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Full Length Research Paper

Strategic outsourcing investment in high technology industry

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In a highly competitive industry, especially high-tech industry, a firm needs to have appropriate outsourcing strategies in order to survive. However, a firm used to have a strategic dilemma between supplier-oriented strategy and production-oriented strategy. Because of increasing complexity in the socio-economic surroundings along with rapidly changing technologies, how to have a suitable outsourcing investment is becoming an important focus for companies. However, there is no such a research in previous literatures. In order to fill the vacancy, the paper tries to briefly discuss the mechanisms of strategic outsourcing investment, its critical success criteria, and then introduce different evaluation models to help in having suitable outsourcing investment. Finally, the paper finds that an analytic network process (ANP) associated with benefits, opportunities, costs and risks (BOCR), is optimal to help companies to select the most suitable outsourcing investment projects.

Key words: Analytic Network Process (ANP), Benefits, Opportunities, Costs and Risks (BOCR), strategic outsourcing investment.

INTRODUCTION

Over the past several years, there is an emphasis on strategic outsourcing that establishes long-term mutually beneficial relationship with fewer but better suppliers. (Talluri and Narasimhan, 2004). Strategic outsourcing decisions are generally related with evaluating the potential strategic suppliers that can effectively meet the long-term expectations of companies, developing and implementing the strategic partnership with these suppliers by involving in supplier development programs to increase supplier performance and providing continuous feedback to the suppliers (Araz and Ozkarahan, 2007; Chen and Lee, 2009).

In today's global economy where concurrent product and supplier development are often the rule, strategic supplier decisions must not be solely based on traditional selection criteria, such as cost, quality and delivery. In strategic outsourcing, many other criteria should be considered with the aim of developing a long-term supplier relationship such as quality management practices, long-term management practices, financial strength, technology and innovativeness level, suppliers' cooperative attitude, supplier's co-design capabilities, and cost reduction capabilities (Talluri and Narasimhan, 2004; Busom and Ferbabdez-Ribas, 2008; Bai and Sarkis, 2010). Empirical studies show that there is no such thing as best critical success factors (CSFs) of strategic outsourcing investment. CSFs change along with product complexities, chosen technologies, size and structure of an organization, project characteristics and uncertain circumstances (Taps and Steger-Jensen, 2007).

In addition, because increasing complexity in the socio-economic surroundings along with rapidly changing technologies, how to have a suitable outsourcing investment is becoming an important focus for companies. Then, the paper tries to briefly discuss the mechanisms of strategic outsourcing investment, its critical success criteria, and then introduce different evaluation models to help in having the suitable investment. Finally, the paper finds that an analytic network process (ANP) associated with benefits, opportunities, costs and risks (BOCR), is optimal to help companies to select the most suitable outsourcing investment projects.

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LITERATURE REVIEW

Manufacturing outsourcing is an important phenomenon in the business world. An increasing number of corporate organizations are discussing manufacturing outsourcing as a way of leveraging both internal and external capabilities (Ehie, 2001). Dickson (1966) identified 23 supplier criteria for selecting suppliers. Dickson indicated that cost, quality, and delivery performance were the three most important criteria in supplier selection. Supplier-related delays and overall project delays are significantly related. In addition, the priority that the buyer's top management places on the project and the degree of technical change were also significantly related to overall project delays (Hartley et al., 1997). Weber et al., (1991) also confirmed that quality, delivery, and cost were considered to be the most important criteria. However, with the increasing significance of strategic outsourcing and global competition, the approach to traditional criteria has been changed to reflect the new requirements according to the role of suppliers in the supply chain (Choy et al., 2005). Firms have increasingly turned to outsourcing in an effort to capture cost savings. The paper extends both transaction cost theory (TCT) and resource-based view (RBV) to explain conditions leading to strategic outsourcing (Holcomb and Hitt, 2007). Strategic evaluation of suppliers requires consideration of supplier practices (such as managerial, quality and financial criteria) and supplier capabilities (such as design capabilities, cost reduction capabilities, technical skills) (Talluri and Narasimhan, 2004). Due to the importance of concurrent engineering and supplier involvement in new product development, several works are focused on design capability of suppliers when assessing the performance. Busom and Fernandez-Ribas (2008) defined the design criteria as supplier’s effort within the project team. The concept of outsourcing, along with an account of the economic benefits, is achieved by reconfiguring the organization and reducing the transaction costs of providing products and services (Mccarrthy and Anagnostou, 2004). De Toni and Nassimbeni (2001) presented a framework for the evaluation of supplier’s design effort. Most of them were offered by suppliers in the development stages as evaluation criteria such as support in product simplification, support in component selection, and support in design for manufacturing activities. The use of these techniques led to substantial improvement in quality, cost and delivery performance (Maffin and Braiden, 2001). Some papers show a successful framework to select partners for development (Emden et al., 2006; Siakas and Hyvärinen, 2006; Siakas and Balstrup, 2006). Those framework reveal three broad phases: (1) technological alignment (technical ability, market knowledge complementarities, and overlapping knowledge bases); (2) strategic alignment (motivation correspondence, goal correspondence); and (3) relational alignment (compatible cultures, propensity to change, long-term orientation). The new paradigm requires that the manufacturer be able to produce mass customization products based on individual customer demand. Thus speed, flexibility, quality and cost are becoming increasingly important in the fast changing competitive environment (Olhager and Selldin, 2004). Choi and Hartley (1996) evaluated suppliers based on consistency, reliability, relationship, flexibility, price, service, technological capability and finances, and also addressed 26 supplier selection criteria. Verma and Pullman (1998) ranked the importance of the supplier attributes of quality, on-time delivery, cost, lead time and flexibility. In addition, Vonderembse and Tracey (1999) concluded that supplier and manufacturing performance were determined by supplier selection criteria and supplier involvement. They described that the supplier selection criteria could be evaluated by quality, availability, reliability and performance, while supplier involvement could be evaluated by R&D and products improvement, and supplier performance could be evaluated by delivery, damage and quality. Furthermore, manufacturing performance could be evaluated by cost, quality, inventory and delivery (Chang et al., 2006). After comparing the advantages and limitations of nine previously developed methods of supplier evaluation, Muralidharan et al. (2002) concluded that the attributes of quality, delivery, price, technique capability, finances, attitude, facility, flexibility and service were used for supplier evaluation, and the attributes of knowledge, skill, attitude and experience were used for individual assessments. In addition, Mcivor and Humphreys (2004) provided insights into the strategic factors that affect the dynamics of the early supplier involvement (ESI) process. The findings suggest that the ability to specify partner activities and assess partner capabilities can influence the timing and nature of partner involvement (Perks, 2005). Early supplier involvement in supply chain design, product design and process design is a key coordinating process to cut customer development time, improve quality, reduce the cost of new products and facilitate the smooth launch of new products (Petersen et al., 2005). While there have been numerous reports of benefits associated with adoption of early supplier involvement in product design, this study extends a recent stream of research indicating that ESI may be a useful tool for managing supply risk (Zsidisin and Smith, 2005; Francas and Minner, 2009).

