A HIERARCHICAL VENDOR SELECTION OPTIMIZATION TECHNIQUE FOR MULTIPLE SOURCING

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Abstract: The paper addresses a crucial objective of the strategic function of purchasing in supply chains, i.e., vendor rating, proposing a hierarchical model for supplier business intelligence. A three-level optimization process for supplier selection in a multiple sourcing strategy context is proposed. First, the Data Envelopment Analysis, the most widespread method for supplier selection, is used to evaluate the efficiency of suppliers. Second, the well-known Analytic Hierarchy Process is applied to rank the efficient suppliers given by the previous step. Third, a linear programming problem is solved to find the quantities to order from each efficient supplier. We show the model effectiveness on a simulated case study of a C class component.

1 INTRODUCTION

A Supply Chain (SC) is a business network interconnecting independent manufacturing and logistics companies that perform critical functions in the order fulfilment process (Dotoli et al., 2006). The SC configuration is essential to pursue a competitive advantage and meet the market demand. This paper focuses on one of the strategic purchasing function tasks in a private SC, i.e., vendor ranking (Costantino et al., 2009). Vendor rating systems identify top suppliers, i.e., the candidate partners that are best equipped to meet the customer's expected level of performance, and check them periodically. Therefore, vendor selection is a multi-objective decision problem, including conflicting objectives such as, besides the obvious goal of (low) price, quality, quantity, delivery, performance, capacity, communication, service, geographical location etc. (Degraeve et al., 2000).

Numerous multi-criteria decision making approaches have been suggested to solve the vendor evaluation and selection problem and, among these, individual approaches and integrated ones can be distinguished. The most important individual methods are: the Data Envelopment Analysis (DEA), mathematical programming, the Analytic Hierarchy Process (AHP), case-based reasoning, fuzzy decision making, genetic algorithms and many more. The so-called integrated approaches join together different techniques (e.g., integrated AHP, DEA, and artificial neural networks, integrated AHP and goal programming, etc.). Individual approaches are more popular than integrated ones, with the most widespread individual technique being DEA, due to its robustness (Ho et al. 2010) and its ability to be implemented also considering qualitative criteria: as an example, Talluri et al. (2006) extend the classical DEA technique considering risk evaluation. However, DEA presents the drawback that its efficient alternatives are by definition equally optimal and no difference can be singled out with respect to their different effectiveness.

In the private sector, the buyer can choose between a single or multiple sourcing approach. Single sourcing is defined as the fulfilment of all corporate requirements for a particular product by a selected supplier. On the other hand, multiple sourcing is the splitting of an order among multiple sellers, i.e., the company has two (dual sourcing) or

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more suppliers for the same component. Obviously, each solution presents advantages and drawbacks.

In this paper we propose a hierarchical strategy for optimal supplier evaluation and selection in multiple sourcing supplies based on three levels. First, we use the well-known DEA method to evaluate the weights of input and output criteria and divide suppliers into two categories: efficient and inefficient ones. Second, we apply the widespread decision making AHP technique (Saaty, 1990) to rank the efficient alternatives and select the effective ones. AHP is a multi-objective decision technique in which all the elements of the decision problem (overall goal, criteria, alternatives) are arranged in a hierarchical structure and objectives are of varying degrees of importance. Although in many cases optimization methods lead to similar results, here we select AHP because it relies on pairwise comparisons of the solutions, providing an approach to rank alternatives based on their reciprocal assessment. Third, after ranking the efficient solutions and identifying the most effective ones, a linear programming problem is solved to calculate the quantities of product to require from each effective supplier in the multiple sourcing context. Summing up, we provide a decision support tool for supplier business intelligence, to rank vendors and provide the buyer with a simple instrument to determine the quantities to order from each effective supplier in a multiple sourcing strategy context.

2 THE HIERARCHICAL SUPPLIER SELECTION TECHNIQUE

A vendor selection problem is defined by a set of bidding suppliers $S=\{s_1,s_2,.....,s_F\}$ and a set of conflicting criteria $C=\{c_1,c_2,.....,c_n\}$, according to which vendors have to be ranked. The criterion set is partitioned as $C=C_I \cup C_O$, with $C_I=\{c_1,c_2,.....,c_H\}$, $C_O=\{c_{H+1},c_{H+2},.....,c_{H+K}\}$, and $H+K=n$ respectively representing the input and output criteria sets, and the criteria number.

