Supplier Evaluation and Rationalization via Data Envelopment Analysis: An Empirical Examination

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SUMMARY

Strategic evaluation of supplier performance assists firms in improving their operations across a variety of dimensions. Specifically, it aids in supplier process improvement, which in turn enhances firm performance, allows for optimal allocation of resources for supplier development programs, and assists managers in restructuring their supplier network based on performance. In order to address these issues, this article proposes a methodology for effective supplier performance evaluation based on data envelopment analysis (DEA), a multi-factor productivity analysis technique. The efficiencies derived from the DEA model are utilized in conjunction with managerial performance ratings in identifying supplier clusters, which are categorized into high performers and efficient (HE), high performers and inefficient (HI), low performers and efficient (LE), and low performers and inefficient (LI). Effective benchmarks from the HE cluster are identified for improving the operations of suppliers in the HI, LE, and LI clusters. Finally, managerial insights and implications from the study are discussed.

EXAM ALERT Modules 1 & 2

INTRODUCTION

Supplier evaluation is an area that is continuing to receive significant attention in the literature. Effective evaluation and selection of suppliers is considered to be one of the critical responsibilities of purchasing managers. The evaluation process often involves the simultaneous consideration of several important supplier performance attributes that include price, delivery leadtimes, and quality. The criticality of supplier selection is evident from its impact on firm performance and, more specifically, on final product attributes such as cost, design, manufacturability, quality, and so forth (Burt 1984; Burton 1988). Several researchers have emphasized the importance of the supplier evaluation process (Banker and Khosla 1995; Burt 1984; Burton 1988; Dickson 1966; Dobler et al. 1990). More recently, Banker and Khosla (1995) have identified the supplier evaluation issue as an important decision area in operations management.

The motivation for this research primarily stems from three critical issues associated with the supplier evaluation problem in industry. First, supplier evaluation techniques utilized in industry are mostly based on simple, weighted scoring methods that primarily rely on subjective judgments and opinions of purchasing managers or staff involved in the supplier evaluation process. While this approach has its advantages (e.g., the experience and contextual knowledge of purchasing staff is used in evaluating suppliers), one of its limitations is that the weights for various supplier performance attributes used in the weighted, additive scoring model are arbitrarily set. Thus, the final ranking of suppliers is heavily dependent on the assignment of these weights, which are often difficult to specify in an objective manner. Two problems are encountered in real settings. Supplier evaluations are usually done in a group setting. In group evaluations, although it is relatively easy to get concurrence on the importance rankings for the first few supplier performance attributes, it is difficult to reach consensus beyond the first few attributes of performance. The consensus decisions will have to be revisited as the group composition changes due to resignations and job reassignments. A more balanced approach that effectively integrates managerial judgments with objective methods can significantly improve the *consistency* of the decision-making process.

Second, in most firms, the evaluation process is based only on supplier performance outcomes such as price, quality, and delivery. While these outcome measures are important in evaluating supplier performance, they only deal with part of the supplier evaluation problem. For example, a supplier may be achieving high levels of performance by utilizing enormous amounts of resources and thus be an inefficient performer. From a strategic perspective, firms may be more inclined to develop long-term relationships with suppliers that are both high performers and highly efficient. This is because such suppliers are more likely to have the infrastructure and organizational capabilities in place to effectively meet the changing demands of the buying firm in the long run. Thus, in order to comprehensively evaluate the performance of suppliers, it is also necessary to consider the type and amount of input resources (i.e., practices relating to the technical, managerial, and operational capabilities) utilized in generating performance outcomes. Therefore, a measure of *efficiency* in addition to performance solely based on outputs (e.g., cost, quality, and delivery performance) is warranted.

Third, in order for firms to improve their decision-making effectiveness relating to supplier development efforts through supplier process improvement and benchmarking, effective deployment of scarce resources for supplier development programs, and restructuring of the supply base and reallocation of order quantities among suppliers, an objective and comprehensive method that can be consistently applied across all suppliers is needed.