There are many CSFs of supplier evaluation, and CSFs change when environment changes. Therefore, in order to obtain objective results, it is necessary to carry out extensive questionnaire, organize experts’ opinions and then use statistical analysis. After an extensive research from aforementioned statement, 38 CSFs are collected and shown in Table 1. Nine CSFs with eigenvalues larger than one were extracted as common factor dimensions through factor analysis and varimax rotation method by SPSS software. Kaiser-Meyer-Olkin (KMO) statistics was used to measure sampling adequacy, that is, if data were

Table 1. Critical success factors for strategic outsourcing selection.

Cost	Quality	Delivery
Management	Overlapping knowledge bases	Market knowledge complementarities
Finance	Technology	Motivation correspondence
Goal correspondence	Flexibility	Speed
Consistency	Reliability	Relationship
Trust	Compromise	Price
Service	Time	Lead time
Availability	Design	R&d
Products improvement	Inventory	Attitude
Facility	Resources	Experiences
Skill	Compatible culture	Long-term orientation
Support in product simplification	Support in component selection	Support in design for manufacturing activities
Propensity to change	Closeness	

Table 2. Factors, eigenvalues and cumulative variance in each dimension

	Critical success factor	Eigen value	Variance (%)	Cumulative variance (%)
1.	Compatible cultures, propensity to change, long-term orientation, relationship, trust, compromise, attitude, service	6.56	15.26	15.26
2.	Technology, market complementarities, and overlapping knowledge bases, skill, R&D, products improvement	5.28	13.37	28.63
3.	Design, support in product simplification, support in component selection, support in design for manufacturing activities, R&D	4.65	11.49	40.12
4.	Time, speed, delivery, lead time, flexibility	4.18	9.78	49.90
5.	Cost, finance, price, inventory, flexibility, availability	3.24	7.06	56.96
6.	Quality, management, consistency, reliability	2.37	5.53	62.49
7.	Motivation correspondence, goal, long-term orientation	2.15	5.12	67.61
8.	Closeness, resources, experience	1.49	4.47	72.07
9.	Facility	1.23	3.81	75.88

likely to factor well. Since the KMO statistic was 0.7131, a value greater than the satisfactory value of 0.5, it was appropriate to proceed with factor analysis. In addition, Bartlett's test of sphericity tests the null hypothesis that the variables in the correlation matrix are uncorrelated. In the study, the observed significance level was 0.000, and it was small enough to reject the hypothesis. This also suggested that a factor analysis for the data could proceed. Table 2 lists the Eigen values, variance and cumulative variance of the 9 selected CSFs, and the 9 CSFs can explain 75.88% of the variance in the original data sets. For the naming of extracted factors, this research chose a factor in each dimension with a loading larger than 0.40 as a reference for the name, and used a name that represented the aggregates of observed factors. After factor analysis, the most important extracted factors for strategic outsourcing investment are as follows: relational alignment factors, technological alignment factors, design advantage factors, delivery factors, costs factors, quality factors, strategic alignment factors, resources factors, facility factors. Nine critical success criteria summarized in Table 2 with various evaluation models developed in methodology will be applied for strategic outsourcing investment in the subsequent real case study.

