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An analytic hierarchy process approach with linguistic variables for selection of an R&D strategic alliance partner ☆

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ABSTRACT

This study establishes a mechanism for partner selection that emphasizes the relation of criteria and motivation. Since the motivations for establishing strategic alliances follow different enterprises' needs, attempting to identify universal criteria weights that enterprises should employ when seeking a proper partner are not productive. Consequently, the weighting process for criteria must consider the intensity of motivations for establishing the alliance. When evaluating companies with closer levels of performance, the approach of pair-wise comparison is more suitable than the direct scoring method. Considering the strategic level, most comparisons may be vague and linguistic variables defined as fuzzy numbers are applied to this situation. The calculation procedure for the weighting and evaluation processes under a vague environment is proposed and validated by using an illustrative example.

1. Introduction

With increasingly fierce global competition, companies must do their best in research and development (R&D) to strengthen their competitiveness. Unfortunately, R&D not only involves high uncertainty and risk but also consumes much capital in the development of complicated/sophisticated technology. Larger companies may have the resources to do explorative and fundamental research, but it is difficult for small-medium enterprises (SMEs) to invest in R&D because they lack sufficient resources such as capital, R&D personnel and equipment. Therefore, establishing alliances with other companies may be a feasible way for SMEs to acquire the necessary techniques and assistance, despite the risks involved.

Although strategy alliance policies have been adopted by companies for decades, Mathews and Harvey (1988) and Gonzalez (2001) found that only 50% or less of the alliance participants considered the coalition successful. Some reports and studies (Broadhead, 1995; Brouthers, Brouthers, & Wilkinson, 1995; Dacin, Hitt, & Levitas, 1997; Das & Teng, 1998; Hill & Jones, 1998; Hoffman & Schlosser, 2001; Kim & Lee, 2003; Neill, Pfeiffer, & Young-Ybarra, 2001) indicated that most of the strategic alliances failed because the partners were not capable of performing their assigned function in the venture or became dissatisfied with each other, and finally the groupings broke up. When an enterprise has resolved to form a strategic alliance, it should thus carefully select the partner in order to ensure success.

When selecting an R&D strategic alliance partner, it is risky to consider only their financial contribution to the association, since many other criteria, such as level of technology, enterprise culture, top manager attitude and marketing ability must also be considered. To establish a comprehensive procedure, the analytic hierarchy process (AHP) is employed to develop a partner selection mechanism. The AHP was introduced by Saaty (1980, 1988) for solving unstructured problems and it has been applied widely for many multiple criteria decision-making problems (Cheng, Yang, & Hwang, 1999; Chi & Kuo, 2000; Murtaza, 2003; Zahedi, 1986). Vaidya and Kumar (2006) made a comprehensive literature review of the applications of analytic hierarchy process for readers' reference. But since most of the criteria for R&D alliance partner selection are qualitative, the evaluation can become mired in subjective comparisons as the weighting and evaluation processes become vague. Thus, this research uses the concept of fuzzy sets theory, as developed by Zadeh (1965, 1975, 1976). The concept and arrangement of fuzzy numbers presented by Dubois and Prade (1978, 1980, 1981, 1986) are employed to improve the presentation of the fuzzily defined system. There are many studies that apply fuzzy sets theory to AHP, the earliest of which is in Van Laarhoven and Pedrycz (1983) and Buckley (1985). These two papers compared fuzzy ratios for triangular and for trapezoidal membership functions respectively. Wang, Luo, and Hua (2008)

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showed some shortcomings in the research of Chang (1996) that addressed the application of extent analysis method for fuzzy AHP and made suggestions to avoid any possible misapplications. Zhu, Jing, and Chang (1999) discussed extent analysis method applied to the basic theory of the triangular fuzzy number in fuzzy AHP. Cheng (1996) proposed an algorithm for evaluating a naval tactical missile system by AHP, using the grade value of the membership function of fuzzy numbers. Cheng et al. (1999) proposed a method for evaluating weapon systems by AHP using linguistic variable weights. Weck, Klocke, Schell, and Ruenauver (1997) used the extended fuzzy AHP method to evaluate and choose the alternatives for producing a component. Kreng and Wu (2007) proposed a fuzzy AHP approach to help experts evaluate individual knowledge portal development tools. Tseng, Chiang, and Lan (2009) proposed a hierarchical evaluation framework which applied a non-additive fuzzy integral that can eliminate the interactivity of expert subjective judgment problem to assist the expert group to select the supplier in the supply chain management strategy. Garcia-Cascales and Lamata (2009) used AHP method to a multi-criteria management maintenance processes for carrying out environmental impact assessment. Bahinipati, Kanda, and Deshmukh (2009) provided an AHP-fuzzy logic model to comprehensively assess the degree of collaboration with a view to check feasibility for satisfying customer requirements.

