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Vendor evaluation with performance variability: A max–min approach

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Abstract

The importance of incorporating multi-dimensional information into vendor evaluation is well established in the literature. Over the years, several multi-criteria techniques have been proposed for effective evaluation and selection of vendors. However, these models have not considered performance variability measures in evaluating alternative vendors. It is critical for the buyer to derive and incorporate such type of measures into the evaluation process because it provides for a more accurate portrayal of vendor's performance. This paper fills this gap by proposing a *max–min* productivity based approach that derives vendor performance variability measures, which are then utilized in a nonparametric statistical technique in identifying vendor groups for effective selection. The primary advantage of this technique is that it provides the buyer with effective alternative choices within a vendor group. Thus, allowing the buyer to base the final decision on other intangible factors that could not be incorporated into the analysis. The model application is demonstrated through a previously reported dataset from a pharmaceutical company.

Keywords: Linear programming; Optimization; Productivity; Purchasing

1. Introduction

One of the important areas in purchasing research that has significant practical implications is vendor evaluation and selection. Several researchers have addressed the strategic importance of the vendor evaluation process (Banker and Khosla, 1995; Burt, 1984; Burton, 1988; Dobler et al., 1990). These studies have mainly emphasized the impact of vendor selection decisions on various functional areas of business from procurement to production and delivery of the products to the end customer.

While the traditional vendor evaluation methods primarily considered financial measures in the decision making process, more recent emphasis on manufacturing strategies such as just-in-time (JIT) has placed increasing importance on the incorporation of multiple vendor criteria into the evaluation process (Chapman, 1989; Chapman and Carter, 1990). Thus, researchers have sought the

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adoption of multi-criteria decision models for vendor selection purposes. The evaluation process often incorporated important product and service related decision variables such as price, delivery performance, and quality.

While research in vendor selection process is flooded with several decision models that envelop simple weighted techniques to advanced mathematical programming methods, there has been little work in the area of incorporating performance variability measures into the selection process. It is critical for the buyer to estimate and include such type of measures in order to more accurately evaluate vendor's performance and improve the effectiveness of the decision-making process. In this paper we define performance variability as the vendor's multi-factor efficiency variation when evaluated against the targets set by the buyer. It is critical to understand the strengths and weaknesses of a vendor and effectively utilize this information for vendor selection decisions. Traditional multi-factor vendor evaluation methods, such as data envelopment analysis, have primarily relied on evaluating vendors based on their strengths and failed to incorporate their weaknesses into the selection process. Such approaches would not be able to effectively differentiate between vendors with comparable strengths but significantly different weaknesses. Thus, vendor's performance variability is a key issue that needs to be considered in the evaluation process. To this end, this paper proposes an approach based on *max–min* productivity methods. The approach estimates vendor performance variability measures, which are then utilized in a non-parametric statistical technique in identifying homogeneous vendor groups. It provides the buyer with effective alternative choices within a vendor group. Thus, allowing the buyer to base the final decision on other intangible factors that could not be considered in the analysis. The model application is demonstrated through a previously reported vendor dataset from a pharmaceutical company.

The rest of the paper is organized as follows. The next section discusses the existing literature in vendor evaluation process, which is followed by the discussion of the *max–min* approach. The model application is then detailed through a case dataset. Finally, conclusions and future research directions are presented.

2. Literature review

Methodologies for vendor evaluation have included conceptual, empirical, and modeling approaches. The initial work in this area by Dickson (1966) concluded that cost, quality, and delivery performance are the three most important criteria that need to be considered for vendor evaluation purposes. The conceptual research in this field primarily emphasized the strategic importance of vendor evaluation and the trade-off among cost, quality, and delivery performance. Included in the stream of conceptual research are works by Ansari and Modarress (1986), Benton and Krajeski (1990), Bernard (1989), Browning et al. (1983), Burton (1988), Ellram (1990), Hahn et al. (1983), Jackson (1983), Kralijic (1983), and Treleven (1987).