METHODOLOGY

Analytic network process (ANP) generalizes Analytic Hierarchical Process (AHP) by replacing hierarchies with networks (Karsak, et al. 2002). A shortcoming of AHP is that each element in the hierarchy is assumed to be independent; that is the interdependence among criteria and among alternatives is not considered (Saaty, 1996). ANP may be necessary to solve the problem since the oversimplification of the model may not lead to good evaluation results. When a network is not too complicated and has a structure as depicted in Figure 1, a simplified matrix manipulation approach may be employed (Lee and Kim, 2000; Bandinelli, et al., 2006). The procedures are as follows:

1. Determine the importance of each criterion with respect to achieving the overall objective. Criteria are compared pair wisely,

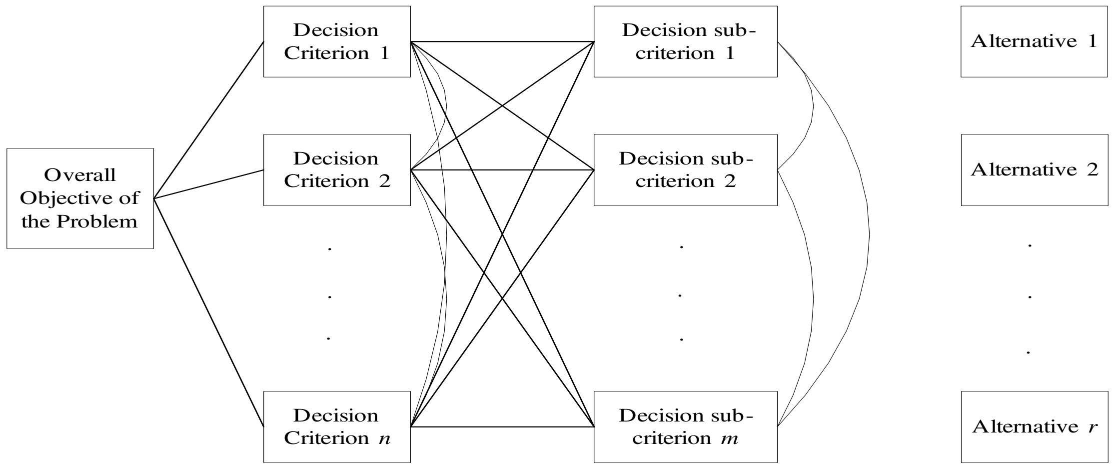

Figure 1. The conventional structure of analytic network process.

and relative ratings are assigned. A paired comparison matrix is formed after each criterion has been compared. For example, *m* criteria, denoted by X_1, X_2, X_3 …Xm, are compared in pairs according to their relative weights, denoted by W_1 , W_2 , W_3 … W_m, respectively. A matrix, W_1, can be formed to represent the pair wise comparisons (Saaty, 1980).

$$\mathbf{W}_1 = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array}}{\begin{bmatrix} \frac{\mathrm{w}_1}{\mathrm{w}_1} & \frac{\mathrm{w}_1}{\mathrm{w}_2} & \cdots & \frac{\mathrm{w}_1}{\mathrm{w}_m} \\ \frac{\mathrm{w}_2}{\mathrm{w}_1} & \frac{\mathrm{w}_2}{\mathrm{w}_2} & \cdots & \frac{\mathrm{w}_2}{\mathrm{w}_m} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\mathrm{w}_m}{\mathrm{w}_1} & \frac{\mathrm{w}_m}{\mathrm{w}_2} & \cdots & \frac{\mathrm{w}_m}{\mathrm{w}_m} \end{bmatrix}} = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \overset{\begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array}}{\begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix}} \quad (1)$$

Calculate the maximum eigenvalue and eigenvector (w_1) with the following formula:

$$\mathbf{W_1} \cdot w = \lambda_{\max} \cdot w \quad (2)$$

$$w_1 = \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_m \end{bmatrix} \quad (3)$$

where *w* is the eigenvector, the weight vector, of $\mathbf{W_1}$, $\lambda_{\max}$ is the largest eigenvalue of $\mathbf{W_1}$, and *m* is the number of criteria. Check the consistency property of the matrix to ensure consistency of judgments in the pairwise comparison. The consistency index (CI) and consistency ratio (CR) are defined as (Saaty, 1980):

$$CI = \frac{\lambda_{\max} - m}{m-1} \quad (4)$$

$$CR = \frac{CI}{\mathrm{RI}} \quad (5)$$

where *m* is the number of items being compared in the matrix, and RI is random index, the average consistency index of randomly generated pairwise comparison matrix of similar size.

In the case that the calculated CR value exceeds the threshold CR values, an inconsistent judgment is indicated, and the original values in the pairwise comparison matrix must be revised by the decision makers (Saaty, 1994).

2. Assume that there is no dependence among sub-criteria; determine the importance of each sub-criterion with respect to its upper level criterion. After the check of consistency property, the matrix and the eigenvector with respect to an upper level criterion (*m*) are as follows:

$$\mathbf{W}_{2m} = \begin{array}{c} \\ D_{1(m)} \\ D_{2(m)} \\ \vdots \\ D_{n(m)} \end{array} \overset{\begin{array}{cccc} D_{1(m)} & D_{2(m)} & \cdots & D_{n(m)} \end{array}}{\begin{bmatrix} d_{11(m)} & d_{12(m)} & \cdots & d_{1n(m)} \\ d_{21(m)} & d_{22(m)} & \cdots & d_{2n(m)} \\ \vdots & \vdots & \vdots & \vdots \\ d_{n1(m)} & d_{n2(m)} & \cdots & d_{nn(m)} \end{bmatrix}}, \text{ for each } m. \quad (6)$$

and $$w_{2m} = \begin{array}{c} D_{1(m)} \\ D_{2(m)} \\ \vdots \\ D_{n(m)} \end{array} \begin{bmatrix} d_{1(m)} \\ d_{2(m)} \\ \vdots \\ d_{n(m)} \end{bmatrix}, \text{ for each } m. \quad (7)$$

where $n(m)$ is the number of sub-criteria respective to an upper level *m*, and the total number of sub-criteria *n* is equal to the sum of all $n(m)$, that is, $n = n(1) + n(2) + ... + n(m)$.

