

Decision Aiding

A buyer–seller game model for selection and negotiation
of purchasing bids

Srinivas Talluri *

*Department of Marketing and Supply Chain Management, Eli Broad College of Business, Michigan State University,
N370 North Business Complex, East Lansing, MI 48824, USA*

Received 3 October 2000; accepted 25 September 2001

Abstract

Selection and negotiation of purchasing bids is a complex decision making process that requires consideration of a variety of vendor attributes such as price, delivery performance, and quality. Although several decision models have been utilized for vendor evaluation and selection, this paper proposes a buyer–seller game model that has distinct advantages over existing methods for bid selection and negotiation. The model effectively evaluates alternative bids based on the ideal targets set by the buyer. The alternative bid ratings are then utilized in an integer programming model in selecting an optimal set of bids that satisfy the buyer's demand requirements. The model also assists in proposing effective negotiation strategies for unselected bids in order to make them competitive. Finally, the paper proposes four variations of the model for evaluating different bid scenarios thereby providing flexibility for the buyer in selecting the appropriate method. The model application is demonstrated through a previously published dataset from a pharmaceutical company.

© 2002 Elsevier Science B.V. All rights reserved.

Keywords: Game models; Integer programming; Linear programming; Productivity; Purchasing

1. Introduction

Selection and negotiation of vendor bids is a critical decision faced by purchasing managers. The process often involves the consideration of several important bid attributes such as price, delivery performance, and quality. The selection of vendors that excel on various attributes is crucial because of their direct impact on a variety of final product dimensions such as cost, product and de-

sign quality, and manufacturability (Burton, 1988).

With the more recent emphasis on business-to-business (B2B) transactions between buyers and sellers, the importance of vendor evaluation has become even more critical to firms. In a recent paper, Wise and Morrison (2000) suggest that one of the fatal flaws in the current B2B model is that it primarily stresses on price-driven transactions between buyers and sellers, and fails to emphasize and incorporate other important factors such as quality, delivery, and customization. While price-driven strategies may be appropriate for commodity type transactions, the procurement of

* Tel.: +1-517-3536381; fax: +1-517-4321112.E-mail address: talluri@pilot.msu.edu (S. Talluri).

specialized products and services demands the consideration of factors beyond price. Wise and Morrison (2000) state that these price-driven strategies have placed tremendous pressure on the highest-quality and most innovative suppliers thereby reducing their participation in B2B exchanges. Thus, in order to effectively satisfy buyer's complex demands, it is critical for solution providers to develop models and software that consider a variety of vendor attributes in conducting complex B2B transactions between buyers and sellers. Companies such as FreeMarkets, Milpro.com, and Biztro.com have made some initial progress in this area.

Vijayan (2000) discusses the importance of considering multiple vendor related attributes for custom-engineered products or that involve multiple supply chain partners. It is suggested by him that companies such as TradeAccess and Convergent Technologies are developing software that is considering several factors beyond price for effective B2B transactions. He also stresses the need for structured negotiations in B2B exchanges and suggests that digital transactions need to support negotiations between buyers and sellers.

Baatz (1999) contests that buying products through traditional on-line auctions may not be the most dependable way to source due to issues relating to supplier credibility, product specifications, and lead-times. Copeland (2000) discusses issues involved in analyzing vendors in large and complex bid exchanges for specialty products.

In light of all these developments, it is important to build models that can be applied for evaluating vendor bids in the presence of multiple attributes. Although several decision models have been proposed for vendor evaluation and selection, spanning from simple weighted techniques to advanced mathematical programming methods, this paper presents a buyer–seller game model that has distinct advantages over existing methods in bid selection and negotiation. The proposed methods in this paper will have high practical value for solution providers developing software that supports complex B2B transactions between buyers and sellers.

The model developed in this paper effectively rates alternative vendor bids based on ideal targets

for bid attributes set by the buyer. More specifically, if there are a set of n vendor bids with t attributes, the buyer sets ideal targets by selecting the best values for each of the t attributes across all n bids. The vendor performance ratings are determined by evaluating against these ideal targets set by the buyer. These ratings are utilized in a 0–1 integer programming model in selecting an optimal set of bids by matching demand and capacity constraints. Decisions regarding vendor bid selection and negotiation are then performed.