The empirical research in this area mainly focused on studying the relative importance of various vendor attributes such as price, quality, and delivery performance. Some of the well-known studies in this area include works by Cardozo and Cagley (1971), Chapman and Carter (1990), Monczka et al. (1981), Moriarity (1983), Tullous and Munson (1991), and Woodside and Vyas (1987). For example, Cardozo and Cagley (1971) concluded that the relative importance assigned to a vendor attribute was primarily based on the type of risk involved in a specific purchasing situation. Woodside and Vyas (1987) suggested that management would generally be willing to pay 4–6% higher than the lowest acceptable bid if the product performance is superior. Based on a comprehensive review of vendor evaluation methods, Weber et al. (1991) concluded that quality was the highest ranked factor followed by delivery performance and cost. It can be concluded from these studies that vendor selection decisions must not be exclusively based on least cost criterion and that other critical factors such as quality and delivery performance need to be incorporated into the evaluation and selection process. Although the conceptual and empirical research stresses the strategic importance of vendor evaluation and the consideration of multiple measures, they do not specifically propose any evaluation models. We now turn our attention towards the vendor evaluation models proposed in the literature.

3. Analytical approaches to vendor evaluation

Analytical models for vendor evaluation have ranged from simple weighted techniques to complex mathematical programming approaches. The more recent approaches have also incorporated multiple vendor criteria into the evaluation process. A comprehensive review of vendor selection methods by Weber et al. (1991) reported that 47 of the 76 articles in the review utilized more than one criterion.

Some of the simple techniques for vendor evaluation include categorical, weighted point, and cost ratio approaches (Willis et al., 1993). In the categorical method, buyer rates each vendor as being preferred, unsatisfactory, or neutral on all the attributes considered in the evaluation process. The limitation with this approach is that all the attributes are weighted equally. The weighted point method assigns weights to each attribute and evaluates the sum-product of the weights and attribute scores for each alternative. Assigning attribute weights in an objective manner and standardizing all the attribute units are some of the key issues with this approach. The cost ratio method evaluates the cost of each factor as a percentage of total purchases for the vendor. However, this approach has difficulties in developing cost accounting systems for this purpose.

Several multi-criteria, mathematical programming, and other advanced methodologies have also been proposed for vendor selection. Some of these methods are shown in Table 1.

Although several effective techniques and models have been utilized for evaluating vendor performance, there is little work in incorporating variability measures into the evaluation process. Clearly, integration of performance variability into the decision making process, and the identification of effective alternative choices provides the buyer with flexibility in the final selection process. The *max–min* approach that addresses these issues is proposed and discussed next.

Table 1
Vendor evaluation techniques

Evaluation technique	Authors
Weighted linear models	Lamberson et al. (1976), Timmerman (1986), Wind and Robinson (1968)
Linear programming	Pan (1989), Turner (1988)
Mixed integer programming	Weber and Current (1993)
Grouping methods	Hinkle et al. (1969)
Analytical hierarchy process	Barbarosoglu and Yazgac (1997), Hill and Nydick (1992), Narasimhan (1983)
Analytical network process	Sarkis and Talluri (2002)
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)
Data envelopment analysis	Narasimhan et al. (2001), Talluri (2002a), Weber and Desai (1996), Weber et al. (1998)
Interpretive structural modeling	Mandal and Deshmukh (1994)
Game models	Talluri (2002b)
Statistical analysis	Mummalaneni et al. (1996)
Discrete choice analysis experiments	Verma and Pullman (1998)
Neural networks	Siying et al. (1997)

4. Max–min approach for vendor evaluation

The concept behind the *max–min* approach is to maximize and minimize the performance of a vendor against the best target measures set by the buyer. The combination of models utilized in this approach provides two measures of performance for each vendor, where higher values indicate better levels of performance. While the first model is structured in a way to identify the areas in which a vendor is excelling, the second model identifies the areas in which a vendor is performing poorly. Both these measures are jointly utilized in order to achieve a comprehensive understanding of a vendor's performance.