The input criteria are defined as the supplier attributes considered before the supply takes place (e.g., price, geographical distance of the supplier, ICT integration, etc.) while the output criteria are connected to the supplier once the goods arrive at the firm (e.g., quality, reliability, lead time, etc.). Figure 1 shows the presented hierarchical integrated approach to determine effective suppliers and the requested product quantities.

2.1 The First Level of the Hierarchical Optimization - the DEA Method

The first level of the supplier selection approach in Fig. 1 employs the Data Envelopment Analysis (DEA) (Charnes et al., 1978), a linear programming-based technique for determining the efficiency of different decision making units. As regards the application of DEA to supplier selection, the strength of this technique is the distinction between input and output performance measures. Input performance is given by the amount of resource used by the vendor to carry out the supply process (for instance, the purchasing price), while output parameters express how good is the service provided by the suppliers to the buyer (examples for these are the quality of purchased product or the timeliness of deliveries).

The efficiency of supplier $s_f \in S$ is defined as:

$$E_f=\frac{\sum_{k=1}^{K} u_k \cdot y_{kf}}{\sum_{h=1}^{H} v_h \cdot x_{hf}} \quad \text{with } f=1,\ldots,F, \qquad (1)$$

where y_{kf} (x_{hf}) is the k-th (h-th) output (input) performance for the f-th actor and u_k (v_h) its weight.

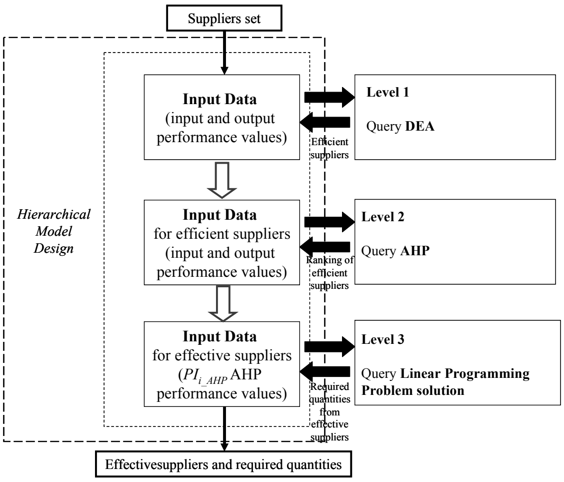

Figure 1: The hierarchical supplier selection approach.

In the DEA method, the efficiency of each actor is obtained by determining the set of coefficients u_k and v_h which maximizes this value, taking into account that for each actor it holds by definition

$E_f \leq 1$. Hence, the measure of supplier efficiency can be obtained by solving the following optimization problem for each considered vendor:

$$\max E_f \quad \text{with } f=1,\ldots,F, \tag{2}$$

subject to (s.t.):

$$\frac{\sum_{k=1}^{K} u_k \cdot y_{kj}}{\sum_{h=1}^{H} v_h \cdot x_{hj}} \leq 1 \quad \text{with } j=1,\ldots,F, \tag{3}$$

$$u_k, v_h \geq 0 \quad \text{for } k=1,\ldots,K \text{ and } h=1,\ldots,H. \tag{4}$$

Problem (2)-(3)-(4) can be linearized by minimizing the inputs and keeping fixed output values (input-oriented method) or maximizing the outputs and keeping fixed input values (output-oriented method) (Wang and Chin, 2010). Using the latter solution, the problem is modified as follows:

$$\max E_f = \sum_{k=1}^{K} u_k \cdot y_{kf} \quad \text{with } f=1,\ldots,F, \tag{5}$$

s.t.:

$$\sum_{k=1}^{K} u_k \cdot y_{kj} - \sum_{h=1}^{H} v_h \cdot x_{hj} \leq 0 \quad \text{with } j=1,\ldots,F, \tag{6}$$

$$\sum_{h=1}^{H} v_h \cdot x_{hf} = 1 \quad \text{with } f=1,\ldots,F, \tag{7}$$

and (4).

The efficiency of analyzed suppliers can be found solving problem (5)-(6)-(7)-(4) for each f-th supplier for f=1,2 ,…,F. Obviously, the f-th vendor is maximally efficient if E_f=1. Therefore, suppliers can be ranked based on their efficiency value E_f.