The methodology discussed in this article addresses the above issues in developing a framework for effective supplier evaluation and rationalization. This article utilizes DEA, a nonparametric, multi-factor productivity analysis tool, which effectively considers multiple input and output measures in evaluating relative efficiencies. DEA does not require *a priori* assignment of weights to performance dimensions utilized in the evaluation process. It allows for identifying appropriate benchmarks for poorly performing suppliers that are potentially important to the buying firm in the long run.

LITERATURE REVIEW

Literature in the area of supplier evaluation has been primarily in three methodological streams: conceptual, empirical, and modeling. Since this article approaches the problem mainly from a modeling perspective, the detailed discussion is limited to existing modeling research pertaining to supplier evaluation.

Literature in supplier evaluation dates back to the 1960s, when Dickson (1966) studied the importance of supplier evaluation criteria for industrial purchasing managers. This study presented over 20 supplier attributes that managers consider in supplier evaluation. Based on the data from 170 purchasing managers, Dickson concluded that cost, quality, and delivery performance were the three most important criteria in supplier evaluation. Subsequent work in this area has been mostly conceptual and empirical in nature. Included in the stream of conceptual research are works by Hahn et al. (1983), Jackson (1983), Kraljic (1983), Browning et al. (1983), Ansari and Modarress (1986), Treleven (1987), Burton (1988), Bernard (1989), Benton and Krajeski (1990), and Ellram (1990). These articles primarily emphasized the strategic importance of the supplier evaluation/selection process and the trade-off among supplier performance attributes such as cost, quality, and delivery.

Several researchers empirically studied the relative importance of various supplier attributes (Cardozo and Cagley 1971; Monczka et al. 1981; Moriarity 1983; Woodside and Vyas 1987; Chapman and Carter 1990; Tullous and Munson 1991; Weber et al. 1991). These works focused on identifying the relative importance that purchasing managers placed on various performance criteria such as price, quality, and delivery times. Cardozo and Cagley (1971) evaluated various supplier attributes and concluded that the relative importance assigned to an attribute primarily depended on the type of risk involved in a specific purchasing situation. Woodside and Vyas (1987) found that management was generally willing to pay 4 percent to 6 percent higher than the lowest acceptable bid for superior product performance. Based on a review of 74 articles on supplier evaluation, Weber et al. (1991) concluded that quality was the most important factor, followed by delivery performance and cost.

In conclusion, these studies mainly stress that supplier selection decisions must not be based solely on least-cost criteria and that other important factors such as quality and delivery performance must be incorporated into the decisionmaking process. While research relating to the conceptual and empirical work in supplier evaluation is numerous, these studies have not specifically developed methods for effective supplier evaluation.

SUPPLIER EVALUATION MODELS

Analytical models for supplier evaluation have ranged from simple weighted scoring models to complex mathematical programming approaches. While early approaches failed to consider multiple supplier performance factors, more recent models and techniques have incorporated several important factors into the evaluation process. In a comprehensive review of supplier selection methods, Weber et al. (1991) reported that 47 of the 74 articles in the review utilized multiple criteria. Also, the ongoing emphasis on manufacturing strategies such as Just-In-Time (JIT) places increased importance on multiple supplier performance attributes such as price, product quality, and delivery (Chapman 1989; Chapman and Carter 1990).

The limitations of traditional supplier evaluation methods such as categorical, weighted point, and cost ratio approaches are well known in the literature (see Willis et al. 1993 for a comprehensive review). The primary issues associated with categorical and weighted point methods are in identifying appropriate weights in computing a composite index for supplier performance. Similarly, the cost ratio approach, which evaluates the cost of each factor as a percentage of total purchases for the supplier, requires the development of a sophisticated cost accounting system.

Several techniques for supplier evaluation have been proposed in the literature. Some of these methodologies include weighted linear model approaches (Lamberson et al. 1976; Timmerman 1986; Wind and Robinson 1968), linear programming models (Pan 1989; Turner 1988), mixed integer programming (Weber and Current 1993), clustering methods on performance factors and supplier's technical capabilities (Hinkle et al. 1969), analytical hierarchy process (Barbarosoglu and Yazgac 1997; Narasimhan 1983; Hill and Nydick 1992), 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), discreet choice analysis experiments (Verma and Pullman 1998), and neural networks (Siying et al. 1997).

