

A hybrid MCDM model for strategic vendor selection

Huan-Jyh Shyur^{a,1}, Hsu-Shih Shih^{b,*}

^a *Department of Information Management, Tamkang University, Tamsui, Taipei 25137, Taiwan, ROC*

^b *Graduate Institute of Management Sciences, Tamkang University, Tamsui, Taipei 25137, Taiwan, ROC*

Received 19 April 2005; accepted 28 April 2005

Abstract

Proposed in this study is a hybrid model for supporting the vendor selection process in new task situations. First, the vendor evaluation problem is formulated by the combined use of the multi-criteria decision-making (MCDM) approach and a proposed five-step hybrid process, which incorporates the technique of an analytic network process (ANP). Then the modified TOPSIS (technique for order performance by similarity to idea solution) is adopted to rank competing products in terms of their overall performances. The newly developed ANP will eventually yield the relative weights of the multiple evaluation criteria, which are obtained from the nominal group technique (NGT) with interdependence. An example is solved to illustrate the effectiveness and feasibility of the suggested model. The empirical study has demonstrated how the approach can be used for the strategic vendor selection problem.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: TOPSIS; ANP; NGT; Multiple criteria analysis; Vendor selection; Criteria interdependence

1. Introduction

Because of the emphasis on outsourcing, strategic partnering, strategic alliances, and relationship marketing, many organizations purchase not only raw materials and basic supplies but also complex fabricated components with very high value-added content and services over the last two decades. Vendor selection or supplier evaluation continues to be a key element in the industrial buying process and appears to be one of the major activities of the professional industrial [1,2]. Selecting an appropriate vendor is often a non-trivial task, in which multiple criteria need to be carefully examined. However, many decision makers or experts select vendors based on their experience and intuition. These approaches are obviously subjective and their weakness has been addressed in several previous studies [3,4].

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 vendors from a pool of providers. The MCDM provides an effective framework for vendor comparison based on the evaluation of multiple conflict criteria. de Boer et al. [5] gave a good review and classification of the MCDM approach for supporting vendor selection.

* Corresponding author. Tel.: +886 2 8631 3221; fax: +886 2 8631 3214.

E-mail addresses: shyur@mail.im.tku.edu.tw (H.-J. Shyur), hshih@mail.tku.edu.tw (H.-S. Shih).

¹ Tel.: +886 2 2621 5656x2881; fax: +886 2 2620 9737.

In order to manage the difficulty of determining the performance of a vendor 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 [6,7]. Ghodsypour and O'Brien [6] argue that AHP is more accurate than other scoring methods for vendor selection. Theoretically, the methodology is valuable when the decision-making framework has a unidirectional hierarchical relationship among decision levels. However, Carney and Wallnau [8] 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. Moreover, AHP is not practically usable if the number of alternatives and criteria is large, since the repetitive assessments may cause fatigue in decision-making [9].

Another favorable technique for solving MCDM problems is the TOPSIS (technique for order performance by similarity to idea solution) [3]. TOPSIS is based on the concept that the optimal alternative should have the shortest distance from the positive idea solution (PIS) and the farthest distance from the negative idea solution (NIS). The concept of TOPSIS is rational and understandable, and the computation involved is uncomplicated. However, the inherent difficulty of assigning reliable subjective preferences to the criteria is worth noting.

Due to the fact that criteria are usually interdependent on each other in the real world, traditional approaches, in this regard, cannot be applied appropriately. We will introduce the analytic network process (ANP) [10], an extension of AHP [11], for obtaining a set of suitable weights of the criteria. According to the characteristics of the problem and the techniques, the study will establish a five-step hybrid model, mainly combining ANP and modified TOPSIS, for vendor evaluation. Here, the function of ANP is used to obtain the relative weights of criteria but not the entire evaluation process, which reduces the large number of pair-wise comparisons. As to the performance exhibited by each alternative, the function of the modified TOPSIS, which exploits a newly defined weighted Euclidean distance, aims to rank competing products in terms of their overall performance with multiple criteria. The advantages of the aforementioned two techniques when combined indeed pave a new way for vendor selection, given the fact that they do not account for deriving the evaluation criteria for the selection in the first place. Moreover, our proposed model shall provide organizations with a way to devise and refine adequate criteria and alleviate the risk of selecting sub-optimal solutions.

The rest of this paper is structured as follows. In the next section, the proposed vendor selection procedure is presented and an overview of the techniques is given. Section 3 will focus on the proposed hybrid model. Then an empirical example is illustrated in Section 4. In the final section, some conclusions are drawn for the study.

2. Literature survey

Vendor 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 vendor(s) for the organizations based on various vendors' capabilities. This usually happens when the purchase is complex, high-dollar-value, and perhaps critical [12]. Also, a process of formal vendor evaluation and ranking is necessary. The process for vendor selection is indeed a problem-solving process, which covers the works of problem definition, formulation of criteria, qualification, and choice [13]. However, most articles deal with qualification and choice phases to which operations research related techniques are adapted [5,14].

Due to the fact that the evaluation always involves conflicting performance criteria of vendors, the techniques of MCDM are coherently derived to manage the problem. We can roughly divide these quantitative approaches into four categories: multi-attribute decision making (or a general view of linear weighting models), multi-objective optimization (or a general view of mathematical/linear programming models), statistics/probabilistic approaches, intelligent approaches, and others [5,15,16]. Five categories, each with their own related approaches and examples, are listed in Table 1.