3. Obtain the priorities of alternatives with respect to each of the sub-criterion. The general form of matrix and eigenvector are as follows:

b. $$\mathbf{W}_{en} = \begin{array}{c} \\ E_{1(n)} \\ E_{2(n)} \\ \vdots \\ E_{p(n)} \end{array} \begin{array}{c} \begin{array}{cccc} E_{1(n)} & E_{2(n)} & \cdots & E_{p(n)} \end{array} \\ \begin{bmatrix} e_{11(n)} & e_{12(n)} & \cdots & e_{1p(n)} \\ e_{21(n)} & e_{22(n)} & \cdots & e_{2p(n)} \\ \vdots & \vdots & \vdots & \vdots \\ e_{p1(n)} & e_{p2(n)} & \cdots & e_{pp(n)} \end{bmatrix} \end{array}$$ for each *n*. (8)

$$w_{en} = \begin{array}{c} E_{1(n)} \\ E_{2(n)} \\ \vdots \\ E_{p(n)} \end{array} \begin{bmatrix} e_{1(n)} \\ e_{2(n)} \\ \vdots \\ e_{p(n)} \end{bmatrix}$$, for each *n*. (9)

where p is the number of alternatives. Combine the above eigenvectors with respect to criterion m and obtain the following matrix:

$$\mathbf{W}_{3m} = \begin{array}{c} \\ E_1 \\ E_2 \\ \vdots \\ E_p \end{array} \begin{array}{c} \begin{array}{cccc} D_{1(m)} & D_{2(m)} & \cdots & D_{n(m)} \end{array} \\ \begin{bmatrix} e_{1(1)} & e_{1(2)} & \cdots & e_{1(n)} \\ e_{2(1)} & e_{2(2)} & \cdots & e_{2(n)} \\ \vdots & \vdots & \vdots & \vdots \\ e_{p(1)} & e_{p(2)} & \cdots & e_{p(n)} \end{bmatrix} \end{array}$$ for each *m*. (10)

4. Determine the interdependence among sub-criteria. The inner dependence among sub-criteria under the same criterion is calculated through analyzing the impact of each sub-criterion on other sub-criteria with the same upper level criterion. The interdependence weight matrix of sub-criteria with the same upper level criterion is:

$$\mathbf{W}_{4m} = \begin{array}{c} \\ D_{1(m)} \\ D_{2(m)} \\ \vdots \\ D_{n(m)} \end{array} \begin{array}{c} \begin{array}{cccc} D_{1(m)} & D_{2(m)} & \cdots & D_{n(m)} \end{array} \\ \begin{bmatrix} k_{11(m)} & k_{12(m)} & \cdots & k_{1n(m)} \\ k_{21(m)} & k_{22(m)} & \cdots & k_{2n(m)} \\ \vdots & \vdots & \vdots & \vdots \\ k_{n1(m)} & k_{n2(m)} & \cdots & k_{nn(m)} \end{bmatrix} \end{array}$$ for each *m*. (11)

5. Obtain the interdependence priorities, $w_{DC(m)}$, of the sub-criteria by synthesizing the results from Step 2 and Step 4.

$$w_{DC(m)} = \mathbf{W}_{4m} \times w_{2m}$$ for each *m*. (12)

6. Determine the priorities of alternatives, $w_{21(m)}$, with respect to each criterion by synthesizing the results from Step 3 and Step 5 as follows:

$$w_{21(m)} = \mathbf{W}_{3m} \times w_{DC(m)}$$ for each *m*. (13)

The matrix $\mathbf{W}_{21}$ groups together the columns of $w_{21(m)}$ for all *m*'s is:

$$\mathbf{W}_{21} = \left(w_{21(1)}, w_{21(2),\ldots}, w_{21(m)}\right) \quad (14)$$

7. The overall priorities for the alternatives are obtained by synthesizing the results from Step 1 and Step 6; that is, multiplying $\mathbf{W}_{21}$ by w_1.

$$w = \mathbf{W}_{21} \times w_1 \quad (15)$$

The final ANP results will be (alternative 1, alternative 2… alternative *m*).

The “unknown” or “other” that affects our lives is what we usually want to know about uncertainty. We often suspect that it affects us with partial and indefinite evidence that it exists but we only have uncertain feelings about it. Even when we do not know what it is, we would like to allow for its influence in our explaining the outcome of a decision. One way to deal with the many factors of a decision is to include the unknown as one of them and then determine its priority of influence on the outcome by comparing it with other factors shown in Figure 2 (Ozdemir and Saaty, 2006). The main advantage of including a factor called “other” or the “unknown” is that it makes it possible for the decision maker to do sensitivity analysis to test the potential stability of the outcome with respect to the “unknown” according to his belief. It is an alternative that involves the use of uncertain knowledge instead of statistical methods of projection to determine the degree of confidence in the outcome of a decision under uncertainty. Its procedure is exactly the same as step 1 through step 7, and will be illustrated with examples in the subsequent section.