In most prior works, the fuzzy AHP approach was developed hierarchically from enterprise's general goal to criteria allocated in different layers. The relative weights of these criteria are determined by pair-wise comparison subjectively. They might not consider the influence factor that may affect the weighting process. In our paper, we claim that the influential factor of motivations should be involved in the criteria's weighting process. Therefore, we first address the situation of how the weighting process for criteria is affected by the intensity of motivations. Since the motivations for establishing strategic alliances vary according to different needs, attempting to identify a universal set of criteria weights that enterprises should employ when seeking a proper partner would be futile. Consequently, the weighting process for criteria must consider the intensities of motivations for establishing the alliance. The development procedure for the proposed model is first to identify what motivations that drive a company to forge the strategic alliance with other companies and determine their associate intensities. After that, the relative weights for criteria with respect to each individual motivation are calculated. Finally, the composite relative important weights for criteria are available by multiplying their relative wrights by the intensities of the corresponding motivations. This approach should be able to avoid the plight of subjective comparison.

When evaluating companies with closer levels of performance or when each candidate company has its own particular merits, the approach of pair-wise comparison is more suitable than the direct scoring method. However, Saaty's AHP creates and deals with a very unbalanced ratio of estimations for the reciprocal operation (Cheng, 1996). To overcome these problems, in this research, linguistic variables defined as fuzzy numbers are applied to these pair-wise comparisons for measuring the relative intensities and weights of motivations and criteria. Since all the comparisons are based on linguistic variables, realizing the computing complexity, in this research we proposed an approximate approach based on the extension principle of fuzzy set theory for handling the multiplication of fuzzy numbers. It can diminish the load of calculation and enhance the applicability of this proposed approach.

To select an appropriate strategic alliance partner, the motivations, criteria and measurable sub-criteria for evaluating the potential partners must be identified before the AHP approach is implemented. In the next section, the motivations that drive an enterprise to establish an R&D strategic alliance with other enterprises are examined. Then, the criteria and corresponding sub-criteria are presented and employed to evaluate the suitability of each of the potential enterprises. Based on this, the AHP approach with fuzzy weighting processes and linguistic evaluation is developed. An illustrative example is proposed and conclusions for this study are presented.

2. Motivations for forming strategic alliance

Strategic alliances are risky and should be avoided unless there is a real lack of resources in terms of technology, skills, specific equipment, marketing capability or finances (Brouthers et al., 1995). Despite the inherent risks, it is often necessary for enterprises, especially SMEs that lack necessary resources, to establish strategic alliances with other firms to acquire complementary skills. Before establishing a formal relationship with other enterprises, an enterprise must realize its motivations and the intensities that are driving the company to form a strategic alliance. The general motivations for establishing a strategic alliance include sharing the costs of R&D activities, acquiring the resources necessary for technological development, learning new technologies and developing marketing capability to strengthen competitiveness. Many researchers have explored the theories of motivations for strategic alliance (Badaracco, 1991; Barney & Baysinger, 1990; Hagedoorn, 1993; Hagedoorn & Narula, 1996; Lambe & Spekman, 1997; Robertson & Gatignon, 1998; Sakakibara, 1997; Tripsas, Schrader, & Sobrero, 1995; Zuckerman & D'Aunno, 1990). Four clusters of motivations have appeared as recurring themes in these studies and in this study will be referred to as the following four motivations with different orientations.

2.1. Strategy-oriented

Enterprises establish alliances for strategic objectives such as maximizing profit and possible cooperation. Tactical practices include increasing the market share, having more employee exchanges, shortening the time for technological development or new products, and preventing cut-throat competition with competitors.

2.2. Cost-oriented

Another motivation behind establishing an alliance is to reduce costs. To share the cost for developing a technology and avoid duplicating investment, to reduce the cost of searching for necessary information, to reduce the risk of R&D, and to cooperate with governmental organizations for tax policy are common factors in this motivation.

2.3. Resource-oriented

Availability of critical resources is the third motivation for establishing an alliance. To exchange critical equipment and technologies with the alliance partner to reduce R&D risks and to use marketing channels of the partner can benefit participants in the alliance.

2.4. Learning-oriented

Learning the newest knowledge and technology is the fourth motivation for establishing an alliance. R&D personnel can learn from the partner by conducting joint technological development. Communicating and exchanging technological information and joint experience can reduce the development time risks in a new technology.

In short, through a successful alliance, companies that participate in a joint venture cannot only benefit from the strengths of complementary skills of participants, but can also acquire the necessary resources for developing new technologies and products. The application of skills existing in an enterprise can be extended to other area of products offered by the alliance partners. Interactive learning will extend the sources of knowledge, thus enhancing the creativity and competitive ability of an organization.

3. Criteria and their associated measurable sub-criteria

Technological improvement, financial ability or the ability to open a market for new products, are illusory incentives for undertaking an alliance if the participants cannot get along. An appropriate partner is essential for the establishment of a successful alliance. Partner selection for forming strategic alliances has been discussed in the literature from both theoretical and practical points of view. Harrigan (1988) pointed out that when selecting a partner for technical cooperation, consideration must be given to its scale and scope, technological level, management style, and experience in similar affairs. When selecting a partner, although mutual trust and commitment on finance are essential, complementary skills are also important as emphasized by Walters, Peters, and Dess (1994). Subsequently, Brouthers et al. (1995) proposed a thinking schema composed of the 4Cs, namely complementary skill, cooperative culture, compatible goals, and commensurate risks for considering when a strategic alliance should be chosen. Dacin et al. (1997) advised long-term observation and sufficient understanding of the expectations of the partner to ensure success in alliance formation and explored 14 criteria for partner selection. However, Geringer (1998) believed that there is no optimal standard for partner selection procedure; instead, one should consider the two firms' industrial property, relative capability, and complementarities of resources and their organization compatibility. The study of Chang and Tsai (2000) highlighted that complementary resources, symmetrical position, and extension of social resources are necessary conditions for becoming a partner in an alliance. Kim and Lee (2003) had the opinion that partners in an alliance must have mutual trust and be willing to share complementary resources with each other to enhance competitiveness. In these studies, many criteria or factors were explored and discussed. In this current research, we organize these criteria into the following four. For each criterion, a cluster of sub-criteria for evaluating the suitability of candidate partners are also addressed.