A majority of the techniques discussed above utilize multiple supplier criteria in the evaluation process. While these methodologies have their own advantages under specific conditions, some aspects of these techniques and models that need more attention include deriving appropriate weights for supplier performance attributes, the "output" oriented nature of the traditional methods as discussed earlier, and identifying potential benchmarks for improving the operations of poorly performing suppliers.

More recently, DEA was utilized as a supplier evaluation/monitoring tool in a few studies. Included in this stream are works by Kleinsorge et al. (1992), Weber and Desai (1996), and Weber et al. (1998). Kleinsorge et al. (1992) applied a DEA model for continuous performance monitoring of a single supplier over time using multiple input and output variables. Their study specifically did not address issues relating to supplier selection, supplier benchmarking, supplier network optimization, and supplier development initiatives. The articles by Weber and Desai (1996) and Weber et al. (1998) have addressed the issue of supplier selection and negotiation. However, the DEA models used in their studies are in a sense only input oriented, i.e., they did not explicitly consider any output variables except for a constant, one unit of product as output. As discussed earlier, in order to obtain a comprehensive evaluation of supplier performance, the use of both input and output variables is important.

Given the contribution of the existing DEA models for supplier evaluation, the methodology in this study provides a unique application of DEA for supplier evaluation and rationalization. The DEA results are used in conjunction with managerial performance ratings in clustering suppliers into four different classifications and provide benchmarks for improving poorly performing suppliers. The analysis and results have important managerial implications for organizations that are involved in supplier process improvement, for optimal allocation of resources for supplier development programs, and for restructuring the supplier network.

SUPPLIER EFFICIENCY EVALUATION MODEL

The DEA model utilized for supplier evaluation in this study is based on the work by Charnes et al. (1978). The model is referred to as the CCR (Charnes, Cooper, and Rhodes) model in the DEA literature, which is based on the assumption of constant returns to scale. Since the model is well established and extensively applied in the literature, its discussion is limited in this article. A brief description of the model is provided in the Appendix. For more details on model development, please see the indicated Charnes et al. (1978).

FACTOR SELECTION AND DATA ACQUISITION PROCESS

In order to maintain the confidentiality of the telecommunications company in which this study was carried out, it is referred to as Company X throughout the article. Company X is a large multinational corporation in the telecommunications industry, which operates production plants, research and development facilities, and distribution systems on a global basis. It specializes in design, production, and marketing of communication systems.

The company's objectives in procurement and supply management included improving the quality of purchased products/services, reducing leadtime and improving on-time delivery, developing long-term relationships with key suppliers, and securing global competitive pricing. In order to achieve these objectives, Company X has placed emphasis on improving supplier reliability by stressing on-time deliveries and minimal inspection of purchased components, continuous evaluation and feedback of suppliers' performance in order to improve quality, simplification of the purchasing process to optimize the total cost of ownership, and decreasing the supplier base by eliminating those suppliers that do not meet standards. This research specifically addresses performance evaluation and process improvement of Company X's suppliers in order to achieve procurement and supply management objectives.

The initial step in the factor selection and data acquisition process was to define the input and output dimensions to be utilized in the DEA model. This was done through several focus group sessions with management at Company X. Due to the decentralized nature of Company X's supply management system, these focus group sessions required planned coordination efforts. In the initial meeting, the specific product line to be examined was selected. In the subsequent meetings, specific input and output dimensions to be used in the analysis were discussed and a final set of dimensions on which to collect data was compiled. An important consideration in this exercise was the ease with which data could be collected. It was decided early in the study that the data collection effort had to be kept to an acceptable minimum.

Following the identification of the input and output dimensions, two separate questionnaires were constructed — one to assess supplier capabilities (comprising the input dimensions of DEA) and the other to assess supplier performance (comprising the output dimensions of DEA). The questionnaires utilized multiple items to measure the input and output dimensions. The individual items were measured on a binary scale (yes/no responses) to afford maximum objectivity and accuracy of survey responses. The questionnaires were reviewed by Company X's management and revised to reflect their comments and suggestions.

The Supplier Capability Questionnaire was sent out to the suppliers and the Supplier Performance Assessment Questionnaire was sent out to the purchasing staff of Company X. The returned questionnaires were coded to the project staff for data coding, entry, and analysis. The questionnaires were coded and the data were entered into an Excel worksheet.

