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Supplier selection using compromise ranking and outranking methods

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Abstract: In today's highly competitive manufacturing environment, an effective supplier selection process is very important for the success of any business organization. Selection of the best supplier is always a difficult task for the purchasing manager. Suppliers have varied strengths and weaknesses which require careful assessment by the purchasing manager before selecting and ranking them. Any supplier selection procedure is to be based on the establishment of various criteria which may include quality, cost efficiency, delivery dependability, volume flexibility, information and customer service. This paper attempts to solve the supplier selection problem using two most potential multi-criteria decision-making (MCDM) approaches and compares their relative performance for a given organizational environment. The first MCDM approach is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' (VIKOR), a compromise ranking method and the other one is 'ELimination and Et Choice Translating REality' (ELECTRE), an outranking method. These two methods are used to rank the alternative suppliers, for whom several requirements are considered simultaneously. Two real-time examples are cited in order to demonstrate and validate the effectiveness and flexibility of these two MCDM methods. The rankings of the alternative suppliers as obtained using these two MCDM methods almost match with those as derived by the past researchers.

Keywords: *Vendor selection; Multi-criteria decision-making; VIKOR; ELECTRE; Concordance matrix; Discordance matrix*

1. Introduction

One major task of the purchasing department is supplier selection, which includes the acquisition of required materials, services and equipment for all types of business organizations. The increasing importance of supplier selection decisions is forcing the organizations to rethink their purchasing and evaluation strategies because a successful purchasing decision directly depends on selecting the best supplier to fulfil the strategic goals apart from the operational requirements of the organization. One of the important areas in purchasing research that has significant practical implications is supplier evaluation and selection. The supplier selection decision generally depends on a number of different criteria. Traditionally, cost is the main criterion used in selecting a supplier, but other non-price criteria, such as quality of the supplied material, delivery schedule and overall capability of the supplier are also equally important. The decision of selecting the best supplier from a wide supplier-base is an unstructured, complicated and time-consuming task. This decision-making process involves evaluation of different alternatives based on various criteria, some of which are to be maximized and others minimized; some conflict with others, whereas some overlap with others. The supplier selection is an application-specific problem and the strategic management decision of the business organization may affect the criteria used in this decision-making process. This implies that the type of criteria and their relative importance vary from one domain to the other (or even from one organization to another).

Multi-criteria decision-making (MCDM) methods are formal approaches to structure information and decision evaluation in problems with multiple conflicting goals. Supplier evaluation and selection can be a suitable candidate for multi-criteria decision analysis because in this case, outcomes are evaluated in terms of several objectives. These are stated in terms of properties, either desirable or undesirable, that determine the decision maker's preferences for the outcomes. So, every decision needs to be integrated by trading off the relative performance of different suppliers. The aim of supplier selection is to take the outcomes of the supplier analysis, determine the degree to which they satisfy each of the objectives and then make the necess-

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ary trade-offs to arrive at a ranking for the alternative suppliers that correctly express the preferences of the decision maker. This is not any easy decision because there are many different criteria to be considered for a good supplier. The criteria for selecting the best supplier for a specific business organization are typically driven by the expectation of quality, cost efficiency, delivery dependability, volume flexibility, information and customer service. Although research in supplier selection is flooded with several decision models that encompass simple weighted techniques to advanced mathematical programming methods, there has been little work in the area of application of different MCDM methods in solving the supplier selection problems. In this paper, an attempt is made to discover the potentiality and applicability of two almost new MCDM methods while selecting the most appropriate supplier for a specific business organization. The first MCDM approach adopted is VIKOR (a compromise ranking method) and the other one is ELECTRE (an outranking method). Two real-time examples are cited to demonstrate and compare the performance of both these MCDM approaches. The first example (Pi and Low, 2006) deals with the selection of the best supplier among four alternatives based on four criteria, i.e. quality, price, on-time delivery and service, whereas, the second example (Liu *et al.*, 2000) considers five criteria, i.e. price, quality, delivery performance, distance and supply variety, based on which the most potential supplier from 18 alternatives is selected.

As the supplier selection decision-making problems involve both the quantitative as well as qualitative criteria, different solution methodologies are available to deal with these two types of selection criteria. Linear weighting model, categorical model, weighted point model, total cost of ownership model, artificial neural networks and principal component analysis are widely used to solve supplier selection problems with only quantitative information. On the other hand, analytic hierarchy process (AHP), voting analytic hierarchy process, fuzzy extended analytic hierarchy process and multi-attribute utility theory (MAUT) are adopted when the supplier selection problems involve both the quantitative and qualitative information. Both the VIKOR and ELECTRE methods utilize the concept of multi-attribute utility theory.