3.1. Organization compatibility (OC)

The concept of symmetry is the first key to creating cooperative cultures. All significant conditions should be comparable, from the size of financial resources to the internal working environment. This criterion considers the compatibility of corporation strategies (CCS), the symmetry of scale and scope (SSS), management and organization culture (MOC), and mutual trust and commitment (MTC).

3.2. Technology capability (TC)

It is necessary to conduct a comprehensive search to find a partner with complementary technologies. Evaluation should include an examination of skills, technologies, and what the potential partner can produce. In this criterion, we consider the capability of manufacturing technology (CMT), product development and improvement (PDI), capability of innovation and invention (CII), and possible extent of skill application (ESC).

3.3. Resources for R&D (RD)

Alliances in which one party seeks to obtain as much as possible, while giving little in return are bound to fail. Not only should alliance partners be willing to give to one another, they must also be willing to depend on each other (Paap, 1990). Hence, it is necessary to measure what the potential partner can offer the alliance. This criterion concerns measuring the intensity of investment in R&D (IRD), the extent of complementary resources such as equipment or experience in R&D (ECR), number of personnel in R&D (NUP), and quality of personnel in R&D (QUP).

3.4. Financial conditions (FC)

To avoid financial pressures because of problems in the partners' firm, measuring the robustness of their financial situation is important. Enterprises must not enter alliances in which they may be called onto contribute more money than expected, either at the outset or in the future. In this criterion, the return of investment in recent 5 years (ROI), debt ratio and refund ability (DRR), profitability in the future (PRF), and potential for growth (POG) should be considered.

4. AHP with fuzzy weighting and linguistic measurement

The motivations and criteria discussed in the previous two sections are incorporated into the partner selection mechanism, as described in Fig. 1. The overall objective is to select an adequate partner for strategic alliance. The candidate partners are evaluated directly by the measurable sub-criteria developed from the associate criterion deployed in the upper level of the mechanism. The relative importance of the criteria and the relative weights of the sub-criteria must be determined before the mechanism can be employed for partner selection. Briefly speaking, we synthesize each candidate company's desirability index by first summing up the product of its score on each sub-criterion and their relative weights, and then multiplying the weighted score with the relative importance of the criteria. These weighting and evaluation processes are divided into two sub-sections and addressed in the following sub-sections. For the convenience of interpretation, we assume there are K committee members in the decision group. They face a partner selection problem with P motivations and Q criteria, each of which has S_q measurable sub-criteria for T candidate partners.

4.1. Setting criteria weights

Once a company decides to proceed with forming a strategic alliance with other companies, its motivations must be first addressed. Many studies (Badaracco, 1991; Hoffman & Schlosser, 2001; Sampson, 2004) have advised that a company should first determine its motivations before an appropriate alliance partner can be selected. This implies that the criteria weighting is affected by motivations. For instance, if the primary motivation for establishing an alliance is acquiring resources for technological development, then the criteria concerning technological capability and resources for R&D should be assigned greater weights than other criteria. If the primary motivation is extending the market penetration, the criterion of corporation compatibility should be emphasized. A company may have multiple motivations for establishing the strategic alliance, but with different intensities and priorities that in turn will affect the weight set for the criteria importance. Hence, the priority of the motivations must be settled before proceeding to other procedures for partner selection.

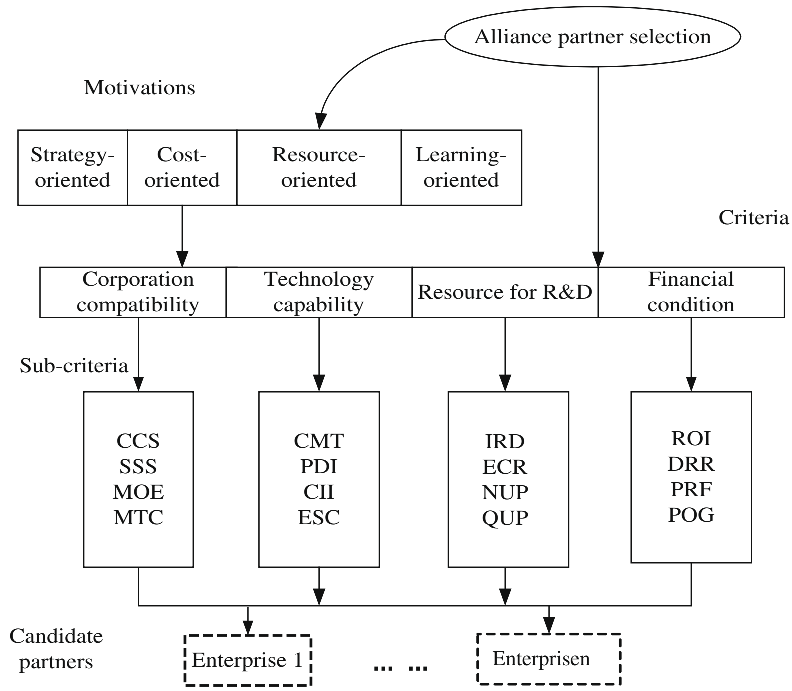


Fig. 1. The relationship between motives, criteria, and sub-criteria in the partner selection.