2.2 The Second Level of the Hierarchical Optimization - the AHP Approach

The Analytic Hierarchy Process (AHP) is a multi-objective decision technique (Saaty, 1990) for ranking a number of alternatives according to a set of conflicting criteria of various degrees of importance. This paper selects AHP to single out in the second level of the optimization the effective suppliers among efficient ones determined at the first level since, being based on alternatives pairwise comparison, AHP turns out to exhibit an enhanced accuracy with respect to other decision making techniques. AHP consists of the following steps.

Step 1. Structuring the decision problem as a hierarchy. Select the first level of the hierarchical structure as the overall goal "Effectiveness". Define the second level, composed by the n criteria contributing to the goal. Determine the third level as the m alternative suppliers to be ranked in terms of the criteria in the second level.

Step 2. Constructing the decision matrix. Determine the decision matrix $\boldsymbol{D}$ of dimensions mxn, where m is the number of alternatives (the efficient suppliers), n is the number of criteria, and element d_{ij} with i=1,…,m and j=1,…,n measures the i-th supplier performance against criterion c_j.

Step 3. Constructing the pairwise comparison matrix $\boldsymbol{C_M}$. Compare the n criteria with each other and construct the nxn pairwise comparison matrix $\boldsymbol{C_M}$ by Saaty's original AHP scale in Table 1. More precisely, determine each element $c_{m_{ij}}$ of $\boldsymbol{C_M}$ with i,j=1,…,n, representing the relative importance of the i-th criterion compared to the j-th one, by interviewing the buyer evaluating the importance of criterion c_i over c_j and associating it an integer value from 1 to 9 according to Table 1. Obviously, less important criteria are defined by reciprocals $c_{m_{ij}} = \frac{1}{c_{m_{ji}}}$ for each i,j=1,…,n.

Step 4. Determining the eigenvector associated to the maximum eigenvalue of the comparison matrix. Calculate the eigenvalues set $\{\lambda_1, \lambda_2, \ldots, \lambda_R\}$ of $\boldsymbol{C_M}$, where R is its rank. Let $\lambda_{\max}$ be the maximum eigenvalue of $\boldsymbol{C_M}$, then determine its eigenvector $\boldsymbol{v_{max}}$. Compute the priority vector:

$$\boldsymbol{P} = \boldsymbol{v_{max}} \cdot n = [p_1 \ldots p_n]^T . \tag{8}$$

where each element p_j with j=1,…,n of $\boldsymbol{P}$ represents the importance degree of the j-th performance index associated to the j-th column of $\boldsymbol{D'}$: the greater p_j, the more important the j-th performance index.

Step 5. Raising alternatives to the criteria power. Determine the alternative values associated to each j-th performance index as follows:

$$\boldsymbol{CRIT_j} = [d_{1j} \ldots d_{mj}] . \tag{9}$$

Table 1: Saaty's AHP scale of comparisons.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgments

for each $j=1,\ldots,n$. Determine the following vectors.

$$\boldsymbol{G_j}=[g_{1j}\ \ldots\ g_{mj}]=\ \boldsymbol{CRIT}_j^{\,p_j}=[d_{1j}^{\ p_j}\ \ldots\ d_{mj}^{\ p_j}]\,. \tag{10}$$

for each $j=1,\ldots,n$.

Step 6. Determining the decision model. For each alternative i with $i=1,\ldots,m$, determine:

$$PI_{i\_AHP}=\min\left(g_{i1},\ldots,g_{in}\right) \tag{11}$$

so that PI_{i_AHP} provides information about the satisfaction of alternative s_i with respect to the performance indices and their importance degree.

Step 7. Ranking the alternatives. Suppliers are ranked according to index PI_{i_AHP}: the best supplier is the one showing the highest index PI_{i_AHP}.

2.3 The Third Level of the Hierarchical Optimization: the Linear Programming Methodology

Linear programming is a mathematical optimization process in which a single objective function states mathematically what is being maximised, e.g., profit, or minimized, e.g., cost.

With the aim of determining the quantities to require from the most effective suppliers singled out in the previous and second level of the hierarchical supplier evaluation procedure, we define the Supply Evaluation Index (SEI) as follows:

$$SEI=\sum_{i=1}^{\mu} q_i \cdot PI_{i\_AHP} \tag{12}$$

that is an overall index measuring the efficiency on the supply considering the $\mu \le m$ most effective suppliers obtained by the second-level AHP optimization among the m efficient vendors obtained by the first-level DEA optimization. In particular, variables q_i with $i=1,..,\ \mu$ are the percentage quantities of product with values ranging from 0 to 1 to request from each vendor to obtain the supply.