Given that there are n vendors with m attributes, the buyer identifies the best values for each attribute across all the vendors. The buyer utilizes this set of ideal targets in evaluating the performance of alternative vendors. Also, the buyer can choose to utilize his/her own benchmark values for setting the ideal targets, which may be different from the best attribute values identified above. For example, should none of the vendors score 100% on delivery performance the buyer can still utilize it as a potential benchmark value. Likewise a product price less than any of the vendors' prices can also be set as the target value. Such modifications can easily be performed in evaluating alternative vendors.

In each case, the vendor productivity, defined as the ratio of weighted outputs to weighted inputs, is maximized and minimized in obtaining a set of dual productivity scores. The maximization case is shown below as model (1):

Model (1)

$$\begin{aligned} \max \quad & \frac{\sum_{r=1}^{v} a_r y_{rp}}{\sum_{s=1}^{u} b_s x_{sp}} \\ \text{s.t.} \quad & \frac{\sum_{r=1}^{v} a_r y_{r^*}}{\sum_{s=1}^{u} b_s x_{s^*}} = 1, \\ & \frac{\sum_{r=1}^{v} a_r y_{ri}}{\sum_{s=1}^{u} b_s x_{si}} \leqslant 1 \quad \forall i, \\ & a_r, b_s \geqslant 0 \quad \forall r, s, \end{aligned}$$

where p represents the vendor being evaluated, v represents the number of vendor outputs, u represents the number of vendor inputs, y_{ri} represents the value of the rth output for the ith vendor, x_{si} represents the sth input value for the ith vendor, y_{r^*} represents the best value for the rth output across all vendors, x_{s^*} represents the best value for the sth input across all vendors, a_r represents the weight given to the rth output, b_s represents the weight given to the sth input.

In model (1), the objective function represents the productivity of vendor p, which is maximized subject to a set of constraints. The first constraint represents the productivity score based on the best measures set by the buyer, which is positioned at a value of 1. This indicates that the productivity for the buyer set measures is efficient, since any vendor or combination of vendors in the evaluation set cannot dominate it (Talluri, 2002b). This definition of efficiency is based on the work by Charnes et al. (1978). The second set of constraints prevents the efficiency scores of all the vendors in the set from exceeding a value of 1, which is more of a normalization type of constraint. Finally, the non-negative constraints are defined for the model.

Model (1) can easily be converted to a linear form as shown in model (2) below:

Model (2)

$$\begin{aligned} \max \quad & \sum_{r=1}^{v} a_r y_{rp} \\ \text{s.t.} \quad & \sum_{s=1}^{u} b_s x_{sp} = 1, \\ & \sum_{r=1}^{v} a_r y_{r^*} - \sum_{s=1}^{u} b_s x_{s^*} = 0, \\ & \sum_{r=1}^{v} a_r y_{ri} - \sum_{s=1}^{u} b_s x_{si} \leqslant 0 \quad \forall i, \\ & a_r, b_s \geqslant 0 \quad \forall r, s. \end{aligned}$$

Model (2) is solved for each vendor in obtaining the productivity scores. The model identifies input/output weights that not only maintain the maximum efficiency for the buyer set target, but also maximize the efficiency of the vendor being evaluated. In essence this model aids in identifying the strengths of the vendor, which are also the strengths of the target set by the buyer. Thus, a vendor that achieves a high efficiency score is considered to be good performer when matched against the buyer set targets.

The second part of the *max–min* approach involves the minimization of the vendor efficiency subject to the same set of constraints utilized in model (2). Model (3) demonstrates the minimization problem.

Model (3)

$$\begin{aligned} \min \quad & \sum_{r=1}^{v} a_r y_{rp} \\ \text{s.t.} \quad & \text{model (2) constraints.} \end{aligned}$$

Model (3) identifies input/output weights that not only maintain the maximum efficiency for the buyer set target, but also minimize the efficiency of the vendor being evaluated. In short, this model assists in identifying the weaknesses of the vendor, which are also the strengths of the target set by the buyer. Thus, a vendor that achieves a high efficiency score is said to be good performer.