To test the hypothesis that the questionnaires might have contained difficult or ambiguous questions, an analysis of responses to individual items was carried out by examining the proportion of sample with missing data on individual items. The analysis showed that there was no evidence to support the hypothesis, confirming that the questionnaire was acceptable (i.e., not difficult to fill out) as a data collection instrument. The following section describes the questionnaires and subsequent sections discuss the data analysis and managerial implications of the study.

Supplier Capability Questionnaire

For the purpose of the DEA evaluation, items on the Supplier Capability Questionnaire were grouped into the following categories, constituting the input variables:

- Quality management practices and systems (QMP)
- Documentation and self-audit (SA)
- Process/manufacturing capability (PMC)
- Management of the firm (MF)
- Design and development capabilities (DD)
- Cost reduction capability (CR)

These six categories were measured with a composite score between 0 and 1. The score was computed as the proportion of "yes" answers to individual questionnaire items in the category. "Blank" and "not applicable" responses were not considered in the calculation of the proportion of the "yes" responses.

Supplier Performance Assessment Questionnaire

Items on the Supplier Performance Assessment Questionnaire were grouped into the following categories, constituting the output variables:

- Quality
- Price
- Delivery
- Cost reduction performance (CRP)
- Other

These categories were also measured with a composite score between 0 and 1. To compute the score, the proportion of "yes" answers was evaluated in each category to provide an "objective" measure of the variables in the category. Table I shows the scaled composite scores for the input and output variables for the 23 suppliers. Although the actual composite scores were utilized in the DEA evaluations, in order to maintain confidentiality, the data were have scaled by dividing each factor by its factor mean score.

For the categories in which "subjective" questions were included, the answers to the questions were normalized to a value between 0 and 1, and then combined with the responses to the "objective" measures on items belonging to the category. This combination was performed by taking a weighted average of the "subjective" and "objective" measures, with 0.4 and 0.6, respectively, as weights for the two, based on the managerial input from Company X.

DATA ANALYSIS

Questionnaires with data from 45 suppliers were returned for the analysis. A total of 34 Supplier Performance Assessment Questionnaires and 35 Supplier Capability Questionnaires contained complete data. Data on both questionnaires were available for 23 suppliers. The CCR DEA model evaluations for the 23 suppliers were conducted and the results are shown in Table II. It can be seen from the analysis that Suppliers 3, 5, 6, 10, 11, 16, 20, 24, 31, 33, and 35 are efficient with scores of 1.000. The remaining 12 suppliers are inefficient with scores of less than 1.000. Table II also presents the performance scores of each of the 23 suppliers. These scores were evaluated by using a weighted average of performance measures for each supplier. The weights were derived from managerial preferences from Company X. The performance score was intended to reflect the

