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Supplier Selection by Balancing and Ranking Method

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Abstract: In this study, Multiple Criteria Decision Model (MCDM) is used for optimization of several conflicting criteria dependent systems. A MCDM approach taking into account the performance defining attributes such as profitability of supplier, relationship closeness, technological capability, conformance quality and conflict resolution, was adopted to determine the performance ranking of suppliers. It is a three-stepped procedure to derive an overall complete final order of the suppliers. The out-ranking matrix is derived, indicating the frequency of the relative superiority of suppliers with respect to each other based on each criterion. The out-ranking matrix is triangularised to obtain an implicit ordering or provisional order of suppliers, based on sequential application of a balancing principle supported by the pair wise comparison of the suppliers with the help of advantages-disadvantages table.

Key words: Supplier selection, supply chain, multiple criteria decision model, balancing principle

INTRODUCTION

Supplier selection or evaluation is a common problem for acquiring the necessary materials to support the outputs of organizations. The problem is to find and to evaluate periodically the best or most suitable supplier(s) for the organizations based on various suppliers' capabilities. This usually happens when the purchase is complex, high-dollar value and perhaps critical. Also, a process of formal supplier evaluation and ranking is necessary. The process for supplier selection is indeed a problem-solving process, which covers the works of problem definition, formulation of criteria, qualification and choice (Shih *et al*., 2004). However, most articles deal with qualification and choice phases to which operations research related techniques are adapted (De Boer *et al*., 2001).

Selecting an appropriate supplier is often a non-trivial task, in which multiple criteria need to be carefully examined. However, many decision makers or experts select suppliers based on their experience and intuition. These approaches are obviously subjective and their weakness has been addressed in several previous studies (Hwang and Yoon, 1981; Kontio, 1996). Alternatively, multiple criteria decision making or multiple attributes decision making (MCDM/MADM) is the approach dealing with the ranking and selection of one or more suppliers from a pool of providers. The MCDM provides an effective framework for supplier comparison based on the evaluation of multiple conflict criteria. In order to manage the difficulty of determining the performance of a supplier on one criterion or the importance of some criterion with a high degree of precision, the Analytic Hierarchy Process (AHP) is now widely used by both researchers and practitioners (Ghodsypour and O'Brien, 1998). Ghodsypour and O'Brien (1998) argued that AHP is more accurate than other scoring methods for supplier selection. Theoretically, the methodology is valuable when the decision making framework has a unidirectional hierarchical relationship among decision levels. However, Carney and Wallnau (1998) point out that the evaluation criteria for alternatives are not always independent of each other, but often interact with one another. An invalid result can be drawn in such a complex environment.

Several influence factors are often not taken into account in the decision making process, such as incomplete information, additional qualitative criteria and imprecision preferences. According to the vast literature on supplier selection (De Boer *et al*., 1998; Choi and Hartley, 1996; Weber *et al*., 1991), it is concluded that some properties are worth considering when solving the decision making problem for supplier selection. First, the criteria may consider quantitative as well as qualitative dimensions (Choi and Hartley, 1996; Dowlatshahi, 2000; Verma and Pullman, 1998; Weber *et al*., 1991, 1998). In general, these objectives among these criteria are

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conflicted. A strategic approach towards supplier selection may further emphasize the need to consider multiple criteria (Donaldson, 1994; Swift, 1995). Second, several decision makers are very often involved in the decision process for supplier selection (De Boer *et al*., 1998). Third, decision making is often influenced by uncertainty in practice. An increasing number of supplier decisions can be characterized as dynamic and unstructured. Situations are changing rapidly or are uncertain and decision variables are difficult or impossible to quantify. Fourth, the types of decision models can be divided into compensatory and non-compensatory methods (De Boer *et al*., 1998; Ghodsypour and O'Brien, 1998; Roodhooft and Konings, 1996).