2. Literature survey

Roodhooft and Konings (1996) proposed an activity based costing approach for supplier selection and evaluation, which allows computation of total cost caused by a supplier in an organization's production process, thereby increasing the objectivity in the selection process. Akarte *et al.* (2001) developed a systematic approach to evaluate the casting quality suppliers using the analytic hierarchy process (AHP), which enables the combination of tangible and intangible criteria, and checking the consistency of the decision-making process. Feng *et al.* (2001) developed a stochastic integer programming approach for simultaneous selection of tolerances and suppliers based on the quality loss function and process capability index values. Oliveria and Lourenço (2002) considered a multi-criteria model to support decisions on the assignment of new orders to service suppliers who are engaged in construction of pipeline networks for gas distribution. Talluri and Narasimhan (2003) proposed a max-min productivity based approach that derives supplier performance variability measures, which are then utilized in a non-parametric statistical technique in identifying supplier groups for effective selection. Liu and Hai (2005) presented a novel weighting procedure in place of the AHP's paired comparison for selecting suppliers, which is called voting analytic hierarchy process. Zhu *et al.* (2006) adopted the interval number analytic hierarchy process to solve the supplier selection problems where the decision maker's preferences are fuzzy owing to the complex purchasing context and limited judgment capability. Amid *et al.* (2006) developed a fuzzy multi-objective linear model to overcome the vagueness of information relating to supplier evaluation and selection. An asymmetric fuzzy decision-making technique is applied to enable the decision maker to assign weights to different supplier selection criteria. Kumar *et al.* (2006) treated the supplier selection problem as a 'fuzzy multi-objective integer programming problem' formulation which incorporates three important goals, i.e. cost-minimization, quality-maximization and maximization of on-time-delivery with some other realistic constraints, such as meeting the buyers' demand, suppliers' capacity, suppliers' quota flexibility etc. Shyur and Shih (2006) formulated the supplier evaluation problem by the combined use of multi-criteria decision-making (MCDM) approach and a hybrid process, incorporating analytic network process (ANP) technique. Chen *et al.* (2006) proposed a multi-criteria decision-making (MCDM) model based on fuzzy set theory to deal with the supplier selection problems in supply chain management domain. Bayazit *et al.* (2006) presented a comprehensive application of

AHP as a real-time case study along with sensitivity analysis in selecting the best supplier for a Turkish construction organization. Wadhwa and Ravindran (2007) compared the performance of several multi-objective optimization methods including weighted objective, goal programming and compromise programming techniques for solving the supplier selection problems. Aissaouia *et al.* (2007) presented a literature review that covers the entire purchasing process, considering both the parts and services outsourcing activities, and includes internet-based procurement environments, such as electronic marketplace auctions. Almeida (2007) proposed a multi-criteria decision model for outsourcing supplier selection, using contributions from utility theory associated with the ELECTRE method.

Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) for solving the supplier selection problems from the perspective of strategic management of a supply chain. Bottani and Rizzi (2008) adopted a structured method to select the most suitable supplier with the purpose to streamline the procurement process using an integrated approach of cluster analysis and multi-criteria decision-making (MCDM) technique. Ng (2008) developed a weighted linear program for the multi-criteria supplier selection problem, which can be solved without an optimizer using a suitable transformation technique. Wu and Blackhurst (2008) demonstrated the application of augmented data envelopment analysis (DEA) with comparison experiments and observed that the augmented DEA model has advantages over the basic DEA model while evaluating and selecting suppliers for a specific business organization. Levary (2008) pointed out that the analytic hierarchy process (AHP) is the appropriate methodology for evaluating and ranking the potential suppliers, involving multiple criteria of supply reliability. Kokangul and Susuz (2008) proposed to integrate the analytic hierarchy process and non-linear integer programming technique, and then applied the multi-objective programming under some constraints, such as quantity discount, capacity and budget to determine the best suppliers in order to place the optimal order quantities among them. Wang *et al.* (2008) proposed a fuzzy hierarchical technique for order preference by similarity to the ideal solution (TOPSIS) to determine the accurate criteria weights and evaluate the fuzziness in problems of supplier selection. Although a lot of research involving different MCDM methods has already been carried out to solve the supplier selection problems, there is still enough scope to augment new and novel mathematical tools to evaluate and solve such types of complex MCDM problems.

3. Compromise ranking method

The VIKOR (the Serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' which means multi-criteria optimization (MCO) and compromise solution) method was mainly established by Zeleny (2002) and later advocated by Opricovic and Tzeng (2004; 2007). This method is developed to solve MCDM problems with conflicting and non-commensurable (attributes with different units) criteria, assuming that a compromise can be acceptable for conflict resolution, when the decision maker wants a solution that is the closest to the ideal solution and farthest from the negative-ideal solution, and the alternatives can be evaluated with respect to all the established criteria. It focuses on ranking and selecting the best alternative from a set of alternatives with conflicting criteria, and on proposing the compromise solution (one or more). The compromise solution is a feasible solution, which is the closest to the ideal solution, and a compromise means an agreement established by mutual concessions made between the alternatives. The following multiple attribute merit for compromise ranking is developed from the L_p-metric used in the compromise programming method (Rao, 2007):

$$L_{p,i} = \left\{ \sum_{j=1}^{M} \left(w_j \left[\left(m_{ij} \right)_{max} - m_{ij} \right] / \left[\left(m_{ij} \right)_{max} - \left(m_{ij} \right)_{min} \right] \right)^{p} \right\}^{1/p} \tag{1}$$

$$1 \le p \le \infty;\ i = 1,2,\ldots,N$$

where M is the number of criteria and N is the number of alternatives. The m_{ij} values (for $i = 1,2,\ldots,N$; $j = 1,2,\ldots,M$) indicate the values of criteria for different alternatives. In the VIKOR method, $L_{1,i}$ and $L_{\infty,i}$ are used to formulate the ranking measure.

The procedural steps for the VIKOR method are enlisted as follows:

Step 1. Identify the major supplier selection criteria as related to a specific business organization and short-list the suppliers on the basis of the identified criteria satisfying the requirements. A quantitative or qualitative value is assigned to each identified criterion to construct the related decision matrix.

Step 2.

a) After short-listing the suppliers and developpment of the decision matrix, determine the best, $(m_{ij})_{max}$ and the worst, $(m_{ij})_{min}$ values of all the criteria.

b) The weights or relative importance of the considered criteria are determined using analytic hierarchy process (AHP) or any other method.

c) Calculate the values of E_i and F_i.