Additionally, the first category concentrates on selection activities, which adopt a limited and countable number of predetermined alternatives through multiple attributes or criteria. The alternatives associate with them the level of achievement of the attributes. Though it may still be in doubt whether they are quantifiable or not, those attributes will act as a platform upon which the final choice is to be made [3]. Most approaches utilized, such as AHP, conjoint analysis, the linear weighting (or scoring) method, and the outranking method can be classified into this category.

The second category involves the design for the best or required alternative by taking into consideration the various interactions within the design constraints that best satisfy the decision maker by way of attaining some acceptable levels of a set of some quantifiable objectives. Its alternatives have been implicitly expressed in the feasible zone of

Table 1
Taxonomy of approaches of vendor evaluation

	Category	Approach	Proposed by
1.	MADM models	AHP Conjoint analysis Linear weighting method Outranking method	Nydick and Hill [17] Mummalaneni et al. [18] Dobler and Burt [12] de Boer et al. [19]
2.	MODM models	ε -constraint method DEA Goal programming	Weber and Current [20] Weber [21] Buffa and Jackson [22]
3.	Statistical/probabilistic approaches	Categorical method Cluster analysis Uncertainty analysis	Zenz [23] Hinkle et al. [24] Soukoup [25]
4.	Intelligence approaches	Case-based reasoning Expert system Genetic algorithm Neural network	Cook [26] Vokurka et al. [27] Ding et al. [28] Wei et al. [29]
5.	Others	Activity-based costing Interpretive structure modeling	Roodhooft and Konings [30] Mandal and Deshmukh [31]

a constraint set, so that the most satisfactory objectives can be obtained [32]. Techniques such as the ε -constraint method, data envelopment analysis (DEA), and goal programming contribute to this category.

The third category focuses on the evaluation which relies on a large number of tests or surveys or deals with the stochastic uncertainty related to the vendor choice (Refs. [5,16]). The categorical method, cluster analysis and uncertainty analysis all fall into this category.

The fourth category will explore some newly developed intelligent techniques, such as case-based reasoning, expert systems, genetic algorithms, and neural networks, to process the activities of vendor selection. It is hoped that the preferred suggestion can be made within this stage. Since problems in the vendor evaluation process are widely examined for various materials and services purposes, some specific techniques are proposed and grouped into the fifth category covering what has been left out in the previous four categories. In addition, since ranking and selection are the major concerns for our problem, this study will devote much effort on the first category, with a deliberate account of the process involved.

One drawback of the above approaches is neglecting the interdependence of attributes or criteria for evaluation. Only a few papers currently address this point, and none of them deal with vendor selection. To overcome the problem of dependence, we take advantage of ANP [10] instead of AHP [11] to elicit the weights of criteria due to their capability of processing the interdependence between criteria. Furthermore, we also utilize TOPSIS for further evaluation to avoid ranking reversal and to ease accommodating a great many candidates (Refs. [13,33]). The advantage associated with the above two approaches is our main concern in developing a tentative hybrid model.

After a choice model is identified, the process starts with obtaining a set of criteria or attributes to describe vendor performance, which will be evaluated accordingly. Since the evaluation is usually under multiple attributes, most formal vendor selection schemes trace vendor performance on quality, price, delivery, and service [34]. From the practical viewpoint, a set of criteria can be defined to fit the requirement for special purposes. Dickson first proposed 23 criteria for vendor selection (see [16]). Swift [35] has examined 21 supply-selection attributes of purchasing managers for single sourcing. At the same time, Mummalaneni et al. [18] have identified six attributes—on-time delivery, quality, price/cost targets, professionalism, responsiveness to customer needs, and long-term relationship with the purchasing company—as the performance criteria of suppliers for Chinese purchasing managers. Furthermore, de Boer et al. [19] considered turnover, distance, cost level, and quality image for evaluating suppliers. Moreover, various organizations evaluate their vendors through different criteria. We list some of these criteria by lines of business in Table 2, with

Table 2
Applications of selected attributes/criteria for vendor evaluation

Lines of business	Attributes/Criteria	Proposed by
1. Baby food manufacturer	Price, Quality, Delivery.	Weber [21]
2. Bicycle manufacturer	Quality, Delivery, Price, Facility, Technical capability, Financial position, Past performance attitude, Flexibility, Service.	Muralidharan et al. [36]
3. Bottling machinery industry	Product price, Shipment quality, Delivery compliance.	Petroni and Braglia [15]
4. Equipment manufacturer	Acquisition costs, Product quality, Delivery reliability.	Karpak et al. [37]
5. High-tech company	Technical, Market, Organizational.	Meade and Presley [38]
6. Public road and rail transportation	Make-up, Processing time, Prototyping time, Design revision time, Quality system, Co-design, Technological level.	Dulmin and Mininno [14]
7. Telecommunications company	Cost (capital expenditure, operating expenditure), Quality (technical, operational, vendor).	Tam and Tummala [39] (five attributes at its lower level)

which seven types of firms are investigated. Also, price, quality, and delivery are the three criteria most concerned for vendor selection. According to the survey, we will later develop a couple of appropriate criteria for our problem.

3. The proposed model

Based on the formation of the partnership pyramid by Weber et al. [40], we modify the selection process to a five-step hybrid procedure, as follows (illustrated in Fig. 1):

- Step 1. Identification of necessary criteria for vendor selection.
- Step 2. Recognition of the interdependence between criteria.
- Step 3. Eliciting the weights of criteria.
- Step 4. Evaluation of vendors.
- Step 5. Negotiation for the purchase.