The proposed approach has several advantages over traditional methods utilized for vendor evaluation and selection. These are: (1) it does not require the buyer to specify a priori importance levels (weights) to attributes, (2) each bid is evaluated against the ideal targets, which allows for identifying bids that excel under the dominating target conditions set by the buyer, (3) proposes effective quantitative negotiation strategies with unselected vendors, which have not been comprehensively investigated in the literature, (4) effectively incorporates multiple bid attributes into the analysis by considering relationships among them, (5) allocates order quantities for vendors based on efficiencies, and (6) provides variations of the model for evaluating different bid scenarios.

2. Literature review

Several methodologies have addressed the issue of vendor evaluation in literature, which include conceptual, empirical, and modeling approaches. In this section we discuss some of these methods while emphasizing more on the modeling literature.

Based on a survey of 170 purchasing managers, Dickson (1966) suggested that cost, quality, and delivery performance are the three most important criteria in vendor evaluation. Subsequent work in this area has mostly been conceptual and empirical in nature. Included in the stream of conceptual research are works by Ansari and Modarress (1986), Benton and Krajieski (1990), Bernard (1989), Burton (1988), Ellram (1990), Kralijic (1983), and Treleven (1987). These articles mainly emphasized the strategic importance of vendor

evaluation and the trade-off among cost, quality, and delivery performance.

Several researchers empirically studied the relative importance of various supplier attributes such as price, quality, and delivery performance (Chapman and Carter, 1990; Monczka et al., 1981; Tullous and Munson, 1991; Woodside and Vyas, 1987). Based on a review of 74 articles on vendor evaluation, Weber et al. (1991) concluded that quality was considered as the most important factor followed by delivery performance and cost. It is suggested in many of these articles that vendor selection decisions must not be exclusively based on least cost criteria and that other important factors such as quality and delivery performance must be incorporated into the analysis. While research relating to the conceptual and empirical work in vendor evaluation is quite exhaustive, these works did not specifically address methods for effective vendor selection and negotiation.

The development of analytical models for vendor evaluation has received significant attention in the literature. Willis et al. (1993) proposed a classification of vendor performance evaluation models that included categorical, weighted point, and cost ratio approaches. In the categorical method, a buyer rates each vendor as being preferred, unsatisfactory, or neutral on all the considered factors. The main problem with this approach is that all the factors are weighted equally. The weighted point approach utilizes the weights assigned by the buyer for each factor and multiplies them with the corresponding factor scores in generating an overall performance index for all the vendors. The issues here are that it is sometimes difficult to objectively assign weights to factors, and also the method requires all the factor units to be standardized. The cost ratio method evaluates the cost of each factor as a percentage of total purchases for the vendor. There can be complexities involved in developing cost accounting systems for this purpose.

Several evaluation techniques for vendor selection have been proposed. Some of these methodologies include weighted linear model approaches (Timmerman, 1986), linear programming models (Pan, 1989), mixed integer programming (Weber and Current, 1993), analytical hierarchy process

(Barbarosoglu and Yazgac, 1997; Narasimhan, 1983), matrix method (Gregory, 1986), multi-objective programming (Weber and Ellram, 1993), total cost of ownership (Ellram, 1995), human judgment models (Patton, 1996), principal component analysis (Petroni and Braglia, 2000), interpretive structural modeling (Mandal and Deshmukh, 1994), statistical analysis (Mummalaneni et al., 1996), discrete choice analysis experiments (Verma and Pullman, 1998), and neural networks (Siyng et al., 1997). Although majority of the above methodologies utilize multiple vendor attributes and have their own strengths under specific conditions, the methods proposed in this paper have distinct advantages over many of these traditional approaches as discussed in the Section 1 of the paper.

In the area of decision models for vendor evaluation and *negotiation*, we have only identified two articles by Weber and Desai (1996) and Weber et al. (1998). In the first paper, a combination of data envelopment analysis (DEA) and parallel coordinates representation methods are jointly utilized to evaluate the performance of vendors and develop negotiation strategies with inefficient vendors. In the second paper, the combined use of DEA and multiobjective programming is utilized for vendor selection and negotiation. These articles provided innovative ways of approaching the vendor evaluation and negotiation problem. According to them, a vendor is considered to be inefficient if the DEA model identifies a target combination of vendors that utilizes lower levels of inputs in generating at least the same output levels. Based on these evaluations the inefficient vendors are provided with benchmarks that act as targets for negotiation. While this is an interesting approach, it has certain limitations. It only allows for negotiation with inefficient vendors. While this may seem logical, it is possible in DEA that some of the inefficient vendors are in fact better overall performers than some of the efficient vendors. This is because an efficient unit may be excelling on only few dimensions and performing poorly on many other dimensions.