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \tag{2}$$

$$F_i = L_{\infty,i} = Max^m \ of \left\{ w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \right\} \tag{3}$$

$$j = 1,2,\ldots,M$$

Equation (2) is applicable to beneficial criteria (whose higher values are desirable for a given situation). For non-beneficial criteria (whose lower values are preferable for a given situation), the term $[(m_{ij})_{max} - m_{ij}]$ in Equation (2) is to be replaced by $[m_{ij} - (m_{ij})_{min}]$. Hence, for non-beneficial criteria, Equation (2) can be rewritten as:

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij}) - (m_{ij})_{min}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \tag{4}$$

d) Calculate P_i value.

$$P_i = v((E_i - E_{i\text{-}min})/(E_{i\text{-}max} - E_{i\text{-}min})) + (1 - v)((F_i - F_{i\text{-}min})/(F_{i\text{-}max} - F_{i\text{-}min})) \tag{5}$$

where $E_{i\text{-}max}$ and $E_{i\text{-}min}$ are the maximum and minimum values of E_i respectively, and $F_{i\text{-}max}$ and $F_{i\text{-}min}$ are the maximum and minimum values of F_i respectively. v is introduced as weight of the strategy of 'the majority of attributes' (or 'the maximum group utility'). The value of v lies in the range of 0 to 1. Normally, the value of v is taken as 0.5. The compromise can be selected with 'voting by majority' ($v > 0.5$), with 'consensus' ($v = 0.5$) or with 'veto' ($v < 0.5$).

e) Arrange the alternative suppliers in the ascending order, according to the values of P_i. Compromise ranking list of the suppliers for a given v can be obtained by ranking with the P_i measure. The best alternative is the one having the minimum P_i value.

The VIKOR method is an effective MCDM tool, specifically applicable to those situations when the decision maker is not able, or does not know to express his/her preference at the beginning of the decision-making process. This method involves a quite simple computational procedure, and it offers a systematic and logical approach to arrive at the best decision. The obtained compromise solution can be accepted by the decision maker because it provides a maximum group utility of the 'majority' and a minimum individual regret of the 'opponent'. The compromise solutions can be the base for negotiations, involving the decision maker's preference on criteria weights (Rao, 2007). The VIKOR results depend on the ideal solution, which stands only for the given set of alternatives. Inclusion (or exclusion) of an alternative can affect the VIKOR ranking of the new set of alternatives.

4. Outranking method

The ELECTRE (ELimination and Et Choice Translating REality) method, developed by Roy and Vincke (1981), is based on multi-attribute utility theory (MAUT) with the intention to improve efficiency without affecting the outcome while considering less information (Cho, 2003). It is a procedure that sequentially reduces the number of alternatives the decision maker is faced within a set of non-dominated alternatives. The concept of an outranking relation S is introduced as a binary relation defined on the set of alternatives A. Given the alternatives A_j and A_k, A_j outranks A_k or A_jSA_k, if given all that is known about the two alternatives, there are enough arguments to decide that A_j is at least as good as A_k.

The goal of this outranking method is to find out all the alternatives that dominate other alternatives while they cannot be dominated by any other alternative. To find the best alternative, the ELECTRE method also requires the knowledge of the weight values for all the criteria. Each criterion $C_i \in C$ is assigned a subjective weight w_i

(the sum of the weights of all the criteria equals to 1), and every pair of the alternatives A_j and A_k is assigned a concordance index, $c(j,k)$, given as below:

$$c(j,k) = \sum_{g_i(j) \geq g_i(k)} w_i, \qquad j,k = 1,2,...,n,\ j \neq k \qquad (6)$$

where $g_i(j)$ and $g_i(k)$ are the normalized measures of performance of j^{th} and k^{th} alternative respectively with respect to i^{th} criterion in the decision matrix. Thus, for an ordered pair of alternatives (A_j, A_k), the concordance index, $c(j,k)$ is the sum of all the weights for those criteria where the performance score of A_j is at least as that of A_k. Clearly, the concordance index lies between 0 and 1. A discordance index, $d(j,k)$ is also calculated as given below:

$$d(j,k) = 0, \text{ if } g_i(j) \geq g_i(k),\ i = 1,2,...,m$$

$$d(j,k) = \frac{\max\limits_{g_i(k) > g_i(j)} \left(g_i(k) - g_i(j)\right)}{\max\limits_{i=1,...,m} \left(\left|g_i(k) - g_i(j)\right|\right)} \quad \text{otherwise,} \qquad (7)$$

$$j,k = 1,2,...,n,\ j \neq k$$

Once these two indices are estimated, an outranking relation S can be defined as:
A_jSA_k if and only if $c(j,k) \geq \hat{c}$ and

$$d(j,k) \leq \hat{d} \qquad (8)$$

where $\hat{c}$ and $\hat{d}$ are the threshold values as set by the decision maker. If the threshold values are high, it will be more difficult to pass the tests (normally, $\hat{c} = 0.7$ and $\hat{d} = 0.3$ (Milani *et al.*, 2006). For an outranking relation to be judged as true, both the concordance and discordance indices should not violate their corresponding threshold values. When these two tests are performed for all the pairs of alternatives, the preferred alternatives are those which outrank more than being outranked. The steps for implementing the ELECTRE method are described as below (Cho, 2003):

Step 1. Obtain the normalized values of all the criteria.