The compensatory decision models leading to an optimal solution for dealing with supplier selection problems. The non-compensatory methods are that use a score of an alternative on a particular criterion can be compensated by high scores on other criteria. From the literature it can be concluded that in supplier selection the classic concept of optimality may not always be the most appropriate model (Boer *et al*., 1998). Jain *et al*. (2007) developed an approach based on fuzzy association rule mining to support the decision makers by enhancing the flexibility in making decisions for evaluating suppliers with both tangibles and intangibles attributes. Chou *et al*. (2007) utilized the supplier positioning matrix, modified from the product-process change matrix, to link the capability of suppliers with the requirements of the customers to identify the strategy-aligned criteria for vendor selection in a modified re-buy situation. Overall it is concluded that supplier selection may involve several and different types of criteria, combination of different decision models, group decision making and various forms of uncertainty. It is difficult to find the best way to evaluate and select supplier and companies use a variety of different methods to deal with it. Therefore, the most important issue in the process of supplier selection is to develop a suitable method to select the right supplier. In essential, the supplier selection problem in supply chain system is a group decision making under multiple criteria. The degree of uncertainty, the number of decision makers and the nature of the criteria those have to be taken into account in solving this problem. In classical MCDM methods, the ratings and the weights of the criteria are known precisely (Delgado *et al*., 1992; Hwang and Yoon, 1981). Mehmet *et al*. (2007) applied a hybrid method of supplier selection to a well-known Turkish company operating in the appliance industry. Theoretically, the methodology is valuable when the decision making framework has a unidirectional hierarchical relationship among decision levels. Chan *et al*. (2007) discussed the fuzzy based Analytic Hierarchy Process (fuzzy-AHP) to efficiently tackle both quantitative and qualitative decision factors involved in selection of global supplier in current business scenario. Sen *et al*. (2008) presented a framework for defining the supplier selection criteria by investigating possible quantitative and qualitative criteria reported by earlier studies according to the levels of buyer-supplier relationship. A survey of the methods has been presented by Hwang and Yoon (1981). In this study focuses on the use of multiple criteria optimization by ranking and balancing method for the selection suppliers. The method adopted in the present paper overcomes some of the deficiencies of other MCDM methods, such as subjective evaluation of criteria, scoring of suppliers, statistical estimation of weights and specification of utility function for criteria (Strassert and Prato, 2002).

THE MCDM APPROACH

Data table, outranking matrix: A high-technology manufacturing company desires to select a suitable material supplier to purchase the key components of new products. After preliminary screening, five suppliers (S_1, S_2, ...S_5) remain for further evaluation. A committee of decision-makers has been formed to select the most suitable supplier. Five benefit criteria are considered:

- Profitability of supplier (C_1)
- Relationship closeness (C_2)
- Technological capability (C_3)
- Conformance quality (C_4)
- Conflict resolution (C_5)

Table 1 shows the criteria values for the five suppliers evaluated. The transitive overall final order of a finite set of suppliers is derived on the basis of a stepwise ordering procedure following the balancing and ranking as the variants of MCDM. The model heeds to the assumptions of pair wise comparison of suppliers among all the selected suppliers and the principle of balancing (Strassert and Prato, 2002). The method overcomes the conventional MCDM approaches based on the empirical relative weight assignments. The MCDM problem is solved on the basis of a three-stepped method called the balancing and ranking method. The ranking of suppliers based on the scores of performance defining attributes such as profitability of supplier, relationship closeness, technological capability, conformance quality and Conflict resolution are taken for the definition of the superiority sequence of the suppliers, on the basis of the data table as given in Table 1. Based on Table 1 and taking into

Table 1: Performances of selected suppliers

		Suppliers (%)				
Criteria	Feature	S_1	S_2	S_3	S_4	S_5
C_1	Profitability of supplier	50.34	33.56	44.87	29.16	56.76
C_2	Relationship closeness	67.07	53.51	60.17	43.86	40.87
C_3	Technological capability	55.08	60.24	67.87	47.56	53.5
C_4	Conformance quality	87.45	76.34	66.35	58.34	60.17
C_5	Conflict resolution	65.96	47.66	51.09	66.87	38.36

Table 2: Advantages-disadvantages table for 10 pairs of suppliers and five criteria