To realize the intensity of the motivations, each committee member will have to answer the question: What is the intensity of the motivations for our company to establish a strategic alliance? A unit scale is employed to express the degree of intensity from very low, low, moderate, high, to very high. Suppose the number m_{ip} is the answer of the ith committee member for the degree of intensity of the pth motivation. The composite fuzzy weight of the intensity of the pth motivation obtained by combining the K committee members could be expressed by the triangular fuzzy number (Kuo, Chi, & Kao, 2002):

$$\widetilde{M}_p = (a_p, b_p, c_p) \tag{1}$$

in which,

$$a_p = \min_i(m_{ip}), \quad c_p = \max_i(m_{ip}) \quad \text{and} \quad b_p = \left(\frac{\prod_{i=1}^{k} m_{ip}}{a_p \times c_p}\right)^{\frac{1}{k-2}}$$
$$p = 1, \ldots, P$$

The second step is to determine the relative importance of those criteria with respect to each of the motivations. The reason for this consideration is the realization that the weight for importance of the criteria should be adjusted as a particular motivation is emphasized. That is to say, a candidate company that satisfies criteria most related to a particular motivation pursued by a company should be considered first as a partner. Questions such as "what is the relative importance of the criteria with respect to the achievement for a particular motivation?" will be provided to the committee members. A unit scale is utilized to express the degrees of relative importance ranging from very unimportant, unimportant, moderate and important, to very important, and similarly denoted by consecutive decimal numbers from 0 to 1. Just as in the process in the previous paragraph, suppose the number n_{ipq} represents the answer of the ith committee member for the degree of relative importance of the qth criteria with respect to the pth motivation. The composite relative importance for the qth criteria with respect to the pth motivation obtained from K committee members could be expressed as the following triangular fuzzy number:

$$\widetilde{N}_{pq} = (d_{pq}, e_{pq}, f_{pq}) \tag{2}$$

In which,

$$d_{pq} = \min(n_{ipq}), \quad f_{pq} = \max(n_{ipq}), \quad e_{pq} = \left(\frac{\prod_{i=1}^{k} n_{ipq}}{d_{pq} \times f_{pq}}\right)^{\frac{1}{k-2}},$$
$$p = 1, \ldots, P; \quad q = 1, \ldots, Q$$

Consequently, the composite fuzzy relative importance for the qth criteria can be obtained by multiplying the $\widetilde{M}_p = (a_p, b_p, c_p)$ with $\widetilde{N}_{pq} = (d_{pq}, e_{pq}, f_{pq})$ as follows:

$$\widetilde{W}_q = \sum_{p=1}^{P} \widetilde{M}_p \otimes \widetilde{N}_{pq}, \quad q = 1, \ldots, Q \tag{3}$$

By the extension principle of fuzzy sets (Zadeh 1975, 1976; Zimmermann 1991) and the definition of the triangular fuzzy number (Dubois & Prade 1978), the product of two triangular fuzzy numbers is still a fuzzy number. The relationship function of fuzzy number $\widetilde{W}_q$ can be expressed as the following Eq. (4) (Lee & Chen, 2002; Liang & Wang, 1994):

$$\widetilde{W}_q(w) \cong \begin{cases} \frac{-B_1}{2A_1} + \left[\left(\frac{B_1}{2A_1}\right)^2 - \frac{C_1 - w}{A_1}\right]^{\frac{1}{2}} & C_1 \leqslant w \leqslant C_2 \\ \frac{B_2}{2A_2} - \left[\left(\frac{B_2}{2A_2}\right)^2 - \frac{C_3 - w}{A_2}\right]^{\frac{1}{2}} & C_2 \leqslant w \leqslant C_3 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where

$$A_1 = \sum_{p=1}^{P} (b_p - a_p)(e_{pq} - d_{pq})$$

$$A_2 = \sum_{p=1}^{P} (c_p - b_p)(f_{pq} - e_{pq})$$

$$B_1 = \sum_{p=1}^{P} (a_p(e_{pq} - d_{pq}) + d_{pq}(b_p - a_p))$$

$$B_2 = \sum_{p=1}^{P} (c_p(f_{pq} - e_{pq})) + (f_{pq}(c_p - b_p))$$

$$C_1 = \sum_{p=1}^{P} a_p d_{pq}$$

$$C_2 = \sum_{p=1}^{P} b_p e_{pq}$$

$$C_3 = \sum_{p=1}^{P} c_p f_{pq}$$

Here, $\widetilde{W}_q$ is not a triangular fuzzy number. For simplicity, in practice the approximation formula $\widetilde{W}_q = \sum_{p=1}^{P} \widetilde{M}_p \otimes \widetilde{N}_{pq} \cong (C_{q1} = C_1, C_{q2} = C_2, C_{q3} = C_3)$ can be used.