The first step is to identify, through the nominal group technique (NGT) [41], the necessary criteria for which the examination of applicability is vital in the vendor selection process for making an objective and unbiased decision. Then, the degree of interdependent relationship between different criteria is determined by the expert group via NGT, and the interdependence will affect the final weights of criteria. Afterwards, each decision maker or expert elicits an appropriate weight for each criterion using the ANP. TOPSIS is modified for group decision making, while all of its activities are investigated. The modified TOPSIS is then employed to create a decision matrix to help ease and finalize the selection process. Also, individual preferences are included in the group consensus ranking procedure. Finally, the organization will negotiate with preferred vendor(s) for targeted strategic purchases. The descriptions of the kernel activities in those major steps are elaborated in the following sub-sections.

3.1. Evaluation criteria with interdependence

In the vendor evaluation process, an objective, unbiased decision is very hard to reach given the numerous criteria that need to be carefully considered and examined. One formal group management technique for determining a set of evaluation criteria is NGT [41]. This well-known process forces everyone to participate and no dominant person is allowed to come out and control the proceedings. In NGT, all ideas have equal stature and will be judged impartially by the group. In our problem, seven potential evaluation criteria are determined as follows:

- ◆ On-time delivery (C1).
- ◆ Product quality (C2).
- ◆ Price/cost (C3).
- ◆ Facility and technology (C4).
- ◆ Responsiveness to customer needs (C5).
- ◆ Professionalism of salesperson (C6).
- ◆ Quality of relationship with vendor (C7).

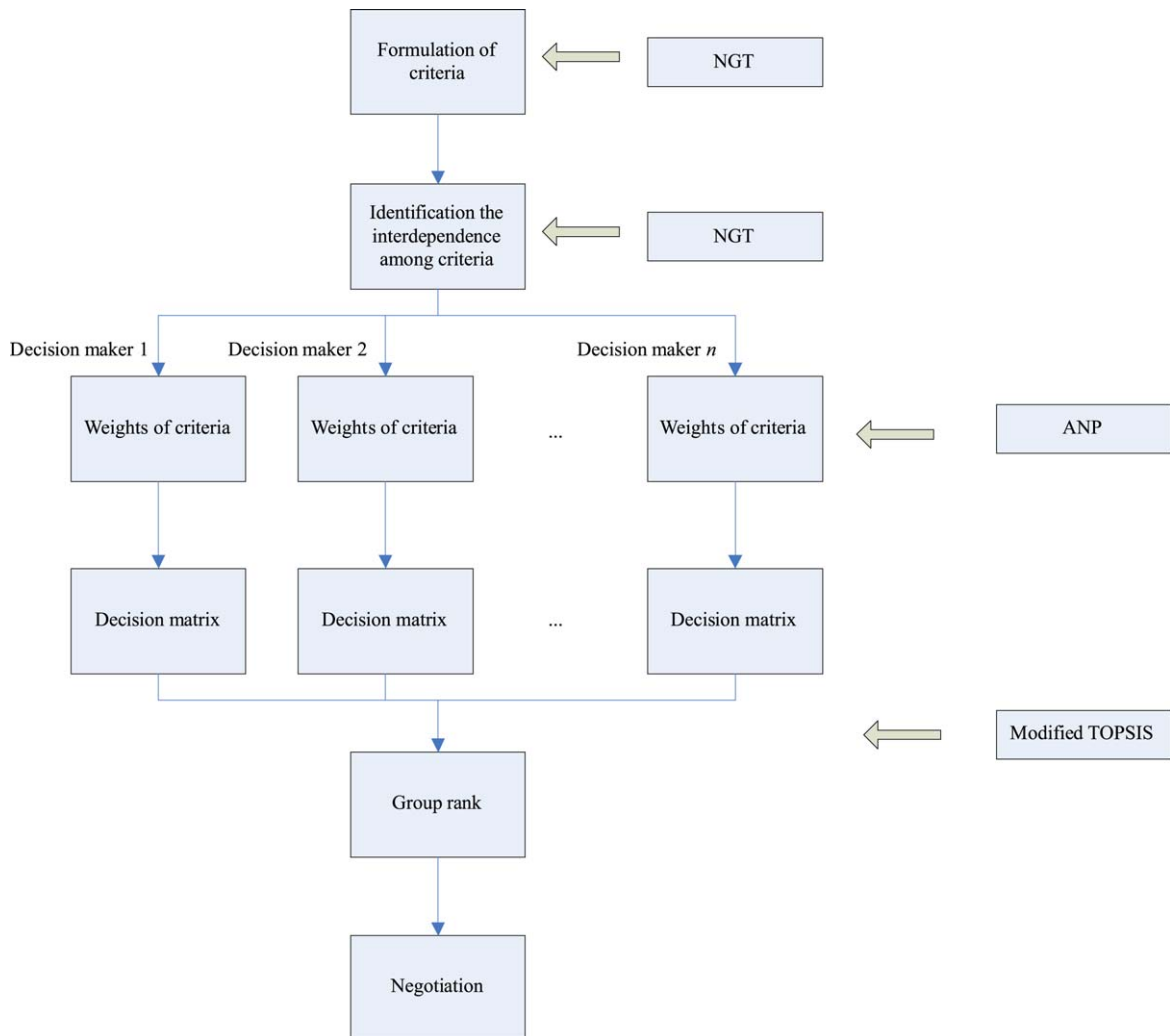


Fig. 1. The proposed framework for vendor selection.

To simplify the process and avoid any misunderstandings, the interaction between any two of these criteria is not considered in the first instance. These criteria may not include all of the decision factors in vendor selection. However, they are indeed meaningful measures and have been emphasized in many leading articles [18,16,42].

Next, in order to reflect the interdependence property between the criteria, we need to identify the exact relationship in a network structure of ANP. Another NGT process is taken to construct the relationship based on the following two recognitions:

- ◆ Price/cost may be influenced by the quality of products and the relationship with vendors.
- ◆ Product quality may be influenced by facility and technology.