Criteria	S_1/S_2	S_1/S_3	S_1/S_4	S_1/S_5	S_2/S_3	S_2/S_4	S_2/S_5	S_3/S_4	S_3/S_5	S_4/S_5
C_1	$_{1/2}A_1$	$_{1/3}A_1$	$_{1/4}A_1$	$_{1/5}D_1$	$_{2/3}D_1$	$_{2/4}A_1$	$_{2/5}D_1$	$_{3/4}A_1$	$_{3/5}D_1$	$_{4/5}D_1$
C_2	$_{1/2}A_2$	$_{1/3}A_2$	$_{1/4}A_2$	$_{1/5}A_2$	$_{2/3}D_2$	$_{2/4}A_2$	$_{2/5}A_2$	$_{3/4}A_2$	$_{3/5}A_2$	$_{4/5}A_2$
C_3	$_{1/2}D_3$	$_{1/3}D_3$	$_{1/4}A_3$	$_{1/5}A_3$	$_{2/3}D_3$	$_{2/4}A_3$	$_{2/5}A_3$	$_{3/4}A_3$	$_{3/5}A_3$	$_{4/5}D_3$
C_4	$_{1/2}A_4$	$_{1/3}A_4$	$_{1/4}A_4$	$_{1/5}A_4$	$_{2/3}A_4$	$_{2/4}A_4$	$_{2/5}A_4$	$_{3/4}A_4$	$_{3/5}A_4$	$_{4/5}D_4$
C_5	$_{1/2}A_5$	$_{1/3}A_5$	$_{1/4}D_5$	$_{1/5}A_5$	$_{2/3}D_5$	$_{2/4}D_5$	$_{2/5}A_5$	$_{3/4}D_5$	$_{3/5}A_5$	$_{4/5}A_5$
$\sum A_i$	4	4	4	4	1	1	4	1	4	2
$\sum D_i$	1	1	1	1	4	4	1	4	1	3

Table 3: Outranking matrix (R)

Suppliers	S_5	S_5	S_5	S_5	S_5
S_1	-	4	4	4	4
S_2	1	-	1	4	4
S_3	1	4	-	4	4
S_4	1	1	1	-	2
S_5	1	1	1	3	-

Table 4: Triangular outranking matrix (R^T)

Suppliers	S_1	S_3	S_2	S_5	S_4
S_1	-	4	4	4	4
S_3	1	-	4	4	4
S_2	1	1	-	4	4
S_5	1	1	1	-	3
S_4	1	1	1	2	-

account the pair wise comparison an advantages-disadvantages table is constructed (Table 2). The data table is used to derive an out-ranking matrix (Table 3). The latter indicates the frequency with which a supplier is superior to other suppliers based on each criterion. Secondly the triangularisation of the out-ranking matrix is carried out to obtain an implicit pre-ordering of suppliers, which is essentially a provisional ordering (Lansdowne, 1997; Bartnick, 1991). Thirdly the provisional ordering is further evaluated using screening and balancing operations based on an advantages-disadvantages table (Table 2), where the advantages and disadvantages are represented as A_i and D_i i = (1,2...,5), respectively. This helps in establishing strict superiority relations for the ordering of pairs of suppliers.

Triangularisation of the out-ranking matrix: Triangularisation of the out-ranking matrices is conducted to obtain a new order of suppliers. This resulting triangular out-ranking matrix is denoted as R^T shown in Table 4. The triangular matrix systematically reorders the j suppliers such that, out of a set of p = j! orders (in this case p = 5! = 120), the sum of the values above the main diagonal is a maximum in the matrix of the final order. The triangularisation method is generally applicable to quadratic matrices, such as input-output matrix or a voting matrix (Bartnick, 1991). In a completely triangular matrix, there are only zeros below the main diagonal, a situation, which is referred to as the total order structure. The occurrence of a total order structure implicates the transitive overall final order of suppliers. Normally the order of suppliers implied by the out-ranking matrix is not the final overall order of suppliers. Therefore Triangularisation can be understood as a method for both, to test and to display the degree of achievement of (strong) transitive overall order of suppliers.

The degree of linearity of triangularised matrix is measured by λ where:

$$\lambda = \frac{\sum_{j<k} r_{jk}}{\sum_{j\neq k} r_{jk}}, \qquad 0.5 \le \lambda \le 1$$

The degree of linearity of the matrix given in the table is 0.78. λ indicates how much an order of suppliers deviates from the ideal case of λ = 1, which implies a strong linear order, say, A-C, for which the transitivity condition applies.