Although many fuzzy ranking methods have been proposed (Campos & Gonzalez, 1989; Garcia-Cascales & Lamata, 2007; Gonzalez, 1990; Kim & Park, 1990; Liou & Wang, 1992), each with its own advantages and disadvantages (Klir & Yuan, 1995). For simplicity of calculation and capacity in problem solving, the centroid ranking method proposed by Yager (1978) is employed to rank the fuzzy number.

Let $R(\widetilde{W}_q)$ be the rank value of fuzzy number $\widetilde{W}_q$, then

$$\begin{aligned} R(\widetilde{W}_q) &= \int w\widetilde{W}_q(w)dw / \widetilde{W}_q(w)dw \\ &= \left[\left(\frac{1}{C_{q2}-C_{q1}}\right)\left(\frac{C_{q2}^3}{3} - \frac{C_{q2}^2 C_{q1}}{2} + \frac{C_{q1}^3}{6}\right)\right. \\ &\quad \left. + \left(\frac{1}{C_{q3}-C_{q2}}\right)\left(\frac{C_{q2}^3}{3} - \frac{C_{q2}^2 C_{q3}}{2} + \frac{C_{q3}^3}{6}\right)\right] \Big/ \left[\frac{1}{2}(C_{q3}-C_{q1})\right] \end{aligned} \tag{5}$$

Finally, after some mathematical rearrangement, the centroid rank value of the approximated triangular fuzzy number becomes:

$$R(\widetilde{W}_q) = \frac{1}{3}(C_{q1} + C_{q2} + C_{q3}), \quad q = 1, \ldots, Q \tag{6}$$

4.2. Fuzzy evaluation for candidate partners

For evaluation, each criterion must be further developed into a set of measurable sub-criteria that can be employed to evaluate each candidate partner. Similarly, the relative importance of sub-criteria with respect to their associate criteria must be determined before the sub-criteria can be utilized to conduct the evaluation. Step 2 in Section 4.1 will be implemented again. A questionnaire with questions such as "What is the relative importance of the sub-criterion with respect to its associate criteria?" will be provided to the committee members. A unit scale will be employed to express the degrees of relative importance ranging from very unimportant, unimportant, moderate, important, to very important and similarly denoted by consecutive decimal numbers from 0 to 1. Such as in the process described in the previous paragraph, suppose the number x_{iqs} represents the answer of the ith committee member for the degree of relative importance of the sth sub-criterion with respect to its associate qth criterion. The composite relative importance for the sth sub-criterion with respect to its associate qth criterion for the K committee members could be expressed as the following triangular fuzzy number:

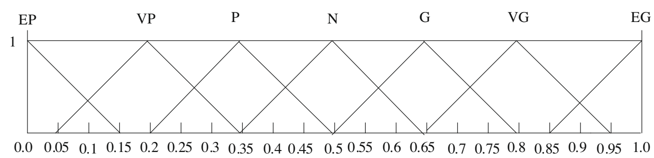
$$\widetilde{X}_{qs} = (a_{qs}, b_{qs}, c_{qs}) \tag{7}$$

In which,

$$a_{qs} = \min(x_{iqs}), \quad c_{qs} = \max(x_{iqs}), \quad b_{qs} = \left(\frac{\prod_{i=1}^{k} x_{iqs}}{a_{qs} \times c_{qs}}\right)^{\frac{1}{k-2}},$$
$$q = 1, \ldots, Q; \quad s = 1, \ldots, S$$

In the next step, we employ the sub-criteria to evaluate each candidate partner. Each committee member conducts a series of pair-wise comparisons between these candidate partners according to each sub-criterion. A seven-point linguistic scale is utilized to express their relative performance. The scale is extremely poor, very poor, poor, neutral, good, very good, and extremely good. The relationship functions of the linguistic values for evaluating the performance of a potential partner are defined as follows (Liang & Wang, 1994):

- *extremely poor*(EP):(0, 0, 0.15)
- *very poor*(VP):(0.05, 0.2, 0.35)
- *poor*(P):(0.2, 0.35, 0.5)
- *neutral*(N):(0.35, 0.5, 0.65)
- *good*(G):(0.5, 0.65, 0.8)
- *very good*(VG):(0.65, 0.8, 0.95)
- *extremely good*(EG):(0.85, 1, 1)



The results of the pair-wise comparison are expressed as a matrix form. The cell in the top-left is the control sub-criterion. The candidate partners reside in the first row and the first column. We compare the performance of the company in the left column with each of the companies at the upper row according to the control sub-criterion. The committee members just need to complete the upper-right part of the matrix. The lower-left part of the matrix is produced automatically as the "reciprocal" of the upper-right part of the matrix. The results are depicted in Table 1.