Step 2. Construct the outranking relations by following the concordance and discordance definitions, and develop a graph representing the dominance relations among the alternatives. In this graph, if alternative A_j outranks alternative A_k, then a directed arc exists from A_j to A_k.

Step 3. Obtain a minimum dominating subset by using the minimum concordance and maximum discordance indices.

Step 4. If the subset has a single element or is small enough to apply value judgment, select the final decision. Otherwise, repeat steps 2-3 until a single element or small subset exists.

Step 5. If a full ranking of the alternatives is required, apply an extension of the ELECTRE, i.e. ELECTRE II method. Calculate another two indices as follows:

Pure concordance index

$$C_j = \sum_{k=1}^{n} c(j,k) - \sum_{j=1}^{n} c(k,j) \quad (j \neq k) \qquad (9)$$

Pure discordance index

$$D_j = \sum_{k=1}^{n} d(j,k) - \sum_{j=1}^{n} d(k,j) \quad (j \neq k) \qquad (10)$$

(a) Once these two indices are computed, obtain two rankings separately.

(b) Determine an average ranking from the two rankings as obtained in step 5(a).

(c) Select that alternative which has the best average rank.

The ELECTRE method differs from other compensatory methods as the weights in this method are treated as the coefficients of importance and moreover, a significantly weak criterion value of an alternative cannot directly be compensated for by other good criteria values.

The pure concordance and discordance indices in the ELECTRE II method incorporate two extreme opposite relationships, i.e. strong and weak relationships, whereby strong and weak rankings are reduced to obtain the final ranking. By interactively changing the threshold values, the size of the subset consisting of the promising pair of alternatives can be changed.

The ELECTRE I method is used to develop a partial ranking and choose a set of the promising alternatives, whereas the ELECTRE II method is used for ranking all the alternatives.

When an outranking creditability between two alternatives is to be measured, the ELECTRE III method is adopted where an outranking degree can be established.

The VIKOR and ELECTRE methods are based

on some similar principles as mentioned below:

a) Both these ranking methods consider a certain global measure (group utility and concordance).

b) The opposition of the other criteria (minority) is not too strong for both these methods.

In the VIKOR method, as it employs linear normalization procedure, the normalized criteria values are not dependant on the evaluation unit of the selection criteria. On the other hand, the ELECTRE methods use vector normalization procedure and the normalized values can vary for different evaluation units of a particular criterion. A comparative analysis of both these MCDM methods shows that under certain assumptions, discordance condition in the ELECTRE method and the decision based on the F_i values in the VIKOR method have the same mathematical foundation, i.e. minimum individual regret.

5. Numerical illustrations

In order to demonstrate and validate the applications of the two above-mentioned MCDM approaches for solving supplier selection problems, the following two real-time examples are cited.

5.1. Example 1

Pi and Low (2006) developed a simple method for supplier evaluation and selection based on four criteria, i.e. quality, on-time delivery, price and service. These four criteria have been quantified in terms of Taguchi quality loss function and then analytic hierarchy process (AHP) has been employed to combine them into one global variable for supplier selection decision-making. Regarding the quality, as the zero-percent-defect is the target of the concerned manufacturing organization, the upper specification limit is set at 2% to indicate the allowable deviation from the target value. Zero-loss will occur at zero-percent-defective-parts and 100%-loss will occur at the specification limit of 2%-defective-parts.

Relating to on-time delivery, a large loss will occur to the manufacturing organization if the supplier delays in delivering the items, but only a small loss will occur if the supplier delivers the items prior to the schedule requirement. But as the lead-time is short in actual practice, the loss when deliveries are delayed always attracts more attention. In case of price, a zero-loss will occur to the supplier if he or she provides the lowest parts among the suppliers and if as much as 20% of the lowest price can be tolerated as the specification. The loss will be 100% when price is up to 20% of the lowest price. As the service factor, being a qualitative criterion, is difficult to quantify, a service factor rating (SFR) method has been employed to measure the supplier service performance. This method includes some important performance factors, like the ability to resolve problems, availability of technical data, forwarding of correlation data, ongoing progress reporting, responsiveness to return authorization and supplier response to corrective action. The detailed data for different supplier selection criteria is given in Table 1. Among these four criteria, only service is a beneficial attribute, whereas, quality, on-time delivery and price are the non-beneficial attributes.

5.1.1. VIKOR method

This supplier evaluation and selection problem is first solved using the VIKOR method. At first, the best and the worst values of all the criteria are identified. Pi and Low (2006) employed the analytic hierarchy process (AHP) method to determine the priority weights for the considered criteria. These priority weights, w_1=0.462, w_2 = 0.101, w_3 = 0.304 and w_4 = 0.133, are used here for the VIKOR method-based analysis. Now, the values of E_i and F_i are calculated using Equations (2) or (4) and (3) respectively, as given in Table 2. Table 2 also exhibits P_i values for v = 0.5 and the compromise ranking list of the alternative suppliers. The candidate suppliers are arranged in ascending order, according to the values of P_i. The best choice of supplier for the given example is supplier *D*. Supplier *C* is the second choice and the last choice is supplier *B*. Pi and Low (2006) obtained a ranking of the alternative suppliers as *D-A-C-B*, whereas, using the VIKOR method, the compromise ranking of suppliers is *D-C-A-B*. It is observed that in the VIKOR method, the ranking of the alternative suppliers remains almost the same.

While calculating the P_i values, the value of v is usually taken as 0.5 (Rao, 2007), but actually, its value lies between 0 and 1. Table 3 exhibits the comprise rankings of the alternative suppliers for two extreme values of v = 0.1 and v = 0.9. In both the cases, the rankings of the alternative suppliers do not change significantly.