We now present a statistical method that utilizes both these scores in identifying homogenous groups of vendors. Since the efficiency scores do not lend themselves to the assumption of normality, we utilize a non-parametric procedure.

5. Non-parametric statistical method: 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 on the test readers are encouraged to 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_a: At least one of the populations tends to yield larger observations that at least one of the other populations.

$$\text{Test statistic:} \quad T = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1),$$

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 $i = 1$ through k; and R_i is the sum of the ranks of observations in each group.

Decision rule: 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:

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

where

$$S^2 = \frac{1}{N-1} \left(\sum_{\text{all ranks}} R(X_{ij})^2 - N \frac{(N+1)^2}{4} \right),$$

$R(X_{ij})$ is the rank assigned to observation j in ith group; t value is the $(1-\alpha/2)$ quantile of t distribution with $N-k$ degrees of freedom. The α value used is the same as in the KW test.

6. Case illustration

A set of six vendors is considered in the evaluation process. The vendor data across multiple measures is derived from a study conducted by Weber and Desai (1996). The operational unit (buyer) considered in the case is a division of a *Fortune 500* pharmaceutical company, which is involved in the implementation of a JIT system. Management has considered product price, quality, and delivery as the three most important factors in evaluating alternative vendors. Price is represented on a per unit basis for each delivered item. Quality is represented as the percentage of shipped units that are rejected, and delivery is measured as the percentage of ordered units that are delayed. The data are shown in Table 2.

Our analysis utilized price as the input factor, and quality and delivery performance measures as the output factors. Price is considered as an input because it represents the amount paid by the buyer. Quality and delivery performance are treated as outputs since they represent the benefits derived by the buyer. Based on our model convention, higher values of outputs and lower values of inputs indicate desirable characteristics. In order to follow this convention we performed a linear scale transformation on the two output measures considered in the study. That is instead of using percentages of rejects and late deliveries for representing quality and delivery performance, we have transformed these numbers by subtracting from 100%. Thus, the transformed measures represent percentages of accepted items and on-time deliveries. Since large values of these measures indicate better levels of performance, it is consistent with our definition of outputs. Table 3 shows the vendor data after the aforementioned transformation.

The maximum efficiency scores were initially evaluated for all the six vendors in Table 3 by utilizing model (2). The ideal targets used in the model are obtained by selecting the best values in each of the three performance measures across all the vendors. Table 3 depicts these values under the heading 'Target', which are \$0.1881/unit for price and 100% for quality and delivery performance. Model (2) is run six times and the results from the respective evaluations are shown in Table 4 across the 'Max. eff.' row. It is evident from Table 4 that vendor 2 achieved the highest efficiency score of 0.992 followed by vendors 1, 4, 6, 5 and 3 with scores of 0.949, 0.904, 0.887, 0.868, and 0.853, respectively. These scores represent the maximum efficiencies obtained by each of the vendors when evaluated against the target measures set by the buyer. In evaluating these scores model (2) selects factor weights that make each of the six vendors look the best they can be while maintaining the target efficiency score at 1. Thus, in some sense

Table 2
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

P: price/unit; R: rejects; LD: late deliveries.

Table 3
Transformed vendor data

Variable	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6	Target
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**

P: price/unit; A: acceptance; OTD: on-time deliveries.

Table 4
Results of max–min evaluations

Efficiency	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6
Max. eff.	0.949	0.992	0.853	0.904	0.868	0.887
Min. eff.	0.913	0.930	0.853	0.885	0.861	0.862

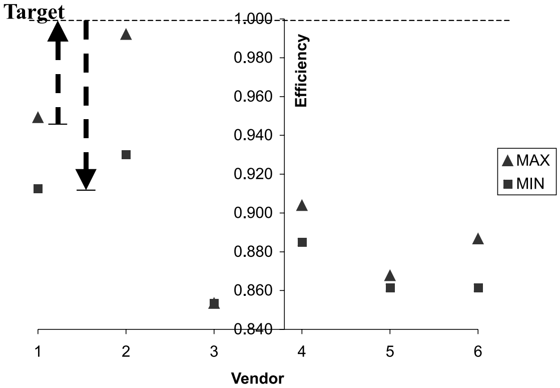

Fig. 1. Maximum and minimum efficiency scores by vendor.