For the convenience of interpretation, let $\widetilde{A} = [\widetilde{m}]_{T\times T}$ be the comparison matrix. Each row's arithmetic average can be interpreted as the performance evaluation of the tth candidate partner on the sth sub-criterion of its associate qth criterion evaluated by the ith committee. This average can be denoted by the triangular fuzzy number $\widetilde{P}_{iqst} = \frac{1}{T}\sum_{v=1}^{T}\widetilde{m}_{tv} = (m_{at}, m_{bt}, m_{ct})$, $t = 1, \ldots, T$. Similarly, the decision group's composite performance evaluation of a particular candidate partner for the particular control sub-criterion can be expressed by the following triangular fuzzy number:

$$\widetilde{Y}_{qst} = \frac{1}{K}\sum_{i=1}^{K}\widetilde{P}_{iqst} = (d_{qst}, e_{qst}, f_{qst}), \quad t = 1, \ldots, T \tag{8}$$

Consequently, the composite weighted performance evaluation of the tth candidate partner on the qth criterion can be calculated by summing the products of Eqs. (7) and (8) as follows:

$$\widetilde{Z}_{qt} = \sum_{s=1}^{q_s}\widetilde{X}_{qs} \otimes \widetilde{Y}_{qst}, \quad q = 1, \ldots, Q; \ t = 1, \ldots, T \tag{9}$$

Again, the membership function of the fuzzy number $\widetilde{Z}_{qt}$ does not have triangular form. For simplicity, the approximation formula can be used in practice.

Table 1
The pair-wise comparison of the performance of candidate companies according to the control sub-criterion.

Control sub-criterion	Candidate 1	Candidate 2	Candidate 3	...	Candidate T
Candidate 1	I	VP	EG	...	VG
Candidate 2	VG	I	G	...	P
Candidate 3	EP	P	I	...	I
⋮				⋱	⋮
Candidate T	VP	G	I	...	I

$$\widetilde{Z}_{qt} = \sum_{s=1}^{q_s} \widetilde{X}_{qs} \otimes \widetilde{Y}_{qst}$$
$$\cong \left(C_{qt1} = \sum_{s=1}^{q_s} a_{qs} \times d_{qst}, C_{qt2} = \sum_{s=1}^{q_s} b_{qs} \times e_{qst}, C_{qt3} = \sum_{s=1}^{q_s} c_{qs} \times f_{qst} \right)$$
$$q = 1, \ldots, Q; \;\; t = 1, \ldots, T \quad (10)$$

The centroid ranking method proposed by Yager (1978) is employed again to rank the fuzzy number. Finally, after some mathematical rearrangement, the centroid rank value of the approximated triangular fuzzy number becomes:

$$R(\widetilde{Z}_{qt}) = \frac{1}{3}(C_{qt1} + C_{qt2} + C_{qt3}) \quad q = 1, \ldots, Q; \;\; t = 1, \ldots, T \quad (11)$$

At this stage, we can synthesize the suitability index for the tth potential partner by multiplying the composite performance on each criterion with its corresponding composite important weight as following equation:

$$D_t = \sum_{q=1}^{Q} R(\widetilde{W}_q) \times R(\widetilde{Z}_{qt}) \quad t = 1, \ldots, T. \quad (12)$$

We summarize below the procedure proposed in this paper for partner selection.

- *Step 1:* Set up a committee for this strategic decision problem.
- *Step 2:* Realize what motivations drive the company to forge a strategic alliance with other companies and determine the intensity of each motivation by calculating its priority index.
- *Step 3:* Understand the relationship between the criteria for evaluation and each of the motivations by calculating the relative importance weights for criteria with respect to each individual motivation.
- *Step 4:* Calculate the composite relative important weight for each criteria by multiplying its relative importance weight by the intensity of the corresponding motivation.
- *Step 5:* Determine the relative weight for each of the sub-criteria with respect to the criterion that it developed from.
- *Step 6:* Evaluate the performance for each of the potential partners using those sub-criteria.
- *Step 7:* Calculate the composite weighted performance of each candidate partner on each criterion by summing up the product of the performance of each candidate partner on each sub-criterion and its relative weight of importance.
- *Step 8:* Synthesize the performance of each candidate partner by summing up the product of the composite important weight of criteria and the composite weighted performance on the criteria.

The capability of representing the situation of vagueness is the intrinsic quality to the fuzzy linguistic variables. For the purpose of being able to be widely applied, precise membership functions do not exist by themselves. They are tendency indices, context-dependent and subjectively assigned by an individual or a group (Dubois & Prade, 1980). The proposed model development processes mentioned in this Section, the membership functions of these linguistic variables and the mapping of the linguistic variables to their associated numerical values, although some relative papers are referred by authors, are somewhat determined intuitively and subjectively. Other types of membership function and their associated mapping functions could be employed in this model as necessary.

5. Illustrative example

For illustration and comparison, a precision machinery company that designs and manufactures reduction and precision gear devices in central Taiwan, Republic of China, serves as the case company. It is a typical SME in Taiwan. To increase the competitiveness and upgrade the technological level of these SMEs, the Ministry of Economic Affairs (MOE) of Taiwan encourages them to forge alliances to develop technology for planned projects through tax reductions and other incentives. Anticipating great prospects for the green energy market, the case company submitted a proposal to develop a new product of wind-power generation set, which was approved by the MOE. Lacking the expertise necessary to develop the product, and encouraged by the government incentives, the case company decided to establish an alliance with other companies to develop the necessary technology. The company hoped to benefit from the alliance by (1) maintaining close contact with other companies, thus strengthening the social relationship of the company in the industry; (2) encouraging their R&D personnel to improve their technology level via information interchange with other companies; (3) learning new aspects of power generation to extend the scope of business in future; and (4) reducing the risk and cost to develop this new wind-power generation set. In the final evaluation, the case company had screened four candidate companies, each of which has its own merits. The AHP approach discussed above was applied to this decision-making problem.