In order to overcome these limitations and provide a more robust method for vendor evaluation and negotiation, this paper proposes a set of

game models that evaluate vendor bids based on ideal targets set by the buyer. The game models are structured in such a way that there is limited scope for a bid, which excels on relatively fewer measures, to be identified as a good performer. Although our models are grounded in the general efficiency theory, they are different from a traditional DEA sense. The game model results are utilized in a 0–1 integer programming model in selecting an optimal set of bids that satisfy the demand requirements of the buyer, and the minimum order necessities of the vendors. Effective negotiation strategies are then proposed for unselected bids in making them competitive.

To the best of our knowledge this type of approach has not been developed in the literature. A method that is to some extent relevant in this context is the maximum decisional efficiency (MDE) technique and its variations proposed by Troutt (1995) and Troutt et al. (1997), respectively. The MDE technique utilizes data based on ideal outcomes from multiple decision-makers in estimating a group ideal outcome. Troutt et al. (1997) suggest that the technique can be applied in vendor evaluation decisions. This approach can also possibly work as a complement to our model for developing the ideal targets in the presence of multiple decision-makers.

3. Model development

In this section, we propose four variations of the model that address different scenarios and provide the buyer with the flexibility to utilize the most appropriate model for a given situation. The four cases are shown in Fig. 1.

Since the evaluations in our model are conducted from a buyer's perspective, we define inputs as the resources spent and outputs as the benefits derived by the buyer. For example, price is treated as an input since it represents the amount the buyer pays to the vendor, and product quality and delivery performance are considered as outputs since they represent benefits derived. However, vendor capabilities such as quality management practices, design and development competencies, and cost reduction initiatives can be utilized as

	Simultaneous	Individual
Single Input-Multiple Output	Case I	Case II
Multiple Input-Multiple Output	Case III	Case IV

Fig. 1. The four scenarios in evaluating vendor bids.

other possible inputs in a more comprehensive evaluation. Such factors will be important to buyers in developing long-term relationships with vendors. Similarly, other output factors can involve performance measures such as service-quality experience and service-quality credence (Kleinsorge et al., 1992). However, it must be noted that some of these measures are only applicable in situations where the buyer has experience with the vendor.

As discussed above, the scenarios include single input–multiple output and multiple input–multiple output cases. We demonstrate that the single input case for simultaneous consideration of n bids provides for a computationally simpler solution method. Although the multiple input cases are direct extensions to the single input cases, the formulation and solution deriving methods are somewhat different. Also, the simultaneous and individual consideration of vendor bids provides useful alternative ways for the buyer to analyze a problem. More insights into the application of these methods are demonstrated in the case example.

Case I (*Single input–multiple output with simultaneous consideration of n vendor bids*). We evaluate the efficiencies, ratios of weighted outputs to weighted inputs, for the n vendor bids with respect to the ideal targets set by the buyer. The efficiency score when evaluated with the ideal measures is 1, since there is no other bid or combination of bids that can possibly excel it. Given this, we try to find the input and output weights that maintain the efficiency level for ideal bid measures at 1, and simultaneously minimize the efficiencies of all n bids. The advantage of this approach is that it

allows identifying bids that excel under the dominating conditions set by the ideal measures. This assists in ranking alternative bids when evaluated against the same target, which makes the comparison much more accurate. A more generic form of the formulation utilized is shown in expression (1).

$$\begin{aligned} \min \quad & \sum_{i=1}^n \left(\frac{\sum_{r=1}^v a_r y_{ri}}{b_1 x_{1i}} \right) \\ \text{s.t.} \quad & \frac{\sum_{r=1}^v a_r y_{ri}}{b_1 x_{1i}} \leq \frac{\sum_{r=1}^v a_r y_{r \text{ ideal}}}{b_1 x_{1 \text{ ideal}}} \quad \forall i, \\ & a_r, b_1 \geq 0 \quad \forall r, \end{aligned} \quad (1)$$

where n represents the number of bids, v represents the number of bid outputs, y_{ri} represents the value of the r th output for the i th bid, x_{1i} represents the input value for the i th bid, $y_{r \text{ ideal}}$ represents the best value for the r th output, $x_{1 \text{ ideal}}$ represents the best value for the input, a_r represents the weight given to the r th output, b_1 represents the weight given to the input.