Fig. 2 represents the relationship of interdependency. A single arrow implies a one-way relationship. For example, the arrow that leaves from C2 and feeds into C3 implies that the relationship of criterion C2 has an influence on criterion C3.

3.2. Determination of the weights of criteria

To determine the relationship of the degree of interdependence, the ANP technique, which is an extension of AHP, is used to address the relative importance of the criteria. ANP is developed to generate priorities for decisions without

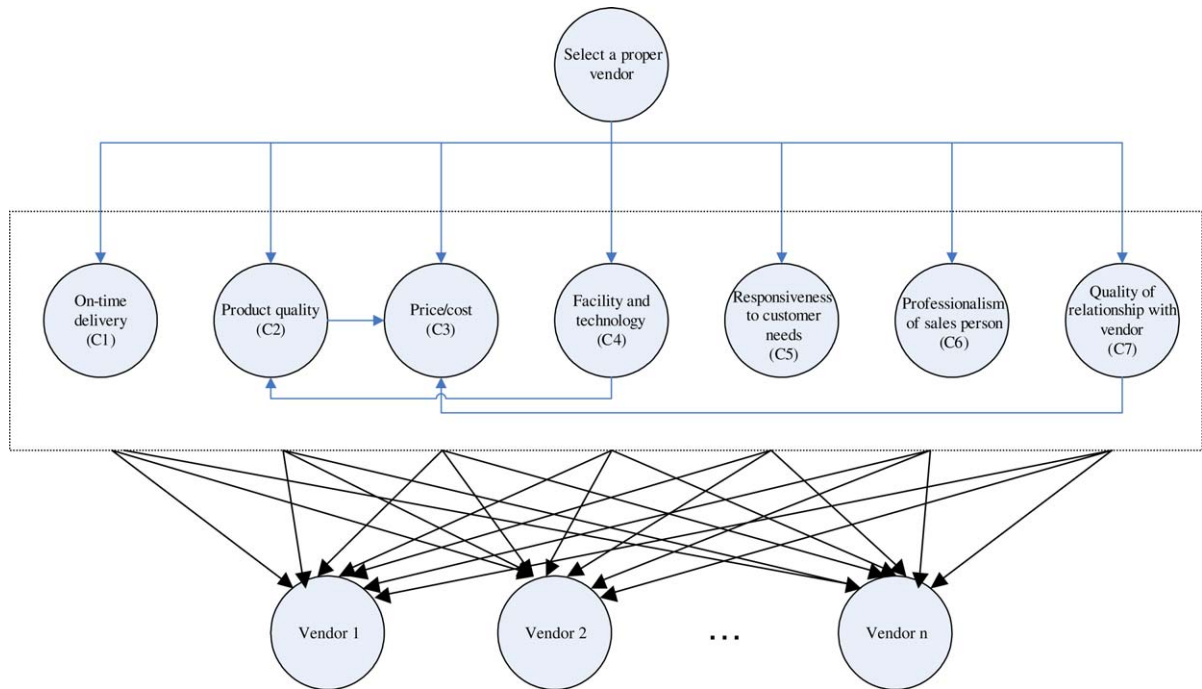


Fig. 2. The interdependent relationship between the selected criteria.

making assumptions about a unidirectional hierarchy relationship between decision levels [10,43]. To take the place of a linear top-to-bottom form of strict hierarchy, the ANP model provides a looser network structure and possibly represents any decision problem. The relative importance or strength of the impacts on a given element is measured on a ratio scale, which is similar to AHP.

In comparison to AHP, ANP is capable of handling interrelationships between the decision levels and attributes by obtaining the composite weights through the development of a “supermatrix”. The supermatrix is a partitioned matrix, where each submatrix is composed of a set of relationships between two components or clusters in a connection network structure. Saaty [10] explains the concept corresponding to the Markov chain process. Here, the matrix manipulation relies on the concept of Saaty and Takizawa [44] instead of Saaty’s original supermatrix for ease of understanding.

Because of the characteristic of vendor selection, we explore the appropriateness of ANP allowing the explicit consideration of interactions in the process (see [45]). The remaining work will deal with three activities described as follows.

Activity 1

Without assuming the interdependence between criteria, the decision makers or experts are asked to evaluate all proposed criteria pair-wise. They responded to questions such as: “Which criteria should be emphasized more in a vendor, and how much more?” The responses were presented numerically and scaled on the basis of Saaty’s 1–9 scale [11], where 1 represents indifference between the two criteria and 9 represents extreme preference for one criterion over the compared criterion. Each pair of criteria is judged only once. A reciprocal value will be assigned automatically for the reverse comparison. Once the pair-wise comparisons are completed, the local priority vector w_1 is computed as the unique solution of

$$Aw_1 = \lambda_{\max} w_1 \quad (1)$$

where λ_{\max} is the largest eigenvalue of pair-wise comparison matrix A . All obtained vectors are further normalized to represent the local priority vector w_2 .

Activity 2

Next, the effects of the interdependence between the criteria are resolved. The group members will examine the impact of all criteria on each other by pair-wise comparisons too. To help smooth the comparison process, a couple of questions such as “Which criterion will influence criterion C3 more: C2 or C7? And how much more?” are answered. Various pair-wise comparison matrices are constructed for each criterion. These pair-wise comparison matrices are needed for identifying the relative impacts of criteria interdependent relationships. The normalized principal eigenvectors for these matrices are calculated and shown as column components in interdependence weight matrix B , where zeros are assigned to the eigenvector weights of the criteria with no interdependent relationship.