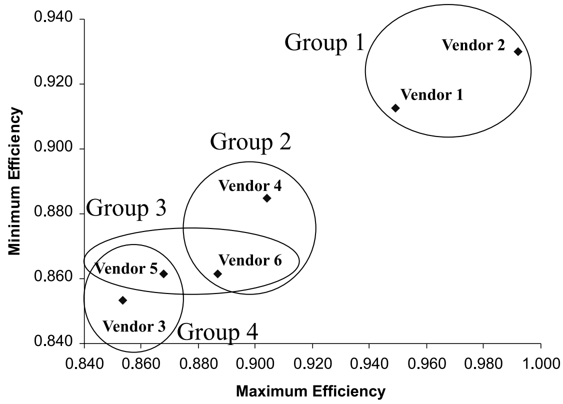

Fig. 2. Homogenous groups of vendors.

model (2) is a generous formulation that emphasizes on the strengths of each of the six vendors. The next step in the decision process involves the estimation of the minimum efficiency scores.

In order to obtain the minimum efficiency scores for each vendor, model (3) is applied to the data in Table 3. The results of the analysis are shown in Table 4 across 'Min. eff.' row. Based on these results, we can conclude that vendor 2 is again the best performer with a score of 0.930 followed by vendors 1, 4, 6, 5 and 3 with scores of 0.913, 0.885, 0.862, 0.861, and 0.853, respectively. Contrary to model (2), model (3) can be described as a selfish model that identifies factor weights that make each of the six vendors look their worst while maintaining the target efficiency score at 1. Thus, it emphasizes the weaknesses of each of the vendors. Fig. 1 effectively summarizes the results from both models. The concept behind the two models is visually depicted in Fig. 1 by considering vendor 1 as an example. The upward arrow corresponding with the maximum efficiency score of vendor 1 illustrates the model (2) evaluation by pulling the score towards the target, and the downward arrow illustrates the model (3) evaluation by pushing the score away from the target. The results of analyses from the two models provide performance variability measures that can be utilized for identifying homogenous groups of vendors.

The two efficiency scores corresponding to each vendor are utilized in performing the KW test. Since the test is non-parametric and is based on ranks, the efficiency scores in Table 4 are converted into ranks as shown in Table 5. The assignment of ranks was performed by starting with a rank of 1 for the lowest score, rank of 2 for the second lowest, so on. Average rank is assigned in the presence of ties. The null hypotheses for the test is rejected at an α value of 0.1 indicating that at least one of the vendors tends to yield larger efficiencies that at least one of the other vendors. We have conducted multiple comparisons and the results are depicted in Fig. 2.

It is evident from Fig. 2 that group 1 vendors, namely, vendors 1 and 2 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 vendors within a group. The buyer can utilize this information in an effective manner for vendor selection decisions. For

Table 5
Ranking of max–min evaluations

Efficiency	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6
Max. eff.	11	12	1.5	8	5	7
Min. eff.	9	10	1.5	6	3	4

Table 6
Vendor capacities and minimum order quantities represented in millions of units

Variable	Vendor 1	Vendor 2	Vendor 3	Vendor 4	Vendor 5	Vendor 6
Minimum order quantity	0.04	0.04	0.04	0.04	0.04	0.04
Capacity	2.4	0.36	2.783	3.0	2.966	2.5