The case company set up a committee composed of the general manager (GM), financial manager (FM), technical innovation manager (TIM), technical development manager (TDM), and production manager (PM). These five persons then held meetings to discuss the alliance partner selection following the procedure detailed in the previous sections. First, each committee member contributed his personal opinion about the intensity of motivations driving the company to establish a strategic alliance with other companies. The committee member tried to reach a consensus. The four motivations discussed in the previous section were proposed for their consideration. Each of them wrote down his own personal opinion and the data were collected and normalized as shown in Table 2. Eq. (1) was employed to calculate the fuzzy priority index for those motivations, and the results are depicted in the right three columns of Table 2. As can be seen, the relative fuzzy intensity index indicates that the most important motivation for this company to forge a strategic alliance is resource-oriented, followed by learning-oriented. The dispersed quality of the fuzzy intensity implies that the committee members hold different opinions concerning the cost-oriented and the strategy-oriented motivations.

The next step is to determine the relative importance of the criteria for each motivation. The left part of Table 3 depicts the normalized data collected from the five committee members for the relative importance of the four criteria with respect to the strategy-oriented motivation. Eq. (2) is employed to establish the fuzzy important weight for these criteria with respect to each of the motivations. The other three are completed in the same way. The fuzzy weights of importance for these criteria are calculated by Eq. (3) with data in the right part of Tables 2 and 3. We summarize the approximated fuzzy weight for these criteria in Table 4. Finally, in Table 5, the composite importance weights of criteria are available after the defuzzifying and normalizing. As can be seen, when selecting an alliance partner, this company will emphasize the criteria of resources for R&D and technology capability. This is partly because the primary motivation of the company for establishing a strategic alliance is resource-oriented, that is seeking critical resources such as critical equipment and technologies to reduce the risk of R&D and use the alliance partner's marketing channels. The normalized importance weights for the criteria are reserved for the final step of evaluation.

In next phase of the partner selection procedure, the sub-criteria of each criterion are used to evaluate the performance of the candidate partner companies. The relative weights of importance

Table 2
The intensity index for the four motivations.

	GM	FM	TIM	TDM	PM	Fuzzy intensity		
						a_p	b_p	c_p
Strategy-oriented	0.333	0.154	0.15	0.217	0.217	0.15	0.194	0.333
Cost-oriented	0.167	0.385	0.05	0.131	0.131	0.05	0.142	0.385
Resource-oriented	0.292	0.231	0.45	0.304	0.391	0.231	0.326	0.45
Learning-oriented	0.208	0.231	0.35	0.348	0.261	0.208	0.276	0.35

Table 3
The relative fuzzy importance weight of the criteria with respect to the motivation of strategic-oriented.

Strategy-oriented	GM	FM	TIM	TDM	PM	Fuzzy weight of importance		
						d_{pq}	e_{pq}	f_{pq}
Organization compatibility	0.28	0.25	0.33	0.263	0.292	0.25	0.278	0.333
Technology capability	0.24	0.15	0.29	0.316	0.25	0.15	0.258	0.316
Resource for R&D	0.28	0.25	0.24	0.263	0.333	0.238	0.264	0.333
Financial condition	0.20	0.35	0.14	0.158	0.125	0.125	0.165	0.35

of the sub-criteria with respect to the criterion from which they develop must be determined before they can be applied to the evaluation process. As in the weighting process for criteria with respect to motivations discussed in the previous paragraph, each member of the committee is required to repeat the process. Four tables the same as in Table 3 are employed to collect the data. Eq. (7) is utilized to set up the fuzzy weights of these sub-criteria with respect to their associated criterion. Table 6 depicts the composite fuzzy weights for these sub-criteria from the committee.

Now we proceed to the step of performance evaluation for these candidate partners according to each of the sub-criterion. Since the level of performance of a company with respect to each sub-criterion is related to other companies' performance, pair-wise comparisons are implemented in this step. The fuzzy linguistic variables defined in the previous section are now applied to this evaluation. Table 7 describes the performance evaluation for these candidate partners according to the sub-criterion of compatibility of corporate strategy by one of the committee members. The fuzzy performance for each of the candidate partners is calculated and entered in the right part of the table. Each committee has to implement the pair-wise comparison of the performance of the four candidate companies with respect to each of the 16 sub-criteria. Eq. (8) is employed to calculate the composite fuzzy performance of the candidate companies according to the sub-criteria. Table 8 depicts the calculation results.