5.1.2. ELECTRE method

Now, the same problem of selecting the best supplier for the given situation is solved using the ELECTRE method. At first, the original decision matrix, as shown in Table 1, is normalized using the following equations and is given in Table 4.

For beneficial attributes:

Normalized element in the decision matrix

$$z_{ij} = \frac{m_{ij}}{\sum_{i=1}^{N} m_{ij}} \quad (j = 1,2,...,M) \tag{11}$$

For non-beneficial attributes:

Normalized element in the decision matrix

$$\text{Matrix} = \frac{1 - z_{ij}}{\sum (1 - z_{ij})} \tag{12}$$

Now using Equation (6), the concordance index values are calculated as follows:

$c(1,2) = 0.101 + 0.304 + 0.133 = 0.538$

$c(1,3) = 0.101 + 0.304 + 0.133 = 0.538$

$c(1,4) = 0.101 + 0.304 = 0.405$ and so on.

While calculating the concordance index values, if there are ties between the alternatives, they would receive one half of the criteria weight (Cho, 2003). The complete set of indices is represented by the concordance matrix, as given in Table 5.

For discordance indices, the following calculations are made using Equation (7) and shown in Table 6 in the form of a discordance matrix.

d(1,2):

$C_1 = 0.2456 - 0.2281 = 0.0175$

$C_2 = 0.2000 - 0.3111 = -0.1111$

$C_3 = 0.2492 - 0.2569 = -0.0077$

$C_4 = 0.2236 - 0.2795 = -0.0559$

$$d(1,2) = \frac{max(0.0175)}{max\left|(0.0175, -0.1111, -0.0077, -0.0559)\right|} = 0.1575$$

d(1,3):

$C_1 = 0.2749 - 0.2281 = 0.0468$

$C_2 = 0.2889 - 0.3111 = -0.0222$

$C_3 = 0.2431 - 0.2569 = -0.0138$

$C_4 = 0.2019 - 0.2795 = -0.0776$

$$d(1,3) = \frac{max(0.0468)}{max\left|(0.0468, -0.0222, -0.0138, -0.0776)\right|} = 0.6031$$

$$d(1,4) = \frac{max(0.0234, 0.0155)}{max\left|(0.0234, -0.1111, -0.0061, 0.0155)\right|} = 0.2106$$

and so on.

Now, suppose that, the decision maker has specified a minimum concordance of 0.80 and a maximum discordance of 0.20, i.e. $c(j,k) > 0.80$ and $d(j,k) < 0.20$. With these specifications, the graph, as shown in Figure 1, is constructed. The directed path which appears in the graph is determined by the set of indices that simultaneously satisfy both these requirements. The set of indices is (*D*, *B*).

Using this graph, the decision maker can determine the best supplier by eliminating the other nodes. The direction of the arrow determines which alternative outranks the others. In Figure 1, supplier *D* outranks supplier *B* and hence, supplier *D* is the best choice among the considered alternatives.

Table 1: Quantitative data for example 1 (Pi and Low, 2006).

Supplier	Quality (Defective rate)	On-time Delivery (Delay time)	Price	Service
A	1.8	1	100	90
B	1.5	6	110	72
C	1	2	118	65
D	1.4	6	108	95

Table 2: E_i, F_i and P_i values for example 1.

Supplier	E_i	F_i	P_i	Rank
A	0.4841	0.4620	0.5661	3
B	0.6606	0.2888	0.6251	4
C	0.4572	0.3040	0.1580	2
D	0.46711	0.2310	0.0244	1

Table 3: Ranking of suppliers for different values of *v*.

Supplier	P_i ($v = 0.1$)	Rank	P_i ($v = 0.9$)	Rank
A	0.9132	3	0.2190	3
B	0.3252	4	0.9250	4
C	0.2844	2	0.0316	1
D	0.0049	1	0.0438	2

Table 4: Normalized decision matrix for example 1.

Supplier	Quality (Defective rate)	On-time delivery (Delay time)	Price	Service
A	0.2281	0.3111	0.2569	0.2795
B	0.2456	0.2000	0.2492	0.2236
C	0.2749	0.2889	0.2431	0.2019
D	0.2515	0.2000	0.2508	0.2950

Table 5: Concordance matrix for example 1.

Supplier	A	B	C	D
A	-	0.538	0.538	0.405
B	0.462	-	0.437	0.051
C	0.462	0.563	-	0.563
D	0.595	0.949	0.437	-

Table 6: Discordance matrix for example 1.

Supplier	A	B	C	D
A	-	0.1575	0.6031	0.2106
B	1	-	1	1
C	1	0.2446	-	1
D	1	0	0.9541	-

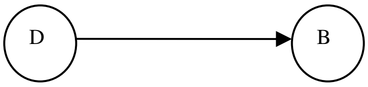

Figure 1: Resulting graph for example 1.

Using the ELECTRE method, it cannot be said how much supplier *D* outranks supplier *B*. This method is useful for selecting the best set of alternatives that outranks the others and also finding out the best alternative in that set. It is sometimes possible that no alternative outranks the others and no decision can be made (Cho, 2003). The ELECTRE (or ELECTRE I) method only finds the outranking relationship between the two best alternatives, whereas, the full ranking of the alternatives can be available in the ELECTRE II, ELECTRE III and ELECTRE IV methods (Almeida, 2005).