The performance orders of the suppliers with respect to each criterion on the basis of Table 1 are given below

$$C_1: S_5 > S_1 > S_3 > S_2 > S_4$$
$$C_2: S_1 > S_3 > S_2 > S_4 > S_5$$
$$C_3: S_3 > S_2 > S_1 > S_5 > S_4$$
$$C_4: S_1 > S_2 > S_3 > S_5 > S_4$$
$$C_5: S_4 > S_1 > S_3 > S_2 > S_5$$

Advantages-disadvantages table: The advantages-disadvantages table is developed, which combines the criteria with the pair wise comparison of suppliers. The head row contains all possible pairs of suppliers. If there are m suppliers, the maximum number of pairs is z = m(m-1)/2. In this case, z = 10. The pair wise comparisons are made in terms of quantities, i.e., on a cardinal scale. For example: S_3 has comparative disadvantage relative to S_5 since S_5 be superior to S_5 with respect to the first criteria (C_1). Hence it is denominated as S_3. This table containing the votes of out-ranking matrix shows how the quasi-votes are split by criteria or equivalently, the criterion dependent advantages and disadvantages.

Balancing of the problems: The balancing problem involves the comparison of two suppliers with respect to a set of advantages and disadvantages, which are separate binary decision problems. For example, in the first column of Table 3 of S_1/S_2 represents separate binary decision problem consisting of four advantages and one disadvantage. This implies that S_1 is at an advantage as compared to S_2. The binary problem is then solved with respect to the advantages and disadvantages of suppliers and they are further reordered. The triangular out-ranking matrix given in Table 4 indicates the following provisional ordering of suppliers: $S_1>S_3>S_2>S_5>S_4$. It is the starting matrix used in the stepwise procedure. This matrix is at the helm of the procedure and the goal of the same is to convert as many pairs of the entries above the diagonal to 5:0 pairs as warranted by the judgments of the decision-maker. A final solution in terms of the overall ordering of the suppliers is reached when this conversion is completed. The provisional ordering of the triangular out-ranking matrix is attempted sequentially so as to attain a maximized value of the difference of $\sum r_{jk}$ below the diagonals from that of the above the diagonal elements (Bartnick, 1991). The logical implication of the transitivity condition is used while going for the stepwise procedure. For example, if the (m-1) pair wise comparisons above and along side the diagonal is given in Table 4 and the remaining pair wise comparisons in the upper triangle are implied by transitivity. To elicit a maximum number of transitivity implications triangularisation is the prime objective, when the (m-1) pairs of suppliers above and along side the diagonal are given. For example, if the pair wise comparisons above and along side the diagonal, S_1/S_2, S_2/S_3, S_3/S_4 and S_4/S_5, are given, the remaining six pair wise comparisons S_1/S_2, S_2/S_3, S_3/S_4, and S_4/S_5 are implied. Such implicative comparisons are determined as follows:

$$S_1 > S_2 \text{ and } S_2 > S_3 \rightarrow S_1 > S_3$$
$$S_1 > S_3 \text{ and } S_3 > S_4 \rightarrow S_1 > S_4$$
$$S_1 > S_4 \text{ and } S_4 > S_5 \rightarrow S_1 > S_5$$
$$S_2 > S_3 \text{ and } S_3 > S_4 \rightarrow S_2 > S_4$$
$$S_2 > S_4 \text{ and } S_4 > S_4 \rightarrow S_2 > S_5$$
$$S_3 > S_4 \text{ and } S_4 > S_5 \rightarrow S_3 > S_5$$

Table 5: Illustration of stepwise procedure to the final triangular outranking matrix and final order of suppliers