The objective function represents the sum of efficiencies for the n vendor bids. The constraint set prevents the efficiency scores for the n bids from exceeding the efficiency derived from using the ideal bid measures. Expression (1) is reformulated as shown in expression (2).

$$\begin{aligned} \min \quad & \sum_{i=1}^n \left(\frac{\sum_{r=1}^v a_r y_{ri}}{b_1 x_{1i}} \right) \\ \text{s.t.} \quad & \frac{\sum_{r=1}^v a_r y_{r \text{ ideal}}}{b_1 x_{1 \text{ ideal}}} = 1, \\ & \frac{\sum_{r=1}^v a_r y_{ri}}{b_1 x_{1i}} \leq 1 \quad \forall i, \\ & a_r, b_1 \geq 0 \quad \forall r. \end{aligned} \quad (2)$$

Here, we blanket the efficiency score for the ideal bid measures to 1, since any vendor or combination of vendors in the set does not dominate it. In order to solve the above problem, one other transformation on the objective function needs to be performed. The objective function in expression (2), which is the sum of efficiencies, is non-linear and must be converted to a linear form. The transformation is performed by first representing expression (2) as shown below:

$$\sum_{i=1}^n \left(\frac{\sum_{r=1}^v a_r y_{ri}}{b_1 x_{1i}} \right) = \frac{\sum_{r=1}^v \sum_{i=1}^n a_r (k y_{ri} / x_{ri})}{k b_1},$$

where k is the least common multiple for $x_{11}, x_{12}, \dots, x_{1n}$.

Thus, this new form of expression (2) can be represented in a linear form as shown in expression (3).

$$\begin{aligned} \min \quad & \sum_{r=1}^v \sum_{i=1}^n a_r \left(\frac{k y_{ri}}{x_{ri}} \right) \\ \text{s.t.} \quad & k b_1 = 1, \\ & \sum_{r=1}^v a_r y_{r \text{ ideal}} - b_1 x_{1 \text{ ideal}} = 0, \\ & \sum_{r=1}^v a_r y_{ri} - b_1 x_{1i} \leq 0 \quad \forall i, \\ & a_r, b_1 \geq 0 \quad \forall r. \end{aligned} \quad (3)$$

The denominator of the objective function ($k b_1$) is equated to 1 and represented as a constraint in expression (3). Both constraint sets from expression (2) are converted to linear form as shown in expression (3). The above problem can be solved using commercial linear programming software. The weights (a_r and b_1) derived from the above model are utilized in identifying the efficiency scores of the n vendor bids. Proposed negotiation is performed by identifying the amount of input to decrease or the amounts of outputs to increase in making a particular vendor bid more competitive.

Case II (Single input–multiple output with individual consideration of n vendor bids). This is similar to Case I in terms of input/output structure, but the vendors are considered individually instead of being evaluated simultaneously. The model of choice is typically left to the buyer. Expression (4) depicts the model.

$$\begin{aligned} \min \quad & \frac{\sum_{r=1}^v a_r y_{rp}}{b_1 x_{1p}} \\ \text{s.t.} \quad & \text{expression (2)'s constraints,} \end{aligned} \quad (4)$$

where p represents the vendor being evaluated.

The problem in expression (4) can easily be linearized as demonstrated earlier. The notation

used in the model is consistent from before. However, the above model needs to be run n times in determining the efficiencies of all the vendor bids. There are some key differences between the above model and the one presented in expression (3). Computationally speaking the model in expression (3) is superior because it requires to be run only once in identifying the efficiencies of all the vendor bids using the obtained input/output weights. However, the model in expression (4) may have better discriminatory power since the vendor bids are evaluated individually, i.e., one at a time. This is because in expression (3) sum of efficiencies is utilized as a surrogate measure in minimizing the independent efficiencies of the n vendor bids. Thus, there may be a scope for the weights to be compromised. At the same time, a possible issue with using expression (4) is that multiple sets of weights may be identified based on the vendor being evaluated, and so there may not be a standard weight set for comparing the vendor bids. However, it should be clearly noted that same ideal target measures are used in every instance. Thus, there are some relative advantages and disadvantages in using the two cases explained for the single input–multiple output problems.

