents a new rank-and-choose decision model for vendor selection problem. The proposed approach is illustrated by a numerical example.

Introduction

The selection of vendors is an important aspect of strategic management and operational decision making since it not only plays a crucial role in the production and distribution process, but also impacts all areas of a company. The single product, multiple-vendors selection model is well known in the vendor selection literature. In the early literature, decision makers considered the vendors as competitors and only selected the vendors for one product at a time. However, the recent development of internet and e-commerce allows the decision makers to build a long term relationships with vendors and encourages vendors to team up for a better competitive advantage by sharing information and standardizing the parts/components. Net Marketplace in e-commerce provides opportunity to business for selecting multiple products from multiple vendors to achieve the economies of scale and competitive advantage. The mature of online payment system and online transaction technology help business to develop competitive marketing strategies. One of these key marketing strategies is bundling in net pricing, which offers two or more products for discount price. Therefore, vendor selection plays an important role in the marketing strategies in e-commerce. Many models and solution methodologies have been proposed to address the vendor selection problem (refer to recent review in [1-4]).

Weber et al classified 74 articles related to the industrial customer vendor selection criteria and found multiple criteria in these articles [2]. Butaney and van Nederpelt adopted product quality, credit standing of vendor, product profitability, vendor shouldering product liability, availability of technical assistance from vendor as criteria to select vendors, and introduced the principal component analysis (PCA) to find a way of condensing the complicated information [5]. Roodhooft and Fonings proposed an Activity Based Costing (ABC) approach for vendor selection and evaluation [6]. They used the exceeded delivery date, quantity problems, quality problems, administration and price difference as criteria to evaluate the vendor score. In the literature [1, 2] quality criteria is the important attribute in the process of vendor evaluation. Different quality related criteria are discussed in the literature: total quality management program, inspection and control, defect rate, quality assurance production, correctness of testing data, quality abnormal rate, capability to prevent repeated error, error judgment rate and many other criteria.

This paper proposes a two-steps decision model with the evaluation procedure of vendors via a data envelopment analysis (DEA) approach on quality management criteria and the selection procedure of vendors via a nonlinear multiple criteria decision analysis (MCDA) approach on vendor interdependent criteria . Our contribution in this paper is to propose a mixed integer nonlinear programming model to address the interdependent relationship among vendors and items. The rest of the paper is organized as follows. In the next section, we discuss the problem of vendor selection with bundling, then present a two-steps decision model and solution method to address the issue of interdependency with a numerical example, followed by our summary and interests of our future research work.

Vendor Selection with Bundling

In today's large manufacturers or international companies, supply chain managers are under tremendous pressure to evaluate and choose hundreds or even thousands of vendors for their product lines. Under the influence of global competition and trend of flexible manufacturing, the production lines in most companies are used to assemble multiple products with full capacity and high operation efficiency. Global competition also cause vendors to provide bundling or volume discount in order to lower the price in the contract, in the meantime to receive the benefit from the economies of scale [7, 8]. There are two types of business volume discount schedule. One schedule is pricing on the same item based on the volume, which has been studied by some researchers [9-12]. The other schedule is pricing on bundles of items. While bundling is a common practice among the vendors, few researchers have addressed the issue of bundling due to the complexity of the problems [7, 8]. In this study, we assume that the volume discount schedule for bundling is restricted to two situations to simplify the pricing schedule: vendors selected by the decision maker will provide all of their items in the selection pool (Table 1) together as a bundle or provide nothing.

Decision Model and Solution Method

The decision model in this paper consists of two steps: evaluation and selection. The evaluation process of multiple vendors is based on an extension of DEA model using quality management criteria and reports the rank of the vendors on each product to create a preferred vendor pool. The selection process of multiple vendors is a nonlinear MCDM model based on the analysis of the interdependence among the products and vendors from the pool of preferred vendors and reports the best groups of vendors.