Although alternatives provide new opportunities and benefits, some additional costs and risks are inevitable. That means that the “unknown” or “other” can be further analyzed into opportunities and risks. Therefore, before adopting new selection, the benefits, opportunities, costs, and, risks (BOCR) of these alternatives, need to be evaluated (Saaty, 2003). Such evaluation of the alternatives results in complex decision problems depending on the number of groups that should contribute to and eventually get influenced by the decision. The involvement of these groups into the decision making process should improve the decision quality by reflecting their standpoints in the problem (Erdogmus, et al., 2005). Conventional ANP, commonly used multiple criteria decision making models, usually adopt pairwise comparison of criteria (or alternatives) to rank the final priority. However, considering the aspects of benefits, opportunities, costs and risks of an alternative, and synthesizing the positive criteria of benefits and opportunities and the negative criteria of costs and risks with rating calculation (not pairwise comparison) by a method such as additive, subtractive and multiplicative is a more comprehensive and instinctive way in daily life (Saaty, 1996). Because they are opposite in value to positive priorities, we need a special way to combine the two. The overall outcome for the alternatives is obtained by weighting and subtracting their weights with respect to the negative criterion from those with respect to the positive criterion.

One of the general theories of the ANP, which was also proposed by Saaty (1996), let decision makers to deal with the benefits, opportunities, costs, and risks (the BOCR merits) of a decision. A network can consist of four sub-networks: benefits, opportunities, costs, and risks. A systematic ANP model with BOCR is proposed in this section (Lee et al., 2009). The steps are summarized as follows:

1. Construct a control hierarchy for the problem. A control hierarchy shown in Figure 3 contains strategic criteria, the very basic criteria used to assess the problem, and the four merits, benefits, opportunities, costs and risks.
2. Determine the priorities of the strategic criteria. Using the procedures described in Step 3 through 5 to obtain the desired Eigen values and eigenvectors.
3. Determine the importance of benefits, opportunities, costs and risks to each strategic criterion. A five-step scale is used, and the

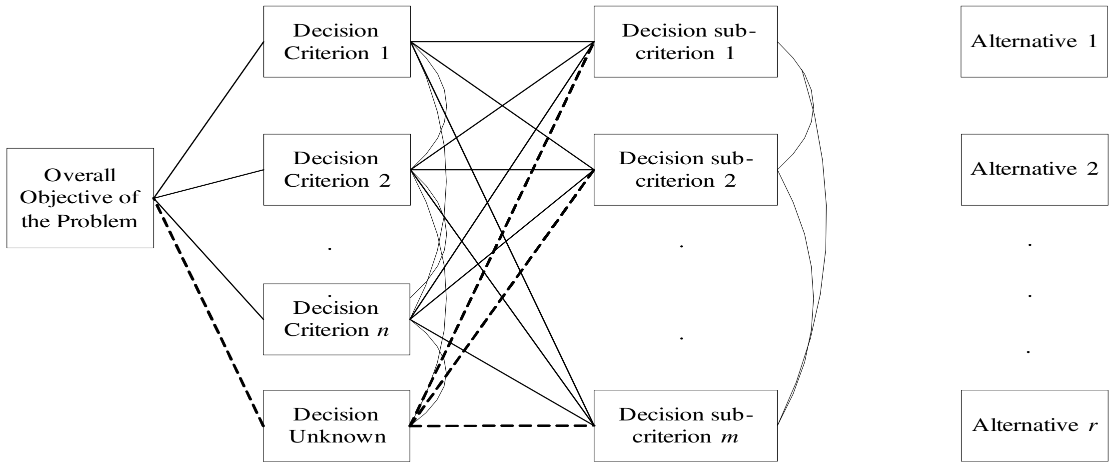

Figure 2. The unknown structure of analytic network process.