Activity 3

Now we can obtain the interdependence priorities of the criteria by synthesizing the results from the previous two steps as follows:

$$w_c = Bw_2^T. \quad (2)$$

Thus, the weights of the evaluation criteria can be determined.

3.3. The ranking and selection process

Once the weights of criteria are obtained, a modified TOPSIS approach is proposed for conducting the ranking process. The full ANP, even AHP, solution is usable in a realistic or sensitive way only if the number of criteria and alternatives is limited. Also, the number of pair-wise comparisons, performed by decision makers or experts, must remain below a reasonable threshold. For example, if there are n criteria that have been assigned the importance weights and m alternatives, then there are $n \cdot m \cdot (m-1)/2$ pair-wise comparisons remaining to be performed for running a full ANP solution. Due to a large number of potential available vendors in the current marketing environment, a full ANP decision process becomes impractical in some cases. To avoid an unreasonably large number of pair-wise comparisons, we choose TOPSIS as the ranking technique because of its concept's ease of use (see [13]). Also, ANP is adopted simply for the acquisition of the weights of criteria.

Moreover, to include the multiple preferences from several decision makers, we modify TOPSIS at its separation measures by taking the geometric mean of the measures of individuals. In the following contents, we first illustrate the activities and then describe the modified activity corresponding to the original one's. First, a general TOPSIS process with six activities is listed below.

Activity 1

Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{matrix} & \begin{matrix} F_1 & F_2 & \cdots & F_j & \cdots & F_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} & \left[\begin{matrix} f_{11} & f_{12} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2j} & \cdots & f_{2n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{i1} & f_{i2} & \cdots & f_{ij} & \cdots & f_{in} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mj} & \cdots & f_{mn} \end{matrix} \right] \end{matrix}$$

where A_i denotes the alternatives i , $i = 1, \dots, m$; F_j represents j th attribute or criterion, $j = 1, \dots, n$, related to i th alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j .

Activity 2

Calculate the normalized decision matrix \mathbf{R} ($=[r_{ij}]$). The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^n f_{ij}^2}}, \quad (3)$$

where $j = 1, \dots, n; i = 1, \dots, m$.

Activity 3

Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_j r_{ij}, \quad j = 1, \dots, n; i = 1, \dots, m, \quad (4)$$

where w_j represents the weight of the j th attribute or criterion.

Activity 4

Determine the PIS and NIS, respectively:

$$\begin{aligned} V^+ &= \{v_1^+, \dots, v_n^+\} \\ &= \{(\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J')\}, \\ V^- &= \{v_1^-, \dots, v_n^-\} \\ &= \{(\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J')\}, \end{aligned} \quad (5)$$

where J is associated with the benefit criteria, and J' is associated with the cost criteria.

Activity 5

Calculate the separation measures, using the m -dimensional Euclidean distance. The separation measure D_i^+ of each alternative from the PIS is given as:

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}, \quad i = 1, \dots, m. \quad (6)$$

Similarly, the separation measure D_i^- of each alternative from the NIS is as follows:

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, \quad i = 1, \dots, m. \quad (7)$$

Activity 6

Calculate the relative closeness to the idea solution and rank the alternatives in descending order. The relative closeness of the alternative A_i with respect to PIS V^+ can be expressed as:

$$\bar{C}_i = \frac{D_i^-}{D_i^+ + D_i^-}, \quad i = 1, \dots, m \quad (8)$$

where the index value of \bar{C}_i lies between 0 and 1. The larger the index value, the better the performance of the alternatives.

We can observe that a set of vendors is to be compared with respect to the criteria in the above activities. The performance rating of each alternative for each criterion is assigned and formed as a decision matrix. Also, the normalization formula, as shown in Eq. (3), is used to transform various scales into a comparable scale. The

normalized decision matrix is weighted by multiplying each column of the matrix by its associated weights of criteria in the above process. Then the overall performance of an alternative is determined by its Euclidean distance to V^+ and V^- . However, Shipley et al. [46] point out that this distance is interrelated with the criteria weights and should be incorporated in the distance measurement. This is because all alternatives are compared with V^+ and V^- , rather than directly among themselves. Deng et al. [47] present the weighted Euclidean distances instead of creating a weighted decision matrix. In the modified process, we define the PIS (R^+) and the NIS (R^-), which are not depend on the weighted decision matrix, as

$$\begin{aligned} R^+ &= \{r_1^+, \dots, r_n^+\} \\ &= \{(\max_i r_{ij} | j \in J), (\min_i r_{ij} | j \in J')\}, \\ R^- &= \{r_1^-, \dots, r_n^-\} \\ &= \{(\min_i r_{ij} | j \in J), (\max_i r_{ij} | j \in J')\}. \end{aligned} \quad (9)$$

The weighted Euclidean distances, between A_i and R^+ , and between A_i and R^- , are calculated, respectively, as

$$D_i^+ = \sqrt{\sum_{j=1}^n w_j (r_{ij} - r_j^+)^2}, \quad D_i^- = \sqrt{\sum_{j=1}^n w_j (r_{ij} - r_j^-)^2}, \quad i = 1, \dots, m, \quad (10)$$

where the value of w_j ($j = 1, \dots, n$) is the element of vector w_c which is obtained from Eq. (2).