Vendor evaluation with DEA model

The methods and process of vendor selection has undergone great changes during the past years. The evaluation criteria and methods of vendor selection has changed and improved to a large extent. Dickson proposed 23 criteria by surveying 273 purchasing managers, such as quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capability, financial position, procedural compliance, management and organization, to tackle the complicated problem of vendor selection [13]. Wu and Olson compared stochastic dominance and stochastic DEA for vendor evaluation [14]. Wu and Blackhurst proposed methodology termed augment DEA based on an extension of data envelopment analysis (DEA) and compared the application of augment DEA with the basic DEA model [15]. According to [1], DEA is one of the most popular approaches on vendor selection.

This paper adopts quality management based DEA model to evaluate the vendors. The quality management based DEA model provides a rounded judgment on vendor performance taking into consideration multiple quality management criteria simultaneously and combining them into a single measure for quality. The mathematical model is solved for every item and the relative quality score of each vendor is determined. The results of DEA show that the higher a vendor's quality score in relation to the corresponding score of another vendor, the higher the rank of this vendor in term of quality.

The output oriented and quality management based DEA model with variable returns to scale is defined: There are n Decision Making Units (DMUs), where each DMU_i $(i = 1, \ldots, n)$ generates q outputs y_{ij} (j = 1,…,q). Let α_i be the DEA coefficient (decision variable) associated with DMU_i. The DEA model is the following linear programming problem:

$$\max \quad \lambda_0 \tag{1}$$

subject to

$$\sum_{i=1}^{n} \alpha_i = 1 \tag{2}$$

$$\sum_{i=1}^{n} y_{ij}\alpha_i \geq y_{i0}\lambda_0 \qquad j=1,...,q \qquad (3)$$

$$\lambda_0 \geq 0, \quad \alpha_i \geq 0, \quad \forall i \qquad (4)$$

The quality score for the DMU_0 in the study is given by λ_0, and it is positive. The quality score λ_0 allows ranking the corresponding DMU_0; Consider DMU_0 be a vendor with poor quality, the optimal solution of the mathematical model provides the set of optimal coefficients $(\alpha_1, \alpha_2, ..., \alpha_n)^0$, and the feasible improvement target outputs Y_{0j} for DMU_0 are defined by:

$$Y_{0j} = \sum_{i=1}^{n} \alpha_i y_{ij} \qquad j=1,...,q \qquad (5)$$

In this way, the feasible quality score can be calculated for each vendor. However, there is a drawback in this model. All the vendors with the same quality score will receive the same ranking. One way to address the ranking problem is to compute the aggregated output to aggregated input ratios, which is known as super-efficiency DEA[16]. In this paper, the ranking problem is not the issue in the evaluation process, which is aimed to produce a pool of preferred vendors. For each item, all high ranking vendors will be considered as the input data of the selection process.

However, pointed out by the researchers in the literature, there are other limitations in DEA for vendor selection. First of all, it is difficult for the researchers and practitioners to agree upon both input/output criteria and the measurement standards for different types of criteria; secondly DEA measures the operation efficiency of the vendors which are independently operated and cannot be used to address the interdependent relationship. The interdependent relationship plays an important role in supply risk and long term partnership. DEA is an effective approach for vendor evaluation but cannot present the supply risk and partnership in the selection process. To address the issues of supply risk and partnership, a nonlinear MCM model is presented in the following section.

Vendor Selection with nonlinear MCDM model

MCDM model is well known to vendor selection in the literature. Weber and Current presented a multi-objective approach to analyze the inherent tradeoffs involved in multi-criteria vendor selection problems systematically [17]. Carlsson and Fuller considered fuzzy MCDM as an appropriate way to select vendors[18]. Tam and Tummala adopted analytic hierarchy process (AHP) to deal with the issues of vendor selection of a telecommunications system[19]. In the literature, AHP is the third most popular approach to vendor selection problem (refer to [20] for a recent review). Hemaida and Schmits used the pair-wise comparison judgment matrices (PCJMs) to research the relationship among price, quality, delivery, and vendor education [21]. However, the models reported by other researchers considered the discrete and independent relationship among the vendors and items. Bottani and Rizzi proposed a group-to-rank approach to evaluate the vendors and items using integrated cluster analysis and AHP [22]. However, they did not discuss the interdependent relationship among the items or vendors. In the real world setting, the highly efficient production lines tend to standardize certain components for multiple products while some vendors can provide a wide range of components to distinguish themselves from others and achieve the benefit of economies of scale. In addition, the common upstream among the vendors can lead to the issue of supply risk. Thus the selection of vendors should take the vendor interdependent relationship for consideration. Very few researchers have investigated the interdependent relationship among the criteria and adopted analytic network process (ANP) approach to address the interdependency [23-25]. ANP extends the capability of AHP by formulating the interdependencies and performing pair-wise comparison between the vendors. However, one of the limitations in ANP is the pair-wise comparison, which cannot be applied to multiple alternatives in the decision model[24]. To address the multiple alternatives problem, a nonlinear MCDM model is proposed next.