Hence, the linear programming problem is:

$$Max(SEI) \tag{13}$$

s.t.:

$$\sum_{i=1}^{\mu} q_i = 1\,, \tag{14}$$

$$q_i \le \gamma_i \ \text{ with }\ 0 \le \gamma_i \le 1 \ \text{ and } i=1,\ldots,\mu, \tag{15}$$

$$q_i \ge \delta_i \ \text{ with }\ \sum_{i=1}^{\mu} \delta_i \le 1\,. \tag{16}$$

In particular, δ_i is a parameter measuring the minimum percentage quantity (eventually equal to zero) that the buyer decides to buy from each effective supplier independently from its ranking to keep the long-term partnership. In addition, γ_i is the given production capacity (expressed in percentage values in a 0-1 range) of the i-th effective supplier with $i=1,\ldots,\mu$. Hence, (14) guarantees that the whole requested quantity is supplied, constraints (15) are connected to the quantities each supplier is able to deliver, (16) models the buyer will of requiring products from each efficient supplier independently from the ranked position.

3 THE CASE STUDY

To show the effectiveness of the presented hierarchical approach, we consider a simulated case study requiring the supply of C class components under multiple sourcing and assuming that the number of existing suppliers equals $F=15$. We remind that spare parts in inventory are usually divided in the literature into three classes according to their money usage (Krajewski and Ritzman, 2002): class A items typically represent only about 20% of the items but account for 80% of the money usage; class B components account for additional 30% of the items but only for 15% of the money usage; finally, 50% of the items falls in class C, representing a mere 5% of financial usage. While for A and B components a strategic partnership between buyer and seller is typically created (so that often single sourcing is applied), C components are such that an increasing competition among suppliers usually allows the buyer to obtain a better price: hence, it is important to rank suppliers and decide the quantities to request them by different criteria.

The case study vendor efficiency is estimated using H=2 input criteria, namely:

- *price* - This attribute measures the price offered by each supplier. It is evaluated as $\overline{p}_f = \frac{p_f}{p_{\max}}$ with f=1,…,F, where p_f is the offered price and $p_{\max} = \max_{f=1,2,\dots,F}(p_f)$ the maximum offered price;
- *geographical distance* - this criterion expresses the geographical distance of the supplier from the buyer. The nearer the supplier, the lower the transportation costs. The normalized performance of the f-th supplier with f=1,…,F is $\overline{d}_f = \frac{d_f}{d_{\max}}$, where d_f is the vendor distance and $d_{\max} = \max_{f=1,2,\dots,F}(d_f)$ the maximum distance.

The K=2 considered output criteria are:

- *quality* - this criterion is strictly related to the number of accepted products: indeed, a high number of defects means high costs of restoration. Hence, we define the index quality of the f-th supplier with f=1,…,F as $IQ_f = \frac{pc_{a,f}}{pc_{v,f}} \cdot \frac{lot_{a,f}}{lot_{v,f}}$, where $pc_{a,f}$ ($pc_{v,f}$) is the number of accepted (verified) items and $lot_{a,f}$ ($lot_{v,f}$) is the amount of accepted (verified) lots. The normalized quality index is hence $\overline{IQ}_f = \frac{IQ_f}{IQ_{\max}}$, with $IQ_{\max} = \max_{f=1,2,\dots,F}(IQ_f)$;
- *lead time* - This criterion is related to the supplier manufacturing capability and flexibility. The lead time is defined as the time span between the placing of an order and the receipt of goods. Obviously, the shorter the lead time, the better the supplier in term of flexibility, production capability and internal organization. Given the lead time index LT_f of the f-th supplier with f=1,…,F, the normalized lead time is $\overline{LT}_f = 1 - \frac{LT_f}{LT_{\max}}$, with $LT_{\max} = \max_{f=1,2,\dots,F}(LT_f)$.

The normalized input performance values of each supplier are collected in Table 2 (second and third column). In the second-last and last column of Table 2 the output indices are reported.

Applying the DEA approach, problem (5)-(6)-(7)-(4) is defined and solved, so that the results in Table 3 are obtained. Analysing Table 3, the efficient suppliers are supplier 3, 5, 10, 11, and 14, so that m=5 suppliers are singled out. For example, supplier 3 is efficient by weighting the price criterion u_1=0.389, the normalized geographical distance u_2=3.591, the quality index v_1=0.517, and the lead time index v_2=0.942.