To derive group preferences provided by multiple decision makers and combine the group synthesis and prioritization stages into a single integrated stage, we employ the geometric mean with the modified TOPSIS approach. Consider a group of k decision makers. The decision maker j can provide a set of weighted Euclidean distances D_{ij}^+ and D_{ij}^- , $i = 1, \dots, m$, by Eq. (10). Both distances from each decision maker can be aggregated as the distances of the group by taking the geometric mean:

$$\overline{D}_i^+ = \left(\prod_{j=1}^k D_{ij}^+ \right)^{\frac{1}{k}}, \quad \overline{D}_i^- = \left(\prod_{j=1}^k D_{ij}^- \right)^{\frac{1}{k}}, \quad i = 1, \dots, m. \quad (11)$$

Thus, referred to Eq. (8), we can also define the group's aggregated separation distances in the following form:

$$\overline{C}_i = \frac{\overline{D}_i^-}{\overline{D}_i^+ + \overline{D}_i^-}, \quad i = 1, \dots, m. \quad (12)$$

Finally, a set of alternatives can be ranked in descending order of closeness coefficient calculated using Eq. (12).

4. An illustrative example

An example of vendor selection, supported by a local Taiwanese company, is performed by the suggested hybrid approach. Four vendors, A1, A2, A3, and A4, are involved for evaluation. A team of three is charged in this project. Seven criteria, defined in Section 3.1, are considered for the selection (Step 1 and Step 2), and the other steps are summarized as follows:

Step 3: The decision makers are asked to evaluate all criteria pair-wise without assuming the interdependence between them. Due to space constraints, we only present an evaluation result of decision maker 1, shown in Table 3. The normalized eigenvector can be calculated as $w_2 = (C1, C2, C3, C4, C5, C6, C7) = (0.347, 0.247, 0.142, 0.035, 0.084, 0.043, 0.101)$ which represents the related local priority of these criteria. The degree of consistency of the pair-wise comparison is measured with the use of the consistency ratio (CR) index [11]. It is considered logically consistent if CR is less than or equal to 0.1. The CR value for this case is 0.058, which is acceptable.

Step 4: The interdependence between the criteria is now considered. All decision makers or group members examine the impact of all the criteria by pair-wise comparison. In total, there are seven comparison matrices generated by all members. The normalized eigenvector for these matrices developed by the first member is calculated and shown as seven columns in Table 4, where zeros are assigned to the eigenvector weights of the criteria with no interdependent

Table 3

The pair-wise comparison matrix for criteria (decision maker 1)

	C1	C2	C3	C4	C5	C6	C7	Vector weights
C1	1	2	4	5	4	6	4	0.346
C2	1/2	1	3	4	4	5	3	0.247
C3	1/4	1/3	1	1/3	2	1/5	1/2	0.142
C4	1/5	1/4	3	1	4	1/2	2	0.035
C5	1/4	1/4	1/2	1/4	1	1/4	1/3	0.084
C6	1/6	1/5	5	2	4	1	3	0.043
C7	1/4	1/3	2	1/2	3	1/3	1	0.101

Table 4

Degree of relative impact for evaluation criteria (decision maker 1)

	C1	C2	C3	C4	C5	C6	C7
C1	1	0	0	0	0	0	0
C2	0	0.866	0.236	0	0	0	0
C3	0	0	0.606	0	0	0	0
C4	0	0.134	0	1	0	0	0
C5	0	0	0	0	1	0	0
C6	0	0	0	0	0	1	0
C7	0	0	0.158	0	0	0	1

Table 5

Normalized decision matrix (decision maker 1)

	C1	C2	C3	C4	C5	C6	C7
A ₁	0.552	0.396	0.431	0.453	0.462	0.629	0.375
A ₂	0.552	0.594	0.323	0.543	0.577	0.449	0.375
A ₃	0.442	0.495	0.647	0.543	0.577	0.449	0.600
A ₄	0.442	0.495	0.539	0.453	0.346	0.449	0.600

relationship. The data in Table 4 imply the relative impact of part of the criteria on others. For example, the degree of relative impact of C2 for C3 is 0.236.

The relative importance of the criteria considering interdependence can be obtained by synthesizing the results:

$$w_c = \begin{bmatrix} C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \\ C7 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.866 & 0.236 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.606 & 0 & 0 & 0 & 0 \\ 0 & 0.134 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0.158 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0.346 \\ 0.247 \\ 0.142 \\ 0.035 \\ 0.084 \\ 0.043 \\ 0.101 \end{bmatrix} = \begin{bmatrix} 0.346 \\ 0.247 \\ 0.086 \\ 0.068 \\ 0.084 \\ 0.043 \\ 0.123 \end{bmatrix}.$$

According to the vector from decision maker 1, C1, C2, and C7 are three of the most important factors related to the evaluation process.

At the next level of the decision process, the decision makers are asked to establish the decision matrix by comparing candidates under each criterion separately. The criteria are assumed to be benefit criteria and they were asked to give a set of crisp values within the range of 1 to 10 to represent the performance of each alternative with respect to each criterion. After the decision matrices are determined, we normalize these matrices via Eq. (3). Table 5 shows the result of decision maker 1.

Step 5: Based on the PIS and NIS, the ranking activities will start. By Eq. (9), the PIS and NIS for decision maker 1 will be:

$$R^+ = (0.552, 0.594, 0.647, 0.543, 0.577, 0.629, 0.600),$$

$$R^- = (0.442, 0.396, 0.323, 0.453, 0.346, 0.449, 0.375).$$

Table 6
Separation distances of the group

	DM#1		DM#2		DM#3		Aggregated separation distances	
	D_i^+	D_i^-	D_i^+	D_i^-	D_i^+	D_i^-	\bar{D}_i^+	\bar{D}_i^-
A_1	0.151	0.064	0.208	0.080	0.236	0.017	0.195	0.044
A_2	0.146	0.120	0.185	0.114	0.141	0.165	0.157	0.131
A_3	0.089	0.165	0.126	0.234	0.025	0.222	0.066	0.205
A_4	0.120	0.119	0.197	0.133	0.160	0.103	0.156	0.118

Note: DM = decision maker.