In the nonlinear MCDM approach, decision maker considers a pool of vendors from the evaluation process simultaneously and choose a set of vendors to address the supply risk and partnership issues. The basic notation of this process is defined as follows.

$N = \{v^1, \ldots, v^n\}$ is set of vendors

$P = \{p^1, \ldots, p^m\}$ is set of items

$v^i, (i = 1, \ldots, n)$ is vendor i

$p^j, \quad (j = 1, \ldots, m)$ is item j

$I(v^i)$ is number of items provided by vendor v^i in the selection pool

$Q = \{1, \ldots, q\}$ is set of criteria

c_k^i is effect of vendor i on criterion k

S_k is a set of vendors that if selected together have some positive or negative effect on criterion k

$\gamma(S_k)$ is the amount of effect (positive or negative) of an interacting set S_k on criterion k

w_k is weight associated with criterion k

$\phi(S)$ is total payoff of a subset of vendors $S \subseteq N$

D is the number of vendors selected.

x_{ij} is equal to 1 if an vendor v^i is selected for item j and 0 otherwise.

$y_i = \dfrac{\sum_{j=1}^{m} x_{ij}}{I(v^i)}$ is equal to 1 if all of items from vendor v^i are selected as a bundle of items and 0 otherwise.

In general, the interdependent relationship can be measured by a number of criteria: economies of scale, resource and risk sharing, and ownership or partnership. With regard to the interdependent relationship, there is a weight to each criterion, and the model is represented by a nonlinear programming function as follows.

$$\max \quad \sum_{\substack{i \in N \\ j \in P}} x_{ij} [\sum_{k \in Q} w_k c_k^i] + \sum_{k \in Q} \sum_{S_k \subseteq N} \left(w_k [\gamma(S_k)] [\sum_{i \in S_k} c_k^i] \right) \prod_{i \in S_k} x_{ij} \qquad (6)$$

$$s.t. \quad \sum_{i \in N} y_i \le D, \; j = 1, \ldots, m \qquad (7)$$

$$x_{ij}, y_i \in \{0,1\}.$$

The nonlinear objective function can be solved by a commercial solver such as CPLEX or LINGO.

Numerical Example

To validate the approach in this paper, a numerical example is presented. Assume that a supply chain manager would like to find at least one but no more than two vendors for each item with minimum cost and risk while maintaining a continuous supply-relationship. The vendors selected can offer a bundle of items to achieve the economies of scale in order to low the price in the contract. There are two types of volume discount schedules. If the vendor provides only one item, it will discount price on the total amount of item ordered. If the vendor provides a bundle of items, it will discount price on the combination. Thus the criterion on economies of scale has different values/standards for different vendors. After evaluating a number of vendors for each item via a quality management based DEA model, the pool of high ranked vendor for each item is presented in Table 1.

Table 1
Selection pool of vendors from evaluation process

Item	Vendors								
	V1	V2	V3	V4	V5	V6	V7	V8	V9
P1	1	1	1		1	1			
P2		1		1	1			1	1
P3			1			1	1	1	
P4			1		1		1	1	