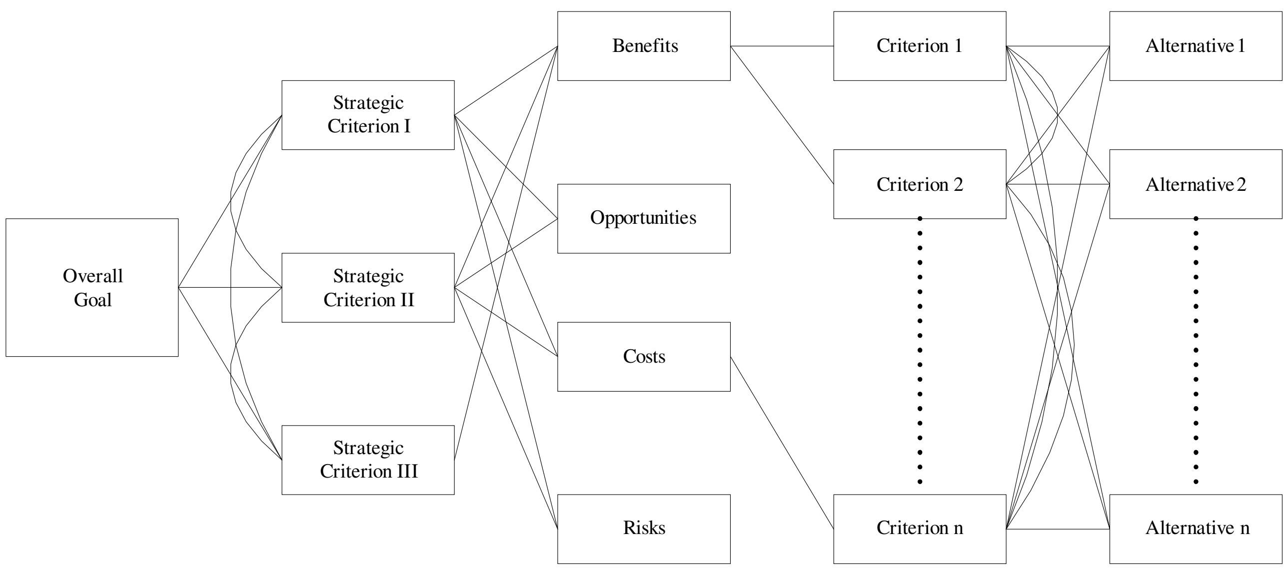

Figure 3. The structure of analytic network process with BOCR.

values of each scale is assigned to be 0.42, 0.26, 0.16, 0.10 and 0.06 for very high, high, medium, low and very low respectively (Saaty, 2004; Erdogmus et al., 2006).

4. Determine the priorities of the merits. Calculate the priority of a merit by Step 3 through 5. Normalize the calculated values of the four merits, and obtain the priorities of benefits, opportunities, costs and risks, that is, b, o, c, r, respectively.

5. Decompose the project selection problem into a network with four sub-networks. Based on literature review and experts' opinions, a network in the form as in Figure 3 is constructed. Four merits, benefits (B), opportunities (O), costs (C) and risks (R) must be considered in achieving the overall goal. A sub-network is formed for each of the merits. For instance, for the sub-network for benefits (B) merit, there are criteria that are related to the achievement of the benefits of the ultimate goal, and the lowest level contains the alternatives that are under evaluation.

6. Formulate a questionnaire based on the networks to pairwise compare elements, or factors, in each level with respect to the same upper level element, and the interdependence among the elements. For benefits (B) and opportunities (O), the question is to ask what gives the most benefit or presents the greatest opportunity to influence fulfillment of the criterion (sub-criterion). For costs (C) and risks (R), the question is to ask what incurs the most cost or faces the greatest risk. Experts in the field are asked to fill out the nine-point-scale questionnaire.

7. Calculate the relative priorities in each sub-network. A similar procedure as in Step 3 through Step 5 is applied to establish relative importance weights of criteria with respect to the same upper-level merit, the interdependence priorities among the criteria that have the same upper-level merit, and the relative performance weights of alternatives with respect to each criterion.

8. Calculate the priorities of alternatives for each merit sub-network. Using the priorities obtained from Step 7, form an unweighted supermatrix, a weighted supermatrix and a limit supermatrix for each sub-network by ANP, which is proposed by Saaty (1996). The priorities of the alternatives under each merit are calculated by

normalizing the alternative-to-goal column of the limit supermatrix of the merit.

9. Calculate overall priorities of alternatives by synthesizing priorities of each alternative under each merit from Step 8 with corresponding normalized weights b, o, c and r from Step 4. There are five ways to combine scores of each alternative under B, O, C and R (Saaty, 2003; Lee, et al., 2009):

i. Additive

$P_i=bB_i+oO_i+c(1/C_i)+r(1/R_i)$

where B_i, O_i, C_i and R_i represent the synthesized results of alternative i under merit B, O, C and R, respectively, and b, o, c and r are normalized weights of merit B, O, C and R, respectively.

ii. Probabilistic additive

$P_i=bB_i+oO_i+c(1-C_i)+r(1-R_i)$

iii. Subtractive

$P_i=bB_i+oO_i-cC_i-rR_i$

iv. Multiplicative priority powers

$P_i=B_i^b O_i^o [(1/C_i)_{Normalized}]^c [(1/R_i)_{Normalized}]^r$

v. Multiplicative

$P_i=B_iO_i/C_iR_i$

RESULTS

An anonymous company is one of the major TFT-LCD manufacturers in China. At present, the company produces TFT-LCD monitors, TFT-LCD modules, color filters (CF), and 4-mask TFT by its own factory. However, because of global competition, the company considers to outsource some of its core components.

Then, in order to examine the impacts on strategic outsourcing investment by different evaluation models, the firm willing to set its strategic outsourcing investment for the purpose of optimally utilizing its suppliers' resources is used as an example.