Case III (*Multiple input–multiple output with simultaneous consideration of n vendor bids*). This case is a direct extension to Case I presented earlier. The consideration of both multiple inputs and outputs presents certain difficulties in minimizing the objective function because of its non-linearity. It is evident from expression (5) that the sum of efficiencies of n vendor bids, shown in the objective function, is non-linear and would not lend itself to a linear form. A surrogate measure that can be utilized is the average vendor bid constructed from the n bids. Thus, the objective function in expression (5) can be replaced by $\sum_{r=1}^v a_r (\sum_{i=1}^n y_{ri}/n) / \sum_{s=1}^u b_s (\sum_{i=1}^n x_{si}/n)$. The only issue is that the weights may be compromised to a certain extent, but the model needs to be run only once in identifying the efficiencies of all vendor bids. Similar to the other cases explained earlier the present model can also be easily converted to a linear program.

$$\begin{aligned} \min \quad & \sum_{i=1}^n \left(\frac{\sum_{r=1}^v a_r y_{ri}}{\sum_{s=1}^u b_s x_{si}} \right) \\ \text{s.t.} \quad & \frac{\sum_{r=1}^v a_r y_{r \text{ ideal}}}{\sum_{s=1}^u b_s x_{s \text{ ideal}}} = 1, \\ & \frac{\sum_{r=1}^v a_r y_{ri}}{\sum_{s=1}^u b_s x_{si}} \leq 1 \quad \forall i, \\ & a_r, b_s \geq 0 \quad \forall r, s, \end{aligned} \quad (5)$$

where u represents the number of bid inputs.

Case IV (*Multiple input–multiple output with individual consideration of n vendor bids*). The scenario presented here is a direct extension to Case II. The model individually evaluates the efficiencies of alternative vendor bids by considering multiple input and output measures. Expression (6) depicts the model.

$$\begin{aligned} \min \quad & \frac{\sum_{r=1}^v a_r y_{rp}}{\sum_{s=1}^u b_s x_{sp}} \\ \text{s.t.} \quad & \text{expression (5)'s constraints,} \end{aligned} \quad (6)$$

where p represents the vendor being evaluated.

The proposed model has identical advantages and disadvantages as the model presented in Case II. The conversion to a linear program is similar to other cases.

3.1. Integer programming model for bid selection

The vendor ratings are evaluated in a 0–1 integer programming model, shown in expression (7), to select an optimal set of bids that satisfies the buyer's demand requirements.

$$\begin{aligned} \min \quad & \sum_{i=1}^n z_i \\ \text{s.t.} \quad & \sum_{i=1}^n \theta_i z_i - \theta_{\text{avg}} \sum_{i=1}^n z_i \geq 0, \\ & \sum_{i=1}^n q_i = D, \\ & q_i - C_{i \max} z_i \leq 0 \quad \forall i, \\ & q_i - O_{i \min} z_i \geq 0 \quad \forall i, \\ & q_i \geq 0 \quad \forall i, \\ & z_i \in (0, 1) \quad \forall i, \end{aligned} \quad (7)$$

where z_i is the binary variable that represents the selection status of vendor bid i (1 indicates selected and 0 otherwise), θ_i is the efficiency of vendor bid i , θ_{avg} is the minimum average efficiency target for selected bids set by the buyer, q_i is the amount ordered from vendor i , D is the buyer's demand requirement, $C_{i\text{max}}$ is the capacity of vendor i , $O_{i\text{min}}$ is the minimum order quantity requirement of vendor i .

4. Empirical illustration

The data utilized in demonstrating our models are derived from the articles of Weber and Desai (1996) and Weber et al. (1998), which are shown in Table 1. The firm considered is a division of a *Fortune* 500 pharmaceutical company. At that time this company was involved in the implementation of a JIT system. Thus, product price, quality, and delivery performance were considered to be the three most important factors in evaluating vendors. The price is represented on a per unit basis for each delivered item. Quality is represented as the percentage of units rejected. Delivery performance is represented as the percentage

of ordered units late. It should be noted that the values of these measures represent the commitments made by the vendors to the buyer.

As discussed earlier, price is utilized as the input, and quality and delivery performance are considered as outputs. Since small values of inputs are preferred to large values, and large values of outputs are preferred to small values, we conducted a scale transformation on the two outputs. Thus, instead of using percentages of rejects and late deliveries, we utilized percentages of accepted items and on-time deliveries (OTD) as the output measures. Table 2 shows the transformed vendor data.

We only illustrate the application of models in Cases I and II since the data are restricted to single input and multiple outputs. However, the application of Cases III and IV can easily be performed in a similar manner. Table 2 depicts the ideal values under the heading 'Ideal', which represent the targets set by the buyer. It is observed that \$0.1881/unit in price and 100% in OTD and accepted items are the best values in this context.