While individual vendor does not share local resource from each other, they might use the same upstream vendor, which can increase the risk among the vendors. Some vendors might form partnership via industrial consortium while others might have financial ownership on each other. Each vendor is evaluated by three criteria and the normalized data is presented in Table 2. For example, since there is no vendor to provide all 4 items by itself, the minimum number of vendors to supply all 4 items is 2, thus the supply chain manager should find exactly least 2 vendors to satisfy the condition of at least one but no more than two vendors for each item. There is a strategic partnership between vendor 1 and vendor 8, which can provide volume discounts but both vendors share the same upstream vendor. If both vendors are selected, it will obtain the benefit of supplying all items with minimum vendors but there is an increase on the supply risk. If both vendors are selected, there is an increase of 15% on the economies of scale criterion, increase of 10% on the partnership criterion and negative 25% on the resource and risk sharing criterion. Similarly, vendor 2 and vendor 7 belong to the same industrial consortium. If vendor 2 and vendor 7 are simultaneously selected, they will supply all items to satisfy the demand. In that case, a positive value of 15% is estimated when it comes to the economies of scale criterion and positive value of 10% on the partnership criterion.

There are many pairs of vendors with overlapped items, which can lead to a low supply risk but decrease on economies of scale criterion. If vendor 2 and vendor 3 are simultaneously selected, there is an overlap for item 2. In that case, an increase of 10% on risk and resource share criterion, negative 15% on economies of scale criterion. The same goes to other pairs such as vendor 2 and vendor 8, vendor 5 and vendor 6, vendor 5 and vendor 7, vendor 6 and vendor 8. If vendor 3 and vendor 5 are simultaneously selected, there is an overlap for item 1 and item 4. In that case, an increase of 15% on risk and resource share criterion, negative 18% on economies of scale criterion. The same goes to other pairs such as vendor 3 and vendor 8, vendor 5 and vendor 8.

Table 2
Normalized interdependent relationship criteria and weight of nine vendors

	Interdependent Relationship Criteria			
	Name	economies of scale	resource and risk sharing	ownership or partnership
	Weight	0.39	0.30	0.31
Vendors	v^1	0.52	0.87	0.42
	v^2	0.73	0.85	0.56
	v^3	0.91	0.65	0.84
	v^4	0.56	0.55	0.75
	v^5	0.94	0.65	0.85
	v^6	0.65	0.72	0.35
	v^7	0.75	0.87	0.83
	v^8	0.92	0.77	0.36
	v^9	0.47	0.73	0.26

In order to illustrate these notations, consider Table 2, we have 9 vendors $N = \{1,2,3,4,5,6,7,8,9\}$ for 4 items $P = \{1,2,3,4\}$, and 3 criteria $Q = \{1,2,3\}$. Vendor 2 has effects of $c_1^2 = 0.73$, $c_2^2 = 0.85$, and $c_3^2 = 0.56$ on criterion 1, 2, and 3, respectively. Weights of criteria are $w = (w_1, w_2, w_3) = (0.39, 0.30, 0.31)$.

If no interdependencies are considered among the vendors, then the payoff value is defined as a simple additive function; for example, for $S = \{v^i, v^j\}$ we have

$$\phi(v^i, v^j) = \phi(v^i) + \phi(v^j) = \sum_{k=1}^{3} w_k c_k^i + \sum_{k=1}^{3} w_k c_k^j \qquad (8)$$

In this case, considering all possible set of 2-vendor alternatives and selecting a subset with the largest payoff value, we have the optimal solution among 12 feasible alternatives in Table 3 as

$\phi(v^5, v^7) = \phi(v^5) + \phi(v^7) = 0.8251 + 0.8108 = 1.6359$,

when vendor 5 and vendor 7 are selected simultaneously. If we consider interdependencies between alternatives and taking into account positive and negative energies, we have a dynamic weight for each criterion when applied to an alternative. The dynamic weight of an alternative depends on its interaction with other alternatives in the selected subset.

Table 3

Calculation of payoff values without interdependency between vendors

Vendor Pair	Payoff Value
v^1, v^8	1.2954
v^2, v^3	1.5236
v^2, v^7	1.5241
v^2, v^8	1.4147
v^3, v^4	1.4262
v^3, v^5	1.6354
v^3, v^8	1.5117
v^3, v^9	1.2932
v^5, v^6	1.4031
v^5, v^7	1.6359
v^5, v^8	1.5265
v^6, v^8	1.2794

Table 4 presents all subset of 2 alternatives and associated weights of each criterion, and the payoff value of the selected subset of alternatives. In Table 4, subset (v^5, v^7) obviously is not any more the optimal solution, as we have $\phi(v^5, v^7)$ =1.5826 However, the subset (v^2, v^7) has the largest payoff of $\phi(v^2, v^7)$ =1.6538, which is optimal.