Table I

SCALED COMPOSITE SCORES FOR SUPPLIER INPUTS AND OUTPUTS

Supplier #	QMP	SA	PMC	Mgt.	DD	CR	Quality	Price	Delivery	CRP	Other
2	0.9662	0.9742	1.0385	1.0808	1.1417	0.7839	0.6211	0.8922	0.1284	1.2107	0.6359
3	0.7054	1.0438	0.7500	0.8782	0.0000	0.8750	0.6932	0.8922	0.3855	0.0000	0.3179
5	0.5611	0.8947	0.7789	0.7205	0.8372	0.7404	1.0205	0.4341	1.5420	0.0000	1.2719
6	1.1272	1.0438	0.9520	0.9607	0.9661	1.1402	1.6639	1.1333	1.5420	1.2107	1.8019
9	1.1272	1.0438	1.1251	1.0808	1.2560	1.2115	0.9983	1.3503	1.1565	1.2107	0.9540
10	0.9877	1.0438	0.9376	1.0808	1.0466	0.9422	1.0426	1.3263	1.7990	2.4214	1.2719
11	0.8051	0.8351	1.0385	0.9607	1.2560	1.0768	1.2201	1.2056	0.7710	2.4214	1.2719
12	1.1809	1.0438	1.1251	1.0208	1.0627	1.0096	0.8429	1.1333	0.6424	1.2107	0.8479
13	1.2346	1.0438	1.1251	1.0808	1.2560	1.1442	0.6433	0.8922	0.3855	0.0000	0.5299
16	0.5904	1.0438	0.6058	0.7629	0.5796	0.4038	1.4419	0.4341	1.4135	0.0000	1.2719
17	0.8642	0.8118	0.8182	0.9536	0.9661	0.8076	0.4215	0.8922	1.0279	0.0000	0.8479
20	0.6441	0.8351	1.0227	1.0208	0.9661	1.0768	1.0205	1.3263	0.7710	1.2107	0.7418
22	1.2346	1.0438	1.1251	1.0808	1.2560	1.2115	0.5546	1.1092	1.0279	1.2107	1.1660
23	1.0662	1.0438	1.1251	1.0808	1.1593	1.2115	0.8208	0.8922	0.8994	1.2107	0.8479
24	1.0100	1.0438	0.8654	1.0208	0.7322	0.6815	1.2423	1.5674	1.4135	2.4214	1.2719
25	0.8978	0.9742	1.0385	1.0208	0.9420	0.8076	1.0205	0.8922	0.3855	0.0000	0.4240
26	1.1272	0.9742	1.0385	1.0208	1.2560	1.0768	1.0205	0.8681	0.7710	0.0000	0.5299
28	1.1809	1.0438	1.1251	1.0808	1.2560	1.2115	1.2201	0.2411	0.0000	0.0000	0.4240
29	1.0735	1.0438	1.1251	0.9007	1.1593	0.9422	1.1647	0.8922	1.4135	1.2107	1.0599
31	1.0735	1.0438	1.1251	1.0808	0.6762	1.1442	0.8429	1.0550	1.4135	1.2107	1.4839
32	1.2346	1.0438	1.1251	1.0133	1.2560	1.2115	0.7764	0.8922	1.0279	0.0000	0.9540
33	1.2346	1.0438	0.9520	1.0808	1.0466	1.2115	1.4642	1.3263	1.7990	2.4214	1.4839
35	1.0735	1.0438	1.0385	1.0172	0.8695	1.0768	1.2423	1.3503	1.2849	2.4214	1.5900

positioning/evaluation of a supplier on criteria that relate to the long-term, strategic issues of interest to Company X such as business risk associated with sourcing from a supplier, strategic fit with Company X's plans for future markets/products and customers, and Company X's plans for business growth worldwide. Table II depicts the suppliers on a performance-efficiency score grid. For purposes of classification, a performance score of 0.5 or higher was deemed "high performance." This cutoff value can, of course, be changed to a different value as appropriate. The last column in Table II shows the following classifications:

- HE: High Performance and Efficient
- HI: High Performance and Inefficient
- LE: Low Performance and Efficient
- LI: Low Performance and Inefficient

Table III shows the DEA-based benchmarks for inefficient suppliers. For example, Supplier 2 can utilize Suppliers 20 and 24 as possible benchmarks for improvement. In DEA, benchmarks are obtained by identifying the reference set of units that dominate the unit under consideration. An efficient unit that appears most frequently in the reference sets is considered to be a superior performer. In this study, for Suppliers 24, 6, and 33, that occurred 11, seven, and five times, respectively. Accordingly, these suppliers are considered to be excelling in performance. Although the efficient suppliers, such as Supplier 3, do not have specific benchmarks, other efficient suppliers, such as Supplier 24, that achieve an efficiency score of 1.000 when evaluated with the input/output weights of Supplier 3 are considered to be in a peer group. This insight allows effective benchmarking to be performed later in the analysis.

Figure 1 shows the four classifications of suppliers: HE, LI, LE, and HI. HE suppliers are the star performers, and these are the type of suppliers with which Company X needs to develop a long-term relationship. LI suppliers are candidates for "pruning." LE suppliers are candidates for further development. It is here that Company X must invest in terms of supplier development programs and initiatives for making this cluster of suppliers improve their performance. Finally, HI suppliers represent potential long-term risk in that they are performing satisfactorily now, but most likely do not have a structure and organizational capabilities that can sustain performance in the future.