The results of Case I analysis are shown in Table 3 under the heading 'Case I Efficiency'. The corresponding input and output weights are shown

Table 1
Vendor data

Variable	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6
P (\$/unit)	0.1958	0.1881	0.2204	0.2081	0.2118	0.2096
% R	1.2	0.8	0.0	2.1	2.3	1.2
% LD	5.0	7.0	0.0	0.0	3.0	4.0
MOR (unit)	40 000	40 000	40 000	40 000	40 000	40 000
C (unit)	2.4 M	0.36 M	2.783 M	3.0 M	2.966 M	2.5 M

P : price/unit; R : rejects; LD: late deliveries; MOR: minimum order requirements; C : capacity repressed in millions (M).

Table 2
Transformed vendor data

Variable	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6	Ideal
P (\$/unit)	0.1958	0.1881	0.2204	0.2081	0.2118	0.2096	0.1881
% A	98.8	99.2	100	97.9	97.7	98.8	100
% OTD	95	93	100	100	97	96	100
MOR (unit)	40 000	40 000	40 000	40 000	40 000	40 000	
C (unit)	2.4 M	0.36 M	2.783 M	3.0 M	2.966 M	2.5 M	

P : price/unit; A : acceptance; OTD: on-time deliveries; MOR: minimum order requirements; C : capacity repressed in millions (M).

Table 3
Vendor efficiencies

Vendor	Case I efficiency	Case II efficiency
1	0.913	0.913
2	0.930	0.930
3	0.853	0.853
4	0.904	0.885
5	0.861	0.861
6	0.862	0.862

in Table 4. It is evident from these results that vendor 2 is the best performer with an efficiency score of 0.930, and the next best performer is vendor 1 with a score of 0.913. The remaining vendors 4, 6, 5, and 3 are ranked in that order with scores of 0.904, 0.862, 0.861, and 0.853, respectively. If the buyer is interested in selecting a single vendor then the optimal choice is vendor 2, this of course assumes that vendor 2 can fully satisfy the demand requirements of the buyer.

For the unselected vendors to be competitive we propose negotiation strategies based on this model results. Since 0.930 is the highest score with respect to the ideal targets set by the buyer, we determine the necessary improvements required from each of the unselected vendors to achieve this target. This can be performed by either decreasing the input levels or by increasing the output levels or a combination of both. To achieve an efficiency score of 0.930, vendors 1, 3, 4, 5, and 6 need to decrease their unit prices to \$0.1922, \$0.2022, \$0.2023, \$0.1961, and \$0.1943, respectively. If they decrease by any more than the above amounts they will achieve an efficiency score higher than vendor 2. Alternatively, vendors 1, 3, 4, 5, and 6 must improve their percentage of OTD to 96.77%,

109.03%, 102.88%, 104.77%, and 103.57%, respectively, and quality levels (accepts) to 100.64%, 109.03%, 100.72%, 105.53%, 106.59%, respectively. The buyer can utilize these types of strategies in negotiating with unselected vendors. It is evident that several of the above output improvements are infeasible. Thus, the reduction in unit prices is considered as a more appropriate negotiation strategy for this case. The results are summarized in Table 5.

An insight that must be noted based on Case I evaluations is that the weight attached to quality levels is zero, thus making the above specified improvements across this dimension inappropriate. The zero weight occurred because the performance across the quality dimension for all the vendors is fairly consistent. If the decision-maker needs to avoid this from happening a lower bound on the weights can be set.

Case II model analysis also provided very similar results in terms of efficiency scores of vendors as shown in Table 3. The corresponding input and output weights are shown in Table 4. In fact all the vendors except vendor 4 achieved identical scores in both models. The efficiency of vendor 4 decreased to 0.885, although it did not specifically change the ordering of vendors. Thus, at least for this situation the model in Case I, which is computationally easier to solve, is on par with the model in Case II. However, this would most likely change when one considers more inputs and outputs into the analysis. Case I's efficiency values will be at the minimum equal to that of Case II's efficiencies. The buyer can select the model that best fits their goals by considering the relative advantages and disadvantages of each.