The next step is to rank the efficient suppliers 3, 5, 10, 11, and 14 in order to calculate the quantities to require for a supply. The results of the AHP optimization are shown in Table 4, collecting the performance values of vendors s_f with f=3,5,10,11,14. The second column reports performance index PI_{i_AHP} and the last column ranks the five efficient suppliers: the best supplier is s_{10}, showing a high value of lead time and a low value of price (the lowest), together with an intermediate geographical distance and a high quality index. Following are suppliers s_{14}, s_{11}, s_3, and s_5.

Table 2: The data for the DEA input and output criteria.

Supplier	Input 1	Input 2	Output 1	Output 2
F	p_f	d_f	IQ_f	LT_f
1	0.689	0.456	0.894	0.237
2	1.000	0.538	0.998	0.347
3	0.798	0.192	0.985	0.521
4	0.790	0.594	0.946	0.125
5	0.589	0.066	0.902	0.000
6	0.487	0.987	0.945	0.568
7	0.897	1.000	0.976	0.625
8	0.657	0.456	0.928	0.544
9	0.984	0.732	1.000	0.875
10	0.123	0.450	0.756	0.757
11	0.235	0.200	0.912	0.359
12	0.357	0.759	1.000	0.915
13	0.573	0.417	0.350	0.830
14	0.233	0.350	0.870	0.765
15	0.467	0.897	0.910	0.935

Table 3: The first-level DEA optimization data and results.

Supplier	Weight	Weight	Weight	Weight	Efficiency
f	u_1	u_2	v_1	v_2	E_f
1	0.520	1.407	0.443	0.000	0.396
2	0.168	1.547	0.223	0.406	0.363
3	0.389	3.591	0.517	0.942	**1.000**
4	0.417	1.129	0.355	0.000	0.336
5	1.303	3.525	1.109	0.000	**1.000**
6	1.358	0.343	0.425	0.000	0.402
7	0.122	0.890	0.094	0.338	0.303
8	0.251	1.831	0.193	0.695	0.557
9	0.090	1.245	0.000	0.597	0.522
10	1.695	1.759	0.000	1.321	**1.000**
11	2.442	2.131	0.949	0.374	**1.000**
12	1.095	0.802	0.330	0.325	0.628
13	0.158	2.181	0.000	1.046	0.868
14	1.463	1.883	0.499	0.740	**1.000**
15	0.715	0.742	0.000	0.558	0.521

Table 4: The second-level AHP optimization results.

Efficient supplier	Perf. index	Position
f	$PI_{i\ AHP}$	i
3	0.132	4
5	0.117	5
10	0.273	1
11	0.219	3
14	0.258	2

Table 5: The third-level linear programming problem data.

Supplier	Minimum requested quantity	Capacity
f	δ_i	γ_i
10	0.200	0.600
11	0.200	0.400
14	0.200	0.700

Table 6: The third-level linear programming results.

Supplier	Required quantity
f	q_i
10	0.400
11	0.200
14	0.400

After rnking the efficient suppliers, the linear programming problem (13)-(14)-(15)-(16) is defined and solved for a multiple sourcing strategy with $\mu=3$. The values of minimum required quantities δ_i and percentage capacities γ_i of suppliers are collected in Table 5. Table 6 shows the results of the linear programming problem solution, i.e., the required quantities from the three effective suppliers s_{10}, s_{11}, and s_{14}. Results show that 40% of the supply will be provided in turn by each of the two most effective suppliers, i.e., s_{10} and s_{14}, whereas the remaining 20% of the requested product will be provided by the third-ranked supplier s_{11}.

4 CONCLUSIONS

The paper focuses on a crucial issue of purchasing in supply chains, i.e., vendor evaluation and selection. A novel three-step methodology based on the Data Envelopment Analysis (DEA) approach, the Analytic Hierarchy Process (AHP), and linear programming is presented. At the first level of the hierarchical technique, a vendor rating technique based on DEA is devised to obtain efficient and inefficient suppliers. Hence, the AHP process is applied to rank the efficient vendors based on the overall performance index. Finally, a linear programming problem is solved to split the supply adopting a multiple sourcing strategy. To the best of the authors' knowledge, no one in the related literature has ever joined these three approaches for supplier selection in such a context. A numerical case study shows the effectiveness of the presented three step method for a C class component. Future perspectives are identifying a real case study to further verify the approach flexibility and simplicity of use by the firm purchasing manager.

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