Table 7
Final rank of the vendor selection problem

Rank	Alternative	Closeness coefficient
1	A_3	0.758
2	A_2	0.457
3	A_4	0.430
4	A_1	0.185

Using the criteria weights (w_c) obtained from step 1–3 and Eq. (10), the weighted Euclidean distances, between A_i and R^+ , and between A_i and R^- , can be calculated immediately. Table 6 represents the separation distances developed by all three members. Next, to derive group priorities, the group's aggregated separation distances are generated by its geometric mean. The last two columns of Table 6 show the results. Finally, the relative closeness to the idea solution of each alternative can be calculated using Eq. (12). The final results can be seen in Table 7. According to the closeness coefficient, the ranking order of the four candidates is A_3 , A_2 , A_4 , and A_1 . Obviously, the best selection is candidate A_3 . In our empirical study, a refinement and negotiation process was performed to form a partnership between the buyer and the seller for strategic materials (Step 6). In the final stage, alternative A_3 is still selected as the final winner after refinement and negotiation process.

5. Conclusions

We present an effective model using both ANP and modified TOPSIS techniques for strategic vendor selection. To accommodate the criteria with interdependence, the ANP method is selected to obtain the relative weight of criteria. As a result of the empirical study, we find that the proposed method is practical for ranking competing vendors in terms of their overall performance with respect to multiple interdependence criteria.

We believe that the approach presented here has room for future enhancement and validation, for example extending the proposed model to handle the inherent uncertainty and imprecision of human judgment. The use of ANP, for determining the criterion weights, requires complex matrix operations on real number; a traditional fuzzy concept cannot be used directly in the matrix calculations of the ANP [48]. Some revisions of ANP for uncertainty may be a new direction for future development.

In conclusion, we hold a firm belief that the underlying concept of this approach is both rational and comprehensible. Consideration of relationships between criteria presented in this paper provides organizations with a way to devise and refine adequate criteria and alleviate the risk of selecting sub-optimal solutions.

Acknowledgements

The authors would like to express their gratitude to Professor E. Stanley Lee at the Department of Industrial and Manufacturing Systems Engineering, Kansas State University, USA and Professor Chi-chiang Jou at the Department of Information Management at Tamkang University, Taiwan for their valuable help. Special thanks are given to National Science Council, Taiwan, ROC, for financial support under the grant numbers: NSC 90-2416-H-032-019, 90-2218-E-214-010, NSC 91-2213-E-032-035, and NSC 92-2213-E-032-032.