Now, in order to obtain the full ranking of the alternative suppliers, the ELECTRE II method is used and the corresponding pure concordance and discordance indices are computed using Equations (9) and (10) respectively. Based on these values, the initial, average and final rankings of the alternative suppliers are determined for the given situation, as shown in Table 7. From this analysis, it is observed that supplier *D* is the best choice. If there is a tie in the ranking, this can be resolved on the basis of the outranking relations or outranking graph as obtained from the concordance and discordance matrices.

Both these MCDM methods, i.e. VIKOR and ELECTRE II give almost the similar ranking (Spearman's rank correlation coefficient, $r_s = 0.9979$) to the alternative suppliers as engaged in the specific business organization. It proves the similarity of mathematical treatments of these two MCDM methods while solving such type of complex supplier selection decision-making problems.

5.2. Example 2

Liu *et al.* (2000) presented a case study to demonstrate the supplier performance evaluation using data envelopment analysis (DEA) in an agricultural and construction equipment manufacturing organization. Five criteria, i.e. price, quality, delivery performance, distance and supply variety are considered while evaluating the performance of 18 alternative suppliers as engaged in supplying hydraulic valves. Among these five criteria, quality, delivery performance and supply variety are the beneficial attributes, and price and distance are the non-beneficial attributes. The detailed information for 18 suppliers is given in Table 8. Liu *et al.* (2000) suggested that only five suppliers, i.e. 1, 10, 12, 15 and 17 are efficient, the remaining suppliers are inefficient. Suppliers 2 and 14 are the most inefficient.

5.2.1 VIKOR method

While solving this problem using the VIKOR method, at first, the best and the worst values of all the criteria are identified. Rao (2007) determined the weights for the five criteria as $w_1 = 0.1361$, $w_2 = 0.4829$, $w_3 = 0.2591$, $w_4 = 0.0438$ and $w_5 = 0.0782$ using analytic hierarchy process (AHP) method. Then using Equations (2) or (4), (3) and (5), the corresponding E_i, F_i and P_i values for 18 alternative suppliers are computed, as given in Table 9. From the compromise ranking of the alternative suppliers for the given problem, as shown in Table 9, it is observed that supplier 15 is the best choice, followed by supplier 17.

Supplier 14 is the worst choice. Hence, a compromise ranking of 15-17-8-12-11-16-10-5-13-1-9-3-4-7-18-6-2-14 is obtained using the VIKOR method. Table 10 shows the compromise rankings of the alternative suppliers when two extreme values of $v = 0.1$ and $v = 0.9$ are chosen. In both these cases, the choice of the best and the worst suppliers for the given problem remain the same.

5.2.2. ELECTRE method

In order to solve this problem using the ELECTRE method, the original decision matrix, shown in Table 8, is normalized using Equations (11) and (12), and is exhibited in Table 11. Now, using Equations (6) and (7), the concordance and discordance indices are calculated, as represented in Tables 12 and 13 respectively.

In this problem, say, the decision maker has fixed a minimum concordance value of 0.60 and a maximum discordance value of 0.40, i.e. $c(j,k) > 0.60$ and $d(j,k) < 0.40$. The sets that simultaneously satisfy both these requirements are (15,14), (17,14), (10,14), (15,11), (15,12), (15,13), (17,11), (17,12) and (17,13). Thus from the concordance and discordance matrices, it is clear that suppliers 15, 17 and 10 are the best among the considered alternatives because no other suppliers outrank them and supplier 14 is the worst choice.

Figure 2 shows the outranking relationship graph between the dominating suppliers. Now to get the full ranking of all the alternative suppliers, the ELECTRE II method is applied and the related initial, average and final rankings are obtained, as given in Table 14. Supplier 17 is evolved out to be best choice which exactly corroborates with the results as obtained by Liu *et al.* (Liu *et al.*, 2000). A high Spearman's rank correlation coefficient value of 0.7273 between the VIKOR and ELECTRE II methods exhibits the similarity and applicability of both these MCDM approaches.

Table 7: Ranking of suppliers for example 1 using ELECTRE II.

Supplier	Pure concordance index	Initial rank	Pure discordance index	Initial rank	Average rank	Final rank
A	-0.038	3	-2.0290	1	2	3
B	-1.101	4	2.5975	4	4	4
C	0.176	2	-0.3121	2	2	2
D	0.963	1	-0.2564	3	2	1

Table 8: Quantitative data for example 2 (Liu *et al.*, 2000).

Supplier	P (Price)	Q (Quality)	DP (Delivery performance)	D (Distance)	SV (Supply variety)
1	100	100	90	249	2
2	100	99.79	80	643	13
3	100	100	90	714	3
4	100	100	90	1809	3
5	100	99.83	90	238	24
6	100	96.59	90	241	28
7	100	100	85	1404	1
8	100	100	97	984	24
9	100	99.91	90	641	11
10	100	97.54	100	588	53
11	100	99.95	95	241	10
12	100	99.85	98	567	7
13	100	99.97	90	567	19
14	100	91.89	90	967	12
15	80	99.99	95	635	33
16	100	100	95	795	2
17	80	99.99	95	689	34
18	100	99.36	85	913	9

Table 9: E_i, F_i and P_i values for example 2.