Table 7
Order quantity allocations

Vendors	Demand (millions)	Order quantities (millions)
1 or 2 or both	$D \leqslant 2.76$	$V_1 \leqslant 2.4$, $V_2 \leqslant 0.36$, $V_1, V_2 \geqslant 0.04$ (if selected)
1, 2, and 4 or 6 or both	$2.76 < D \leqslant 8.26$	$V_1 = 2.4$, $V_2 = 0.36$, $V_4 \leqslant 3$, $V_6 \leqslant 2.5$, $V_4, V_6 \geqslant 0.04$ (if selected)
1, 2, 4, 6, and 3 or 5 or both	$8.76 < D \leqslant 14.509$	$V_1 = 2.4$, $V_2 = 0.36$, $V_4 = 3$, $V_6 = 2.5$, $V_3 \leqslant 2.783$, $V_5 \leqslant 2.966$, $V_3, V_5 \geqslant 0.04$ (if selected)

example, if the buyer is interested in selecting a single vendor then the optimal set from which to choose are vendors 1 and 2. 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 (Christopher et al., 1979).

Fig. 2 also clearly demonstrates that vendor 4 is significantly better than vendors 3 and 5, and vendor 6 is significantly better than vendor 3. This has important implications if the buyer is selecting multiple vendors to do business. Table 6 depicts the capacities and minimum order quantities of vendors and Table 7 allocates the order quantities by vendor in a lexicographical manner. It is evident from Table 7 that when the product demand is less than or equal to 2.76 million units vendors 1 or 2 or both can be selected depending on the demand requirements. These vendors are given preference over the remaining four vendors because of their superior performance as demonstrated in Fig. 2. If the product demand is greater than 2.76 million and less than or equal to 8.26 million units then vendors 1 and 2 are selected, and vendors 4 or 6 or both are also selected in meeting the demand requirements. Other results in Table 7 can be interpreted in a similar manner. However, in each case a vendor is selected the minimum order quantity level of 0.04 million units must be allocated.

7. Conclusions and extensions

This paper proposed a unique approach for vendor selection by incorporating performance variability into the evaluation process. The *max–min* approach for vendor selection presented in this paper allows for comprehensive evaluation of vendor performance by estimating both maximum and minimum efficiencies based on ideal targets set by the buyer. Another key element of this approach is that groups of homogenous vendors can be identified, which provides the buyer with effective alternative choices in making the final selection.

Some of the extensions to this research include the incorporation of buyer based relative preferences for the vendor attributes. This allows for more accurate evaluation and selection of vendors. However, an issue with such preferences is that they are often subjective in nature and the buyer must be astute in developing and utilizing such relationships as a part of the evaluation process. Another interesting extension would be to identify the areas and magnitude of improvements required for vendors in the lower ranking groups to move to the higher ranking groups. This would require investigating the best practices of the high performing vendor groups and utilizing them as targets for improvement. Also, a more comprehensive data analysis that considers several important inputs and outputs needs to be undertaken. For example, we have only utilized a single input measure in the analysis. Other measures that can be incorporated as potential inputs include costs associated with communicating and coordinating with vendors (this may vary depending on the compatibility of the communication infrastructure between the buyer and the vendor), transportation costs, and fixed costs. Similarly, output factors can include various flexibility measures associated with the vendor, such as customization, responding to volume changes, and so on.

Although we have defined and effectively incorporated a measure for performance variability in evaluating alternative vendors, future research is needed in identifying effective ways for incorporating variability in the individual vendor factors by considering the probability distributions for each of the attributes. In such a case, a series of model iterations may need to be performed in identifying vendors that consistently outperform other vendors in the set.

The application of this method in a real world setting needs to be further investigated. Some of the potential issues that managers may encounter are selection of appropriate input and output factors, number of factors, incorporation of managerial preferences into the evaluation process, and identification of buyer targets. Managers must carefully evaluate and select the factors that best represent their competitive priorities, goals, and objectives. The decision on number of factors to include in the analysis is also critical because if they are significantly larger than the number of vendors being evaluated then the discriminatory power of the model may come into question. The incorporation of actual managerial preferences will make the model application more robust and realistic, which could possibly be performed by bounding the input and output weights in the model. Finally, the identification of buyer targets is highly critical because of their impact on the decision making process.

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