Table 4
Input and output weights for Cases I and II

Case	Vendor	P	A	OTD
I	1–6	4.537205	0	0.008534
II	1	5.107252	0	0.009607
	2	5.316321	0	0.01
	3	4.537205	0.008534	0
	4	4.805382	0.009039	0
	5	4.721435	0	0.008881
	6	4.770992	0	0.008974

Table 5
Price, quality, and delivery negotiation targets for vendors

Vendor	P (\$/unit)	A (%)	OTD (%)
1	0.1922	100.64	96.77
3	0.2022	109.03	109.03
4	0.2023	100.72	102.88
5	0.1961	105.53	104.77
6	0.1943	106.59	103.57

Table 6
Vendor selection and order quantities

Vendor	Case I efficiency	Selection	Order quantity (Millions)
1	0.913	1	2.4
2	0.930	1	0.36
3	0.853	0	0
4	0.904	1	3.0
5	0.861	1	2.53
6	0.862	1	2.5

In the present case scenario, more than one vendor needs to be selected because of the demand requirements. The demand for the firm during the planning horizon is 10.79 M (million) units. We utilize the efficiency scores obtained from Case I analysis in a 0–1 integer programming model shown in expression (7). For illustrative purposes, the θ_{avg} value is set at 0.89. The decision-maker must carefully set the θ_{avg} value so as to avoid infeasibility. The minimum order requirements (MOR) and the capacity levels of the vendors are obtained from Table 1. We minimized the number of vendors to be selected in obtaining the solution. The results are shown in Table 6. The model selected vendors 1, 2, 4, 5, and 6 and the order quantities for each of them were identified to be 2.4, 0.36, 3.0, 2.53, and 2.5 M, respectively. The negotiation strategies for the unselected vendor 3 can be derived as demonstrated earlier.

5. Conclusions and extensions

This paper proposed a buyer–seller game model for evaluating alternative vendor bids with

respect to multiple performance criteria. Effective negotiation strategies have also been proposed in order to make the unselected bids competitive. Four variations of the model are developed in order to assist the buyer in different types of purchasing situations, and to provide flexibility in selecting the model of choice. The model evaluations are integrated into a 0–1 integer programming formulation in determining the optimal set of vendors to be selected in meeting the demand requirements of the buyer without violating the minimum order necessities of the vendors. The advantages of this methodology over traditional methods are discussed. The models developed in this paper have potential application in traditional and B2B transactions between buyers and sellers.

Some of the interesting extensions to the proposed methodology include the use of effective methods to incorporate a range for buyer's preferences of attributes, so that the relatively more important attributes are assigned significant weight in the analysis. Note that we are not proposing a fixed weight to be attached to the attributes because that would mean the identification of exact weights, which is often a difficult task for the buyer. A range of weights would imply, for example, the weight provided for quality (v_1) lies somewhere between 1.5 and 3 times the weight given to OTD (v_2), which can be represented as $1.5v_2 \leq v_1 \leq 3v_2$. These weight restrictions can easily be appended to our models as linear constraints. However, the derivation of these ranges can be an issue for buyers. It is critical that buyers consider the goals and competitive priorities of their firms in formulating such preference ranges.

Another interesting extension can involve looking into better ways for identifying physical benchmarks for improving ineffective vendors. This may involve identifying and implementing effective policies and practices of benchmark performers.

Finally, the incorporation of both ordinal and cardinal factors for evaluating alternative bids needs to be investigated. This is important because qualitative factors such as trust, reliability, and courtesy of the vendor are considered to be critical issues in vendor evaluation.