Table II

SUPPLIER CLASSIFICATION BASED ON DEA EFFICIENCY AND PERFORMANCE SCORES

Supplier #	CCR Efficiency	Performance Score	Classification
2	0.602	0.320	LI
3	1.000	0.255	LE
5	1.000	0.464	LE
6	1.000	0.741	HE
9	0.855	0.556	HI
10	1.000	0.725	HE
11	1.000	0.627	HE
12	0.723	0.449	LI
13	0.562	0.272	LI
16	1.000	0.501	HE
17	0.805	0.345	LI
20	1.000	0.494	LE
22	0.773	0.485	LI
23	0.609	0.446	LI
24	1.000	0.736	HE
25	0.764	0.306	LI
26	0.702	0.354	LI
28	0.733	0.218	LI
29	0.904	0.563	HI
31	1.000	0.587	HE
32	0.658	0.399	LI
33	1.000	0.798	HE
35	1.000	0.732	HE

Table III

DEA BENCHMARKS FOR INEFFICIENT SUPPLIERS

Supplier #	Benchmark Suppliers
2	20, 24
3	—
5	—
6	—
9	20, 24
10	—
11	—
12	24
13	20, 4
16	—
17	10, 24, 33
20	—
22	6, 11, 24, 33
23	6, 11, 24, 33
24	—
25	6, 11, 16, 24
26	6, 11, 24
28	6
29	5, 6, 16, 24, 33
31	—
32	6, 24, 33
33	—
35	—

From the perspective of improving the performance of suppliers, the peer groups (for benchmarking purposes) obtained from the DEA model shown as connecting lines in Figure 1 can be examined. For example, Supplier 2 should use Supplier 24 to benchmark itself for performance improvement. In situations where there is more than one peer group member for a supplier, the one with the higher performance score should be selected. All of the other peer group relationships can be similarly interpreted. One other insight that needs to be noted here is the identification of benchmarks for the LE suppliers. Since these suppliers are already efficient, DEA does not provide benchmarks for improvement. As discussed earlier, in cases such as this the corresponding peer group efficient supplier with the highest performance score is used as the benchmark. For example, Supplier 5 needs to utilize Supplier 33 to benchmark itself for improving performance.