Conventional ANP

In the first step, a nine evaluation committee including technology development manager, research manager, manufacturing manager, marketing manager and controller is formed and their first duty is to select critical success criteria. In the second level, three criteria are considered; namely, organization capability, business drive capability, and skills capability. Organization capability concerns the strengths and weaknesses of the firm itself and the opportunity of the firm. Business drive capability stresses on advantages of the firm in the strategic outsourcing selection. Skills capability considers whether the firm possesses advanced knowledge in the strategic outsourcing selection. In the third level of the hierarchy, nine sub-criteria are applied here to evaluate each strategic outsourcing investment. Under criterion organi-zation performance, there are sub-criteria including relational alignment, strategic alignment and resources factor. Under criterion business drive capability, there are factors including delivery, costs, and quality. Technological alignment, design advantages and facility factor are the sub-criteria of criterion skills capability. In the last level, five potential outsourcing policies participate in the analysis represented as alternative A (totally outsourcing), B (outsourcing CF and module), C (outsourcing CF and 4-mask TFT), D (outsourcing CF), and E (without outsourcing). The hierarchical form of determining the firm's overall performance is shown in Figure 1. The next step is to construct the comparison matrices at each level of the hierarchy for pairwise comparison of the factors in that level. The Delphi method was performed to obtain a consensus among the people who were involved. To arrive at a group position regarding an issue, a series of repeated interrogations through questionnaires of experts and managers whose judgments were of interest. The group position was finally determined after several rounds.

In the first level of the hierarchy, the question, "which criteria should be emphasized more in determining the performance, and how much more?" is asked, and a nine-point scale is used to do the pairwise comparison. An eigenvector and an eigenvalue are calculated using the eigenvalue method by equations (2) and (3). The eigenvector shows the priority of the three criteria. To check the consistency of this combination of values in the matrix, $\lambda_{\max}$ is substituted into equation (4) to obtain CI, and CR is calculated by equation (5). The comparison matrices of sub-criteria in accordance to their respective upper level criterion, their eigenvectors and consistent ratios are obtained using equations (2) and (3).

Experts are next asked to give a rating of each alter-native in terms of each sub-criterion in a range of zero to a hundred. Arithmetic average of all experts' ratings for each alternative on each sub-criterion is obtained. In order to have a more significant difference in the ratings of each sub-criterion among alternatives, the concept of utility function is adopted here to obtain a utility index and to show the relative performance of a factor under each alternative. By assigning values of zero and one to the worst and best outcomes obtained by the ratings from all experts, the general formula of a utility linear function of sub-criteria *m* at level 3 is as follows:

$$u_m(x)=\frac{X-X_m^-}{X_m^+-X_m^-}$$

where X_m^+: The best value of sub-criteria *m*, X_m^-: The worst value of sub-criteria *m* and X: The value of sub

Table 3. Final results for strategic outsourcing selection using conventional ANP.

Sub-criterion/alternative	A	B	C	D	E
Relational alignment	0.016	0.019	0.042	0.090	0.021
Strategic alignment	0.018	0.012	0.028	0.042	0.017
Resources factor	0.007	0.024	0.025	0.026	0.018
Delivery factor	0.018	0.036	0.016	0.043	0.034
Costs factor	0.007	0.008	0.012	0.016	0.012
Quality factor	0.022	0.032	0.018	0.052	0.036
Technological alignment	0.010	0.006	0.016	0.009	0.014
Design advantages	0.021	0.014	0.017	0.017	0.030
Facility factor	0.019	0.010	0.014	0.014	0.022
Total	0.138	0.161	0.188	0.309	0.204

Table 4. Results for strategic sourcing selection using ANP with criterion unknown.

Sub-criterion/alternative	A	B	C	D	E
Relational alignment	0.013	0.072	0.021	0.027	0.015
Strategic alignment	0.015	0.035	0.014	0.023	0.0010
Resources factor	0.004	0.013	0.013	0.008	0.012
Delivery factor	0.019	0.029	0.023	0.011	0.017
Costs factor	0.007	0.017	0.006	0.012	0.008
Quality factor	0.014	0.034	0.031	0.015	0.021
Technological alignment	0.002	0.009	0.014	0.016	0.006
Design advantages	0.021	0.017	0.038	0.021	0.019
Facility factor	0.011	0.008	0.014	0.008	0.006
Uncertainty of new technologies	0.016	0.017	0.017	0.018	0.012
Uncertainty of new entrance	0.015	0.019	0.021	0.022	0.014
Uncertainty of new substitutes	0.009	0.020	0.017	0.012	0.011
Total	0.146	0.290	0.229	0.193	0.142

criteria *m* under a certain alternative.

The utility indices are then transformed into weights by dividing each utility index to the total value of the column so that each column can sum to one, and the results that have the same upper level criterion are grouped together. Finally, the overall priorities for the alternatives are obtained by Step 7 and shown in Table 3. The rankings are D (0.309), E (0.204), C (0.188), B (0.161), and A (0.138). Obviously, the firm prefers to select either D (outsourcing CF) or E (without outsourcing). From the respective of managerial level, the firm should produce TFT-LCD monitors with more profitable and less risky.

ANP with criterion unknown

All of the situation is all the same when considering criterion unknown, except that uncertainty of new technologies, uncertainty of new competitors/partners, uncertainty of new substitutes are the sub-criteria of criterion unknown in the third level of the hierarchy. The hierarchical form of determining the firm's overall performance is shown in Figure 2. After same procedure of calculation, the overall priorities for the alternatives are obtained and shown in Table 4. The new rankings are B (0.290), C (0.229), D (0.193), A (0.146), and E (0.142). Because of unknown criterion, including new technologies, new entrance and new substitutes three sub-criteria, the rankings of B (outsourcing CF and module) and C (outsourcing CF and 4-mask TFT) moves to the first and second place. However, the more optimistic strategy may result in severe disaster.