References

- Ansari, A., Modarress, B., 1986. Just-in-time purchasing: Problems and solutions. *Journal of Purchasing and Materials Management* 22 (2), 19–26.
- Baatz, E., 1999. Online auctions start to pick up steam. *Purchasing* 127 (6), 46–50.
- Barbarosoglu, G., Yazgac, T., 1997. An application of the analytic hierarchy process to the supplier selection problem. *Production and Inventory Management Journal* 38 (1), 14–21.
- Benton, W.C., Krajieski, L., 1990. Vendor performance and alternative manufacturing environments. *Decision Sciences* 21 (2), 403–415.
- Bernard, P., 1989. Managing vendor performance. *Production and Inventory Management Journal* 30 (1), 1–7.
- Burton, T.T., 1988. JIT/Repetitive sourcing strategies: Tying the knot with your suppliers. *Production and Inventory Management Journal* 29 (4), 38–41.
- Chapman, S.N., Carter, P.L., 1990. Supplier/customer inventory relationships under just-in-time. *Decision Sciences* 21 (1), 35–51.
- Copeland, L., 2000. B-to-B auctions from A to Z. *Computerworld* 34 (16), 54.
- Dickson, G., 1966. An analysis of vendor selection systems and decisions. *Journal of Purchasing* 2, 28–41.
- Ellram, L.M., 1990. The supplier selection decision in strategic partnerships. *Journal of Purchasing and Materials Management* 26 (4), 8–14.
- Ellram, L.M., 1995. Total cost of ownership: An analysis approach for purchasing. *International Journal of Physical Distribution and Logistics Management* 25 (8), 4–23.
- Gregory, R.E., 1986. Source selection: A matrix approach. *Journal of Purchasing and Materials Management* 22 (2), 24–29.
- Kleinsorge, I.K., Schary, P., Tanner, R., 1992. Data envelopment analysis for monitoring customer–supplier relationships. *Journal of Accounting and Public Policy* 11 (4), 357–372.
- Kraljic, P., 1983. Purchasing must become supply management. *Harvard Business Review* 61 (5), 109–117.
- Mandal, A., Deshmukh, S.G., 1994. Vendor selection using interpretative structural modeling (ISM). *International Journal of Operations and Production Management* 14 (6), 52–59.
- Mummalaneni, V., Dubas, K.M., Chao, C., 1996. Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation. *Industrial Marketing Management* 25 (2), 115–124.
- Monczka, R.M., Giunipero, L.C., Reck, R.F., 1981. Perceived importance of supplier information. *Journal of Purchasing and Materials Management* 17 (1), 21–29.
- Narasimhan, R., 1983. An analytical approach to supplier selection. *Journal of Purchasing and Materials Management* 19 (1), 27–32.
- Pan, A.C., 1989. Allocation of order quantity among suppliers. *Journal of Purchasing and Materials Management* 25 (3), 36–39.
- Patton, W.W., 1996. Use of human judgment models in industrial buyer's vendor selection decisions. *Industrial Marketing Management* 25, 135–149.
- Petroni, A., Braglia, M., 2000. Vendor selection using principal component analysis. *Journal of Supply Chain Management* 36 (2), 63–69.
- Siyang, W., Jinlong, Z., Zhicheng, L., 1997. A supplier-selecting system using a neural network. In: 1997 IEEE International Conference on Intelligent Processing Systems. IEEE Press, New York, pp. 468–471.
- Timmerman, E., 1986. An approach to vendor performance evaluation. *Journal of Purchasing and Materials Management* 22 (4), 2–8.
- Treleven, M., 1987. Single sourcing: A management tool for the quality supplier. *Journal of Purchasing and Materials Management* 23 (1), 19–24.
- Troutt, M.D., 1995. A maximum decisional efficiency estimation principle. *Management Science* 41 (1), 76–82.
- Troutt, M.D., Rai, A., Tadisina, S.K., 1997. Aggregating multiple expert data for linear case valuation models using the MDE principle. *Decision Support Systems* 21 (2), 75–82.
- Tullous, R., Munson, J.M., 1991. Trade-offs under uncertainty: Implications for industrial purchasers. *International Journal of Purchasing and Materials Management* 27 (3), 24–31.
- Verma, R., Pullman, M.E., 1998. An analysis of the supplier selection process. *Omega* 26 (6), 739–750.
- Vijayan, J., 2000. Vendors offer tools to sell customized parts. *Computerworld* 34 (15), 73.
- Weber, C.A., Current, J.R., 1993. A multiobjective approach to vendor selection. *European Journal of Operational Research* 68 (2), 173–184.
- Weber, C.A., Current, J.R., Benton, W.C., 1991. Vendor selection criteria and methods. *European Journal of Operational Research* 50 (1), 2–18.
- Weber, C.A., Current, J.R., Desai, A., 1998. Non-cooperative negotiation strategies for vendor selection. *European Journal of Operational Research* 108 (1), 208–223.
- Weber, C.A., Desai, A., 1996. Determination of paths to vendor market efficiency using parallel coordinates representation: A negotiation tool for buyers. *European Journal of Operational Research* 90 (1), 142–155.
- Weber, C.A., Ellram, L.M., 1993. Supplier selection using multi objective programming: A decision support systems approach. *International Journal of Physical Distribution and Logistics Management* 23 (2), 3–14.
- Willis, T.H., Huston, C.R., Pohlkamp, F., 1993. Evaluation measures of just-in-time supplier performance. *Production and Inventory Management Journal* 34 (2), 1–6.
- Wise, R., Morrison, D., 2000. Beyond the exchange: The future of B2B. *Harvard Business Review* 78 (6), 86–96.
- Woodside, A.G., Vyas, N., 1987. *Industrial Purchasing Strategies*. Lexington Books, Lexington, MA.