MANAGERIAL IMPLICATIONS OF THE STUDY

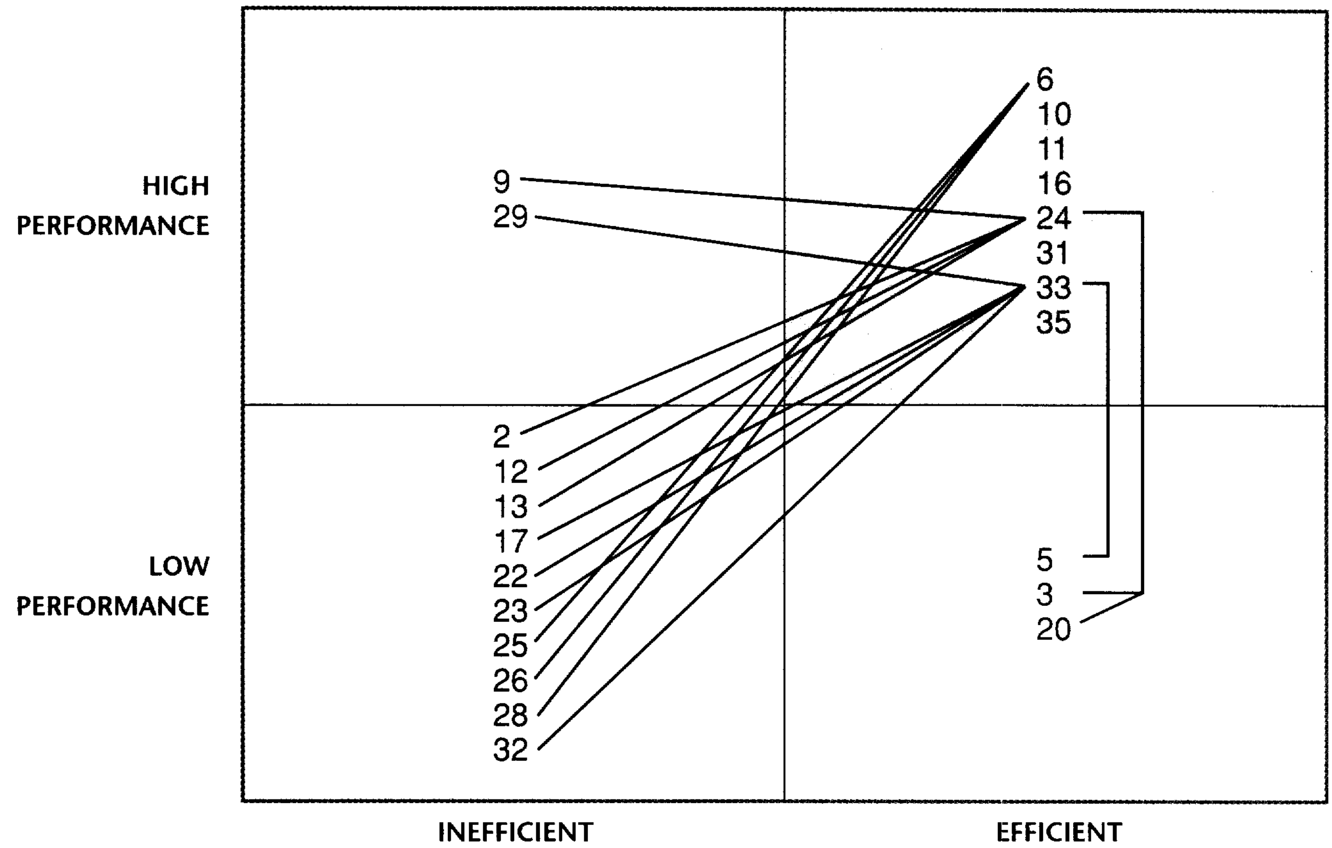
The study performed in this research has important managerial implications. The methodology proposed in this article can be utilized to make critical managerial decisions such as optimization of the supplier network, effective allocation of resources for supplier development programs and initiatives, and initiation of benchmarking and reengineering programs. The following conclusions and recommendations that emerged from this study are currently under consideration for implementation by Company X.

In optimizing the supplier network, managers can utilize the classifications suggested in this study to reduce their supply base, by pruning suppliers in the LI cluster or by allocating less business to these suppliers. Also, management can provide these suppliers with possible benchmarks for improvement and set expectations for target times for matching them. This is one of the critical managerial uses of the proposed methodology.

Effective allocation of resources for supplier development programs is often a difficult decision faced by managers. The methodology in the research suggests that the LE suppliers are the primary candidates for such programs. These suppliers are efficient and have the infrastructure to become high performers with allocation of resources.

Figure 1

CLASSIFICATION AND BENCHMARKS FOR SUPPLIERS BASED ON PERFORMANCE AND EFFICIENCY



Cross-functional teams from Company X can assist LE suppliers to achieve this transformation through supplier development initiatives.

Benchmarking is the initial step that firms must undertake before being involved in business process reengineering and improvement strategies (Camp 1989, 1995). Multidimensional benchmarking assists firms in moving from where they are to where they should be. The proposed methodology provides useful targets for suppliers in making this transition and identifies a peer group of efficient firms against which to benchmark themselves. The actual improvement process may involve identifying the operating practices and procedures of the benchmark suppliers and engaging in reengineering programs.

This methodology is applicable for any organization involved in supplier evaluation and rationalization. The critical steps of the methodology that organizations should follow are:

1. Define and measure context-specific supplier capabilities (i.e., input dimensions) to be considered, which include technical, managerial, and operational capabilities
2. Define and measure relevant supplier performance dimensions (i.e., output dimensions) to be considered
3. Evaluate supplier performance using DEA
4. Develop composite performance score reflecting "strategic fit" for suppliers
5. Map each supplier into HE, HI, LE, or LI clusters in the efficiency-performance grid
6. Identify benchmarks for improving inefficient suppliers
7. Evaluate each cluster to rationalize suppliers and optimally allocate resources to supplier development initiatives

CONCLUSIONS AND EXTENSIONS

This article has proposed a simple framework for supplier evaluation and rationalization. The analysis is based on a DEA model that allows for incorporation of multiple supplier inputs and outputs in determining the relative efficiencies. The efficiency scores in combination with the performance scores are utilized in classifying suppliers into four categories. Benchmarks are provided for improving the operations of poorly performing suppliers. Several interesting and useful managerial insights and implications from the study are discussed.