Supplier	E_i	F_i	P_i	Rank
1	0.3426	0.1361	0.2484	10
2	0.4791	0.2591	0.4897	17
3	0.3541	0.1361	0.2563	12
4	0.3846	0.1361	0.2774	13
5	0.3194	0.1361	0.2323	8
6	0.5064	0.2030	0.4415	16
7	0.4411	0.1943	0.3860	14
8	0.2394	0.1361	0.1770	3
9	0.3454	0.1361	0.2503	11
10	0.2923	0.1465	0.2260	7
11	0.2686	0.1361	0.1972	5
12	0.2493	0.1361	0.1839	4
13	0.3277	0.1361	0.2381	9
14	0.8305	0.4829	1	18
15	0.1065	0.0648	0	1
16	0.2931	0.1361	0.2141	6
17	0.1065	0.0648	0.0001	2
18	0.4535	0.1943	0.3945	15

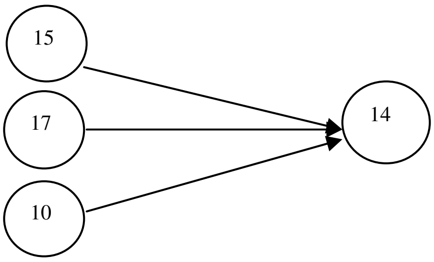

Figure 2: Resulting graph for example 2.

Table 10: Ranking of suppliers for different values of *v*.

P_i ($v = 0.1$)	Supplier (Rank)	P_i ($v = 0.9$)	Supplier (Rank)
0.1861	1 (9)	0.3106	1 (10)
0.4697	2 (17)	0.5097	2 (16)
0.1877	3 (11)	0.3248	3 (12)
0.1919	4 (12)	0.3628	4 (13)
0.1829	5 (7)	0.2817	5 (8)
0.3528	6 (16)	0.5301	6 (17)
0.3251	7 (14)	0.4469	7 (14)
0.1719	8 (3)	0.1822	8 (3)
0.1865	9 (10)	0.3140	9 (11)
0.2015	10 (13)	0.2505	10 (7)
0.1759	11(5)	0.2185	11 (5)
0.1732	12 (4)	0.1945	12 (4)
0.1841	13 (8)	0.2920	13 (9)
1	14 (18)	1	14 (18)
0	15 (1)	0	15 (1)
0.1793	16 (6)	0.2489	16 (6)
0.0001	17 (2)	0.0001	17 (2)
0.3268	18 (15)	0.4623	18 (15)

Table 11: Normalized decision matrix for example 2.

Supplier	P (Price)	Q (Quality)	DP (Delivery performance)	D (Distance)	SV (Supply variety)
1	0.0555	0.0560	0.0547	0.0576	0.0069
2	0.0555	0.0559	0.0486	0.0559	0.0451
3	0.0555	0.0560	0.0547	0.0556	0.0104
4	0.0555	0.0560	0.0547	0.0506	0.0104
5	0.0555	0.0559	0.0547	0.0577	0.0833
6	0.0555	0.0541	0.0547	0.0577	0.0972
7	0.0555	0.0560	0.0517	0.0524	0.0035
8	0.0555	0.0560	0.0590	0.0543	0.0833
9	0.0555	0.0559	0.0547	0.0559	0.0382
10	0.0555	0.0547	0.0608	0.0561	0.1840
11	0.0555	0.0560	0.0578	0.0577	0.0347
12	0.0555	0.0559	0.0598	0.0562	0.0243
13	0.0555	0.0560	0.0547	0.0562	0.0660
14	0.0555	0.0515	0.0547	0.0544	0.0417
15	0.0562	0.0560	0.0578	0.0559	0.1146
16	0.0555	0.0560	0.0578	0.0552	0.0069
17	0.0562	0.0560	0.0578	0.0557	0.1181
18	0.0555	0.0557	0.0517	0.0547	0.0313

Table 12: Concordance matrix for example 2.

Alternative	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18
A1	-	0.853	0.482	0.482	0.681	0.681	0.691	0.353	0.724	0.595	0.551	0.595	0.724	0.724	0.527	0.522	0.527	0.854
A2	0.146	-	0.190	0.190	0.068	0.551	0.190	0.111	0.146	0.551	0.629	0.146	0.068	0.673	0.483	0	0.044	0.673
A3	0.518	0.810	-	0.522	0.681	0.681	0.691	0.353	0.681	0.551	0.551	0.551	0.681	0.724	0.483	0.432	0.483	0.854
A4	0.518	0.810	0.478	-	0.681	0.681	0.647	0.309	0.681	0.551	0.551	0.551	0.681	0.681	0.483	0.388	0.483	0.810
A5	0.319	0.932	0.319	0.319	-	0.724	0.449	0.151	0.320	0.595	0.190	0.190	0.320	0.803	0.044	0.190	0.044	0.932
A6	0.319	0.449	0.319	0.319	0.276	-	0.449	0.190	0.320	0.112	0.168	0.190	0.320	0.803	0.044	0.190	0.044	0.245
A7	0.309	0.810	0.309	0.353	0.551	0.551	-	0.309	0.551	0.551	0.551	0.551	0.551	0.551	0.483	0.310	0.483	0.681
A8	0.646	0.888	0.646	0.691	0.849	0.810	0.691	-	0.888	0.551	0.888	0.629	0.888	0.888	0.742	0.647	0.742	0.888
A9	0.275	0.853	0.319	0.319	0.680	0.680	0.449	0.111	-	0.551	0.146	0.629	0.198	0.724	0	0.190	0.044	0.932
A10	0.405	0.449	0.449	0.449	0.405	0.888	0.449	0.449	0.449	-	0.405	0.405	0.405	0.932	0.381	0.449	0.381	0.449
A11	0.449	0.370	0.449	0.449	0.810	0.832	0.449	0.111	0.854	0.595	-	0.673	0.371	0.854	0.173	0.320	0.173	0.932
A12	0.405	0.853	0.449	0.449	0.810	0.810	0.449	0.370	0.371	0.595	0.327	-	0.349	0.854	0.303	0.449	0.303	0.854
A13	0.275	0.932	0.319	0.319	0.680	0.680	0.449	0.111	0.802	0.595	0.629	0.651	-	0.803	0.044	0.190	0.044	0.932
A14	0.275	0.327	0.275	0.319	0.197	0.197	0.449	0.111	0.276	0.068	0.146	0.146	0.197	-	0	0.146	0	0.405
A15	0.473	0.517	0.517	0.517	0.956	0.956	0.517	0.258	1	0.619	0.827	0.697	0.956	1	-	0.388	0.483	1
A16	0.478	1	0.568	0.612	0.810	0.810	0.690	0.353	0.810	0.551	0.680	0.551	0.810	0.854	0.612	-	0.612	0.854
A17	0.473	0.956	0.517	0.517	0.956	0.956	0.517	0.258	0.956	0.619	0.827	0.697	0.956	1	0.517	0.388	-	1
A18	0.146	0.327	0.146	0.190	0.068	0.755	0.319	0.111	0.068	0.551	0.068	0.146	0.068	0.595	0	0.146	0	-