References

- [1] W.E. Patton, Individual and joint decision making in industrial vendor selection, *Journal of Business Research* 38 (1997) 115–122.
- [2] R. Michaels, A. Kumar, S. Samu, Activity-specific role stress in purchasing, *International Journal of Purchasing and Materials Management* 31 (1) (1995) 11–19.
- [3] C.L. Hwang, K. Yoon, *Multiple Attribute Decision Making*, Springer-Verlag, Berlin, 1981.
- [4] J. Kontio, A case study in applying a systematic method for COTS selection, in: *Proceedings of the 18th International Conference on Software Engineering*, 25–30 March 1996, 1996, pp. 201–209.
- [5] L. de Boer, E. Labro, P. Morlacchi, A review of methods supporting supplier selection, *European Journal of Purchasing and Supply Management* 7 (2001) 75–89.
- [6] S.H. Ghodysypour, C. O'Brien, A decision support system for supplier selection using an integrated analysis hierarchy process and linear programming, *International Journal of Production Economics* 56–57 (1998) 199–212.
- [7] H. Min, Selection of software—the analytic hierarchy process, *International Journal of Physical Distribution and Logistics Management* 22 (1) (1992) 42–52.
- [8] D.J. Carney, K.C. Wallnau, A basis for evaluation of commercial software, *Information and Software Technology* 40 (1998) 851–860.
- [9] L.C. Briand, COTS evaluation and selection, in: *Proceeding of the International Conference on Software Maintenance*, 16–20 November 1998, 1998, pp. 222–223.
- [10] T.L. Saaty, *Decision Making with Dependence and Feedback: the Analytic Network Process*, RWS, Pittsburgh, PA, 1996.
- [11] T.L. Saaty, *The Analytic Hierarchy Process*, McGraw-Hill, New York, 1980.
- [12] D.W. Dobler, D.N. Burt, *Purchasing and Supply Management*, 6th edition, McGraw-Hill, NY, 1996.
- [13] H.S. Shih, C.H. Wang, E.S. Lee, A multiattribute GDSS for aiding problem-solving, *Mathematical and Computer Modelling* 39 (11–12) (2004) 1397–1412.
- [14] R. Dulmin, V. Mininno, Supplier selection using a multi-criteria decision aided method, *Journal of Purchasing and Supply Management* 9 (2003) 177–187.
- [15] A. Petroni, M. Braglia, Vendor selection using principal component analysis, *Journal of Supply Chain Management* 36 (2) (2000) 63–69.
- [16] C.A. Weber, J.R. Current, W.C. Benton, Vendor selection criteria and methods, *European Journal of Operational Research* 50 (1) (1991) 2–18.
- [17] R.I. Nydick, R.P. Hill, Using the analytic hierarchy process to structure the supplier selection procedure, *International Journal of Purchasing and Materials Management* 28 (2) (1992) 31–36.
- [18] V. Mummalaneni, K.M. Dubas, C. Chao, Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation, *Industrial Marketing Management* 25 (1996) 115–124.
- [19] L. de Boer, L. van der Wegen, J. Telgen, Outranking methods in support of supplier selection, *European Journal of Purchasing and Supply Management* 4 (1998) 109–118.
- [20] C.A. Weber, J.R. Current, A multi-objective approach to vendor selection, *European Journal of Operational Research* 68 (2) (1993) 173–184.
- [21] C.A. Weber, A data envelopment analysis approach to measure vendor performance, *Supply Chain Management* 1 (1) (1996) 28–39.
- [22] F.P. Buffa, W.M. Jackson, A goal programming model for purchasing planning, *Journal of Purchasing and Materials Management* 19 (3) (1983) 27–34.
- [23] G. Zenz, *Purchasing and the Management of Materials*, Wiley, New York, 1981.
- [24] C.L. Hinkle, P.J. Green, P.E. Green, Vendor evaluation using cluster analysis, *Journal of Purchasing* 5 (3) (1969) 49–58.
- [25] W.R. Soukup, Supplier selection strategies, *Journal of Purchasing and Materials Management* 23 (3) (1987) 7–12.
- [26] R.L. Cook, Case-based reasoning systems in purchasing: applications and development, *International Journal of Purchasing and Materials Management* 33 (1) (1997) 32–39.
- [27] R.J. Vokurka, J. Choobineh, L. Vadi, A prototype expert system for the evaluation and selection of potential suppliers, *International Journal of Operations and Production Management* 16 (12) (1996) 106–127.
- [28] H. Ding, L. Benyoucef, X. Xie, A simulation-optimization approach using genetic search for supplier selection, in: *Proceeding of the 2003 Winter Simulation Conference*, 7–10 December, New Orleans, LA, USA, vol. 2, 2003, pp. 1260–1267.
- [29] S. Wei, J. Zhang, Z. Li, A supplier-selecting system using a neural network, in: *IEEE International Conference on Intelligent Processing System*, 28–31 October, Beijing, China, vol. 1, 1997, pp. 468–471.
- [30] F. Roodhooft, J. Konings, Vendor selection and evaluation: an activity based costing approach, *European Journal of Operational Research* 96 (1996) 97–102.
- [31] A. Mandal, S.G. Deshmukh, Vendor selection using interpretive structural modeling (ISM), *International Journal of Operations and Production Management* 14 (6) (1994) 52–59.
- [32] C.L. Hwang, A.S.M. Masud, *Multiple Objective Decision Making—Methods and Applications*, Springer-Verlag, Berlin, 1979.
- [33] H.S. Shih, W.Y. Lin, E.S. Lee, Group decision making for TOPSIS, IFSA/NAFIPS 2001, 25–28 July, Vancouver, Canada, 2001, pp. 2712–2717.
- [34] M.R. Leenders, H.E. Fearon, A.E. Flynn, P.F. Johnson, *Purchasing and Supply Management*, 11th edition, McGraw-Hill, NY, 2002.
- [35] C.O. Swift, Preferences for single sourcing and supplier selection criteria, *Journal of Business Research* 32 (1995) 105–111.
- [36] C. Muralidharan, N. Anantharaman, S.G. Deshmukh, A multi-criteria group decision making model for supplier rating, *Journal of Supply Chain Management* 38 (4) (2002) 22–33.
- [37] B. Karpak, E. Kumcu, R. Kasuganti, An application of visual interactive goal programming: a case in vendor selection decisions, *Journal of Multi-criteria Decision Analysis* 8 (1999) 93–105.
- [38] L.M. Meade, A. Presley, R&D project selection using the analytic network process, *IEEE Transactions on Engineering Management* 49 (1) (2002) 59–66.

- [39] M.C.Y. Tam, V.M.R. Tummala, An application of the AHP in vendor selection of a telecommunications system, *Omega* 29 (2001) 171–182.
- [40] C.A. Weber, J.R. Current, A. Desai, VENDOR: a structured approach to vendor selection and negotiation, *Journal of Business Logistics* 21 (1) (2000) 135–167.
- [41] A.L. Delbecq, A.H. Van de Ven, D.H. Gustafson, *Group Techniques for Program Planning*, Scott, Foresman and Company, IL, 1975.
- [42] L. de Boer, L. van der Wegen, Practice and promise of formal supplier selection: a study of four empirical cases, *Journal of Purchasing and Supply Management* 9 (2003) 109–118.
- [43] T.L. Saaty, Fundamentals of the analytic network process, in: *The Fifth International Symposium on the Analytic Hierarchy Process ISAHP*, 12–14 August, Kobe, Japan, 1999, pp. 1–14.
- [44] T.L. Saaty, M. Takizawa, Dependence and independence — from linear hierarchies to nonlinear networks, *European Journal of Operational Research* 26 (1986) 229–237.
- [45] H.J. Shyur, A semi-structured process for ERP systems evaluation, *Journal of e-Business* 5 (1) (2003) 33–49.
- [46] M.F. Shipley, D.K. Korvin, R. Obit, A decision making model for multi-attribute problems incorporating uncertainty and bias measures, *Computers and Operations Research* 18 (1991) 335–342.
- [47] H. Deng, C.H. Yeh, R.J. Willis, Inter-company comparison using modified TOPSIS with objective weights, *Computers and Operations Research* 27 (2000) 963–973.
- [48] L. Mikhailov, M.G. Singh, Fuzzy analytic network process and its application to the development of decision support systems, *IEEE Transactions on Systems, Man, and Cybernetics — Part C: Applications and Reviews* 33 (1) (2003) 33–41.