To illustrate the optimization problem on equation (6), we use the numerical example presented above.

Table 4. Calculation of payoff values when

interdependencies are considered

2-supplier alternatives (v^i, v^j)	w_1	w_2	w_3	$\phi(v^i, v^j)$
1, 8	0.39(1+0.15)=0.4485	0.30(1-0.25)=0.225	.31(1+0.1)=0.341	1.2808
2, 3	0.39(1-0.15)=0.3315	0.30(1+0.1)=0.33	.31	1.4727
2, 7	0.39(1+0.15)=0.4485	0.30	.31(1+0.1)=0.341	1.6538
2, 8	0.39(1-0.15)=0.3315	0.30(1+0.1)=0.33	.31	1.3668
3,4	0.39	0.30	.31	1.3292
3, 5	0.39(1-0.18)=0.3198	0.30(1+0.15)=0.345	.31	1.5640
3, 8	0.39(1-0.18)=0.3198	0.30(1+0.15)=0.345	.31	1.4471
3, 9	0.39	0.30	.31	1.2932
5, 6	0.39(1-0.15)=0.3315	0.30(1+0.1)=0.33	.31	1.3512
5, 7	0.39(1-0.15)=0.3315	0.30(1+0.1)=0.33	.31	1.5826
5, 8	0.39(1-0.18)=0.3198	0.30(1+0.15)=0.345	.31	1.4598
6,8	0.39(1-0.15)=0.3315	0.30(1+0.1)=0.33	.31	1.2323

$$
\begin{aligned}
\max\ & 0.594x_{11} + .7133(x_{21} + x_{22}) \\
& +0.8103(x_{31} + x_{33} + x_{34}) + 0.6159x_{42} \\
& +0.825(x_{51} + x_{52} + x_{54}) \\
& +0.578(x_{61} + x_{63}) + 0.8108(x_{73} + x_{74}) \\
& +0.7014(x_{82} + x_{83} + x_{84}) + 0.4829x_{92} \\
& +0.39(0.15)(0.52 + 0.92)x_{11}(x_{82} + x_{83} + x_{84}) \\
& -0.30(0.25)(0.87 + 0.77)x_{11}(x_{82} + x_{83} + x_{84}) \\
& +0.31(0.10)(0.42 + 0.36)x_{11}(x_{82} + x_{83} + x_{84}) \\
& -0.39(0.15)(0.73 + 0.91)(x_{21} + x_{22})(x_{31} + x_{33} + x_{34}) \\
& +0.30(0.10)(0.85 + 0.65)(x_{21} + x_{22})(x_{31} + x_{33} + x_{34}) \\
& \ldots\ldots \\
& -0.39(0.15)(0.65 + 0.92)(x_{61} + x_{63})(x_{82} + x_{83} + x_{84}) \\
& +0.30(0.10)(0.72 + 0.77)(x_{61} + x_{63})(x_{82} + x_{83} + x_{84}) \\
st\ & y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8 + y_9 \le 2 \\
& x_{ij}, y_i \in \{0,1\}
\end{aligned}
$$

The above nonlinear function is solved by CPLEX and the result obtained gives objective function value of 1.6358 for assignments $x_{21} = x_{22} = x_{73} = x_{74} = y_2 = y_7 = 1$ and the rest of variables as 0.

Conclusions and Future Research Work

This paper introduces a two-step approach on vendor selection with bundling via a nonlinear formulation. The example shows that interdependence between a pair of suppliers within the criteria should be recognized in order to achieve more accurate results and better solutions. The preliminary results illustrate the attractiveness of this modeling method in terms of generating the best alternative and addressing dynamic criteria simultaneously. In the continuing work, the authors intend to carry out further testing of the proposed model on more complex problems in vendor selection with other constraints such as lead-time and capacity.

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