ANP with merits BOCR

When considering ANP with BOCR, three strategic criteria

Table 5. The hierarchical structure of critical criteria for strategic outsourcing selection.

Goal merit	Criteria
Benefits	(a) Delivery factor (b) Quality factor (c) Design advantages
Opportunities	(d) Relational alignment (e) Technological alignment (f) Strategic alignment
Costs	(g) Resources factor (h) Costs factor (i) Facility factor
Risks	(j) New competitors (k) New substitutes (l) New technologies

criteria are considered as organization, business drive capability, and skills capability in the second level. In the third level, there are benefits (B), opportunities (O), costs (C), and risks (R) four merits. In the fourth level of the network, twelve selected criteria shown in Table 5 are applied here to evaluate each strategic outsourcing investment. Under merit benefits, there are three criteria, group factors (a) through (c). Under merit opportunities, there are three criteria, group factor (d), (e) and (f). Group factors (g), (h) and (i) are the criteria of merit costs and group factors (j), (k) and (l) are the criteria of merit risks. In the fifth level, there are five alternates same as above. The hierarchical form of determining the firm's overall performance is shown in Figure 3.

In the first part of the model, experts are asked to evaluate the priorities of benefits, opportunities, costs and risks. Based on each expert's opinion, a pairwise comparison matrix is formed to evaluate the three strategic criteria, and the priorities of the strategic criteria are calculated. An eigenvector and an Eigen value are calculated using Equations (2) and (3). To check the consistency of this combination of values in the matrix, CI and CR are calculated using Equations (4) and (5). Next, experts are asked to assess BOCR according to strategic criteria by the five step scale. The ratings of the four merits on strategic criteria by Delphi method are obtained and the normalized priorities of BOCR are calculated. In the second part of the model, the priorities of the alternatives under each merit are calculated. There are four sub-networks, namely benefits, opportunities, costs, and risks. The relative importance weights of criteria with respect to the same upper level merit, the interdependence priorities among the criteria that have the same upper-level merit are calculated using the Delphi pairwise comparison results. The performance results of different alternatives under various criteria, however, are collected from each expert individually in order to limit the number of pairwise comparisons. For the criteria under benefits and opportunities merits, the higher the score, the better the performance of the alternative is. On the other hand, for the criteria under risks merit, the higher the score, the worse the performance of the alternative is. The synthesized performance value of each alternative on each criterion is calculated by geometric averaging the results from all the experts. These performance values are further transformed into a number between zeros to one by dividing the performance value of an alternative on a criterion by the largest performance value among all alternatives on the same criterion.

The above performance values of alternatives and the priorities of criteria are synthesized to obtain the overall performance of each alternative under each merit. The final ranking of the alternatives are calculated by the five methods to combine the scores of each alternative under B, O, C and R. The results are as shown in Table 6. The final rankings are C (1.1834), B (1.1358), D (0.1126), A (0.7283), and E (0.6359). The ranking should be very stable since the results using five methods described in Step I are all the same.

As we know, the unknown criterion should be further divided into positive and negative factors; otherwise its importance may be overestimated. It is the reason why the ranking of alternative B overpasses that of alternative C and D. In addition, in a daily life, the model using rate calculation in ANP with BOCR is more instinctive than that using pairwise comparison in conventional ANP. Accordingly, we find that the best ranking is alternative C when applying ANP associated with BOCR.

Table 6. Final results for strategic outsourcing selection using ANP with BOCR.

Synthesizing methods	Additive		Probabilistic additive		Subtractive		Multiplicative priority powers		Multiplicative	
Alternative	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank
Alternative A	0.1023	4	0.4137	4	0.0213	4	0.1492	4	0.7283	4
Alternative B	0.2048	2	0.4361	2	0.0358	2	0.2091	2	1.1358	2
Alternative C	0.2591	1	0.4742	1	0.0423	1	0.2654	1	1.1834	1
Alternative D	0 1843	3	0.4285	3	0.0317	3	0.1822	3	0.1126	3
Alternative E	0.1014	5	0.4012	5	0.0179	5	0.1137	5	0.6359	5

DISCUSSION AND CONCLUSION

From our theoretical modeling and empirical demonstration, the paper recommends that an ANP with BOCR model is optimal to help companies to select the most suitable outsourcing investment projects. However, decision makers naturally provide uncertain answers rather than precise values, and the transformation of qualitative preferences to point estimates is difficult. In such a case, the use of fuzzy numbers and linguistic terms may be more suitable. Then, proposing a model integrating ANP, fuzzy sets, and BOCR should be the research direction in the future.

The outcome of above feasibility analysis is the instrument for receiving approval from top management to develop new projects. In addition, strategic outsourcing investment has an important role to play in providing future directions and triggering necessary changes to achieve expected goals.

These decisions should ultimately lead to a market transformation from less acceptable or undesirable solutions to more ideal ones. Simultaneously the sector responsible for designing strategic outsourcing investment is confronting pressure to reduce its expenditures and to manufacture high-quality products more cheaply in a long run which in turn will put more emphasis on impact driven policies and effective resource use.

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