Suppliers	S_1	S_3	S_2	S_5	S_4
Triangular outranking matrix					
S_1	-	4	4	4	4
S_3	1	-	4	4	4
S_2	1	1	-	4	4
S_5	1	1	1	-	3
S_4	1	1	1	2	-
First provisional triangular outranking matrix					
S_1	-	5	4	4	4
S_3	0	-	4	4	4
S_2	1	1	-	4	4
S_5	1	1	1	-	3
S_4	1	1	1	2	-
Second provisional triangular outranking matrix					
S_1	-	5	5	4	4
S_3	0	-	5	4	4
S_2	0	0	-	4	4
S_5	1	1	1	-	3
S_4	1	1	1	2	-
Third triangular outranking matrix					
S_1	-	5	5	5	4
S_3	0	-	5	5	4
S_2	0	0	-	5	4
S_5	0	0	0	-	3
S_4	1	1	1	2	-
Final triangular outranking matrix					
S_1	-	5	5	5	5
S_3	0	-	5	5	5
S_2	0	0	-	5	5
S_5	0	0	0	-	5
S_4	0	0	0	0	-

These implicative comparisons simplify the balancing problems. In the best case, shown above, where all pair wise comparisons above and along side the diagonal (S_1/S_2, S_2/S_3, S_3/S_4 and S_4/S_5) are confirmed which leaves out four balancing problems that are solved as illustrated in Table 5.

To reach the final order of suppliers through the final triangular out-ranking matrix a multi-stepped approach has been adopted. For example suppose that the first decision, S_3 is superior to S_5, instead of S_5 being superior to S_3. Then the entries 3 versus 5 have to be inversed. This change requires a new Triangularisation, which results in another provisional order of suppliers and another first provisional triangular out-ranking matrix. Consequently, the pair wise comparisons above and alongside the diagonal become different and then subsequently another second balancing problem will be chosen and so on, till all the entries above the diagonal are maximized (in the present case it is 5, since the number of criteria are 5), as elaborated in Table 5.

Role of judgment: The balancing approach differs from the traditional MCDM method of assignment of prior weights to the criteria. Further it also allows integration of both the balancing of the relative advantages and disadvantages of pairs of suppliers while simultaneously taking into account the different importance of the criteria. The advantages-disadvantages table operates at the factual level because other than the factual relations between the alternatives comprising each pair no other qualitative relations are taken into account. The final order of suppliers for decision making is determined by solving the 10 balancing problems stated in Table 2.

Final ordering of suppliers: The sequential elimination from the complete enumeration of possible orders, which are inconsistent with the superiority relations, leads to the final ordering of the suppliers. The number of possible orders in our example is p = n ! = 5! = 120. Of these 120 orders, 60 orders having S_1 before S_2 are eliminated as S_1 shows a strict superiority over S_2. If the pair wise comparisons above and along side the diagonal, S_1/S_3, S_1/S_4, S_1/S_5 and S_2/S_4 are as assumed, then a stepwise reduction of the remaining 60 orders becomes possible. Specifically another 20 orders are eliminated from the decision S_1/S_3, another 20 orders are eliminated from the decision S_1/S_4, another 15 orders are eliminated from the decision S_1/S_5 and another 4 orders are eliminated from the decision S_2/S_4 leaving only one order of supplier, which is the optimized supplier elicited from the decision model in terms of the selected set of performance criteria. The ensuing final overall order of suppliers in terms of performance is $S_1>S_3>S_2>S_5>S_4$.

CONCLUSION

Many practitioners and researchers have presented the advantages of supply chain management. In order to increase the competitive advantage, many companies consider that a well designed and implemented supply chain system is an important tool. Under this condition, building on the closeness and long-term relationships between buyers and suppliers is critical success factor to establish the supply chain system. Therefore, supplier selection problem becomes the most important issue to implement a successful supply chain system. The application of a new balancing and ranking method based on the MCDM technique has proved to be useful in performance ranking of the suppliers. The method entails three steps involving the definition of out-ranking matrix based on the criteria values for all the suppliers, while taking into account the frequency of superiority of one supplier, with respect to each supplier. Based on the information from the advantages-disadvantages table the provisional ordering of suppliers through the triangularisation of the out-ranking matrix and the final balancing operations of the provisional ordering of the suppliers has been performed. The balancing of the ordering is supplemented by the construction of auxiliary tables until attainment of the partial or complete strict ordering of the suppliers. Thus, this method is effectual in establishing an analytic preview of the suppliers available for a particular application in terms of its efficiency before the decision-maker. Hence the balancing and ranking method based on the MCDM approach was proved to be a powerful technique for a rapid and comparative assessment of the suppliers.

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