There are several advantages to this approach. The DEA score is a surrogate for "overall competence and capability" of a supplier, which cannot be easily and cost-effectively discerned through supplier audits. To gather, analyze, and evaluate data on suppliers using audits is expensive (since most supplier audits are done by an evaluation team) and time-consuming (in that each supplier audit could take several weeks to complete). Depending on the number of suppliers and the geographical dispersion of suppliers, the cost and time requirements can be prohibitively high. The methodology proposed in this article overcomes some of these difficulties, allowing firms to gather useful data cost-effectively and swiftly. Also, since multiple dimensions are simultaneously considered in evaluating the overall competence of a supplier, it is more robust and comprehensive than any of the typical productivity ratios commonly used in industry.

Another advantage of this approach is in identifying strategically important suppliers. The performance-outcome-based evaluation methods are based on evaluating "point-in-time" data in that the data are a snapshot of the supplier's performance in time. In evaluating suppliers from a strategic perspective, it can be argued that evaluations based on inherent competence and capability are likely to be more comprehensive. That is, firms with high efficiency scores are likely to sustain a high level of capabilities and therefore be better candidates for inclusion in an optimized supply base.

A variety of extensions to this work can be undertaken. In this analysis, the DEA model allowed for complete weight flexibility. In situations where some of the measures are likely to be more important than the others, DEA allows for restricting factor weights through linear constraints. These linear constraints represent ranges for relative preferences among factors based on managerial input. Such an analysis enables effective incorporation of managerial input into the DEA evaluations.

Although the input side of the DEA model was considered somewhat comprehensively, the output measures might bear reexamination. It should be noted that although the input and output dimensions considered in this article are generally useful, they are context specific. Also, in a specific application of this methodology, if in fact the set of inefficient suppliers is deemed an unacceptable result by management, the output dimensions of DEA must be reexamined for relevant but missing dimensions, which might cause them to be inefficient. A reexamination of the proposed methodology along these lines would yield additional insights and lead to a better evaluation of the DEA approach to supplier evaluation and rationalization.

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Appendix A

DATA ENVELOPMENT ANALYSIS

DEA is a nonparametric multi-factor productivity analysis model that evaluates the relative efficiencies of a homogenous set of decisionmaking units in the presence of multiple input and output factors. A unit with an efficiency score of 1 is considered to be efficient and a score of less than 1 indicates that it is inefficient. Model (1) shows the CCR model (Charnes et al. 1978). The model is run n times, where n represents the number of decision-making units, in determining the efficiency scores of all the units. Each unit is allowed to select optimal weights that maximize its efficiency (ratio of weighted output to weighted input), but at the same time the efficiencies of all the units in the set when evaluated with these weights are prevented from exceeding a value of 1.

Model 1

$$\max \sum_{k=1}^{s} v_k y_{kp}$$

$$s.t \quad \sum_{j=1}^{m} u_j x_{jp} = 1$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} = 1 \leq 0, \quad \forall i$$

$$v_k, u_j \geq 0 \quad \forall k, j$$

where: p is the unit being evaluated; s represents the number of outputs; m represents the number of inputs; y_{ki} is the amount of output k provided by unit i; x_{ji} is the amount of input j used by unit i; v_k and u_j are the weights given to output k and input j, respectively.

For every inefficient unit, DEA identifies a set of efficient units that can be utilized as benchmarks for improvement, which can more easily be obtained by utilizing the envelopment side of Model (1) shown as Model (2) below.

Model 2

$$\min \quad \theta$$

$$s.t \quad \sum_{i} \lambda_i x_{ji} \leq \theta x_{jp} \quad \forall j$$

$$\sum_{i} \lambda_i y_{ki} \geq y_{kp} \quad \forall k$$

$$\lambda_i \geq 0 \quad \forall i$$

where: θ represents the efficiency score of unit p; λs represent the dual variables that identify the benchmarks for inefficient units.