Table 13: Discordance matrix for example 2.

Alternative	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18
A1	-	1	1	0.490	1	1	0	1	1	1	1	1	1	1	1	1	1	1
A2	0.159	-	0.175	0.180	1	1	0.070	1	0.875	1	0.880	0.530	1	1	1	0.240	1	0.220
A3	0.611	1	-	0	1	1	0	1	1	1	1	1	1	1	1	0.880	1	1
A4	1	1	1	-	1	1	0.270	1	1	1	1	1	1	1	1	1	1	1
A5	0.001	0	0.001	0	-	1	0	1	0.001	1	0.060	0.080	0.004	0	1	0.040	1	0
A6	0.021	0.034	0.022	0.020	0.130	-	0.020	0.306	0.032	1	0.050	0.070	0.061	0	1	0.030	1	0.020
A7	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1
A8	0.044	0.041	0.017	0	0.800	1	0	-	0.035	1	0.070	0.030	0.110	0	1	0.010	1	0.010
A9	0.057	1	0.002	0	1	1	0	1	-	1	0.880	0.350	1	0.770	1	0.100	1	0
A10	0.009	0.009	0.008	0.010	0.020	0.020	0.010	0.014	0.009	-	0.010	0.010	0.012	0	0.020	0.010	0.021	0.010
A11	0.001	1	0.001	0	1	1	0	1	1	1	-	0.180	1	1	1	0	1	0
A12	0.084	1	0.006	0.010	1	1	0	1	1	1	1	-	1	1	1	0	1	0.880
A13	0.025	0	0.001	0	1	1	0	1	0	1	0.100	0.120	-	0	1	0.050	1	0
A14	0.131	0.728	0.145	0.150	1	1	0.120	1	1	1	0.650	0.280	1	-	1	0.130	1	0.400
A15	0.016	0	0.001	0	0.060	0.100	0	0.039	0	1	0.020	0.020	0.006	0	-	0	1	0
A16	0.820	1	1	0.750	1	1	0	1	1	1	1	1	1	1	1	-	1	1
A17	0.018	0.002	0.001	0	0.060	0.100	0	0.035	0.003	1	0.020	0.020	0.011	0	0.071	0	-	0
A18	0.125	1	0.146	0.150	1	1	0.010	1	1	1	1	1	1	1	1	0.250	1	-

Table 14: Ranking of suppliers for example 2 using ELECTRE II.

Supplier	Pure concordance index	Initial rank	Pure discordance index	Initial rank	Average rank	Final rank
1	4.0054	1	11.3680	16	8.5	8
2	-7.3838	11	1.5150	11	11	13
3	3.4886	2	9.9676	14	8	5
4	2.9620	3	13.5100	17	10	9
5	-3.3607	6	-7.8830	6	6	4
6	-7.5285	12	-10.4040	4	8	6
7	-0.0904	4	16.5000	18	11	11
8	-3.1388	5	-8.2270	5	5	2
9	-9.0431	16	0.2040	8	12	15
10	-8.3518	15	-16.7980	1	8	7
11	-7.7641	14	0.4420	9	11.5	16
12	-7.1442	10	4.2900	12	11	12
13	-7.6120	13	-4.9087	7	10	10
14	-13.1359	18	0.9640	10	14	18
15	-4.3190	8	-12.8300	3	5.5	3
16	-4.7249	9	10.8300	15	12	14
17	-3.9338	7	-14.6810	2	4.5	1
18	-12.9679	17	6.1410	13	15	17

6. Conclusion

Two real-time examples demonstrate the potentiality, applicability and similarity of both the compromise ranking and outranking methods in solving supplier selection decision-making problems in different business organizations, involving qualitative as well as quantitative data. Both these methods can incorporate the decision maker's preferences regarding the relative importance of different criteria. The measures of the qualitative and quantitative criteria, and their relative importance are used together to rank the alternative suppliers, providing a better evaluation of the alternatives. The VIKOR method can make a compromise ranking among the alternative suppliers, whereas the ELECTRE method is able to search out the best and next best suppliers from a given set of alternatives in a specific business organization. The results derived using both these multi-criteria decision-making (MCDM) methods exactly match with those as obtained by the past researchers. The compromise ranking and outranking methods can also be used for any type of decision-making problem, involving any number of qualitative and quantitative criteria, and any number of alternatives.

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