After the fuzzy weights of these sub-criteria and the composite fuzzy performance of the candidate partners of these sub-criteria are obtained, the next step is to compute the weighted performances for these candidate partners. This is calculated by summing up the product of the fuzzy performance of candidate partners of those sub-criteria and the fuzzy weights of those sub-criteria accordingly. From the discussion above, the product of two triangular fuzzy numbers produces a non-triangular fuzzy number. The approximation approach is applied again. Eqs. (9) and (10) are used for handling this situation. As can be seen, Eqs. (9) and (10) group the weighted fuzzy performance by criterion for each candidate partner. The approximated composite weighted performance of candidate partners of each criterion are entered in Table 9. The defuzzified score is calculated by Eq. (11), and its normalized score for each candidate partner of each criterion is also calculated and entered in Table 9. Finally, the suitability index for each candidate partner is obtained by applying Eq. (12) to sum up the product of its normalized score of each criterion and the weight of importance of this criterion (see number in the parentheses under each criterion). As seen in the data shown in the last row of Table 9, since candidate company 3 has a larger suitability index it should be considered first for establishing the strategic alliance. Table 9 also shows that company 3 performs relatively well in the criteria for R&D and technology capability. These two criteria have been given larger weights by the committee,

Table 4
The summary of the approximated fuzzy relative importance weight of the criteria for each of the motivations.

	Strategy-oriented			Cost-oriented			Resource-oriented			Learning-oriented		
	d_{pq}	e_{pq}	f_{pq}	d_{pq}	e_{pq}	f_{pq}	d_{pq}	e_{pq}	f_{pq}	d_{pq}	e_{pq}	f_{pq}
Organization compatibility	0.25	0.278	0.333	0.13	0.159	0.217	0.12	0.157	0.276	0.118	0.144	0.2
Technology capability	0.15	0.258	0.316	0.261	0.321	0.364	0.207	0.251	0.348	0.32	0.351	0.471
Resource for R&D	0.238	0.264	0.333	0.304	0.351	0.409	0.241	0.342	0.391	0.28	0.324	0.375
Financial condition	0.125	0.165	0.35	0.091	0.155	0.227	0.13	0.232	0.304	0.118	0.147	0.2

Table 5
The composite fuzzy, defuzzified, and normalized weights of the relative importance of criteria.

	Composite fuzzy weight			Defuzzified weight	Normalized weight
	C_{q1}	C_{q2}	C_{q3}	$\frac{1}{3}(C_{q1}+C_{q2}+C_{q3})$	
Organization compatibility	0.096	0.167	0.389	0.217	0.195
Technology capability	0.15	0.274	0.567	0.330	0.296
Resource for R&D	0.165	0.302	0.576	0.347	0.312
Financial condition	0.078	0.170	0.411	0.220	0.197

Table 6
Composite fuzzy weights of sub-criteria.

Organization compatibility				Technology capability				Resource for R&D				Financial condition			
Sub-criteria	Fuzzy weight			Sub-criteria	Fuzzy weight			Sub-criteria	Fuzzy weight			Sub-criteria	Fuzzy weight		
	a_{qs}	b_{qs}	c_{qs}		a_{qs}	b_{qs}	c_{qs}		a_{qs}	b_{qs}	c_{qs}		a_{qs}	b_{qs}	c_{qs}
CCS	0.115	0.15	0.217	CMT	0.106	0.144	0.209	IRD	0.201	0.238	0.318	ROI	0.198	0.268	0.348
SSS	0.111	0.228	0.308	PDI	0.206	0.301	0.351	ECR	0.168	0.373	0.436	DRR	0.105	0.135	0.198
MOE	0.19	0.264	0.348	CII	0.168	0.376	0.438	NUP	0.121	0.188	0.277	PRF	0.211	0.268	0.356
MTC	0.174	0.384	0.444	ESC	0.121	0.229	0.314	QUP	0.178	0.262	0.341	POG	0.172	0.362	0.413

Table 7
The evaluation of compatibility of corporate strategies for candidate partners by one member of committee.

Compatibility of corporate strategies	Candidate 1	Candidate 2	Candidate 3	Candidate 4	Fuzzy performance		
					m_{at}	m_{bt}	m_{ct}
Candidate 1	I	P	VP	G	0.275	0.425	0.575
Candidate 2	G	I	P	VG	0.425	0.575	0.725
Candidate 3	VG	G	I	EG	0.588	0.738	0.85
Candidate 4	P	VP	EP	I	0.15	0.263	0.413

Table 8
Composite performance evaluation for the candidate partners.

	Candidate 1			Candidate 2			Candidate 3			Candidate 4		
	d_{qs1}	e_{qs1}	f_{qs1}	d_{qs2}	e_{qs2}	f_{qs2}	d_{qs3}	e_{qs3}	f_{qs3}	d_{qs4}	e_{qs4}	f_{qs4}
CCS	0.283	0.443	0.583	0.398	0.512	0.686	0.591	0.795	0.883	0.142	0.234	0.404
SSS	0.254	0.411	0.521	0.433	0.608	0.755	0.508	0.697	0.799	0.201	0.283	0.474
MOE	0.312	0.466	0.601	0.403	0.552	0.705	0.601	0.754	0.885	0.133	0.245	0.301
MTC	0.265	0.405	0.515	0.465	0.595	0.785	0.528	0.705	0.821	0.224	0.295	0.465
CMT	0.142	0.234	0.404	0.283	0.443	0.583	0.398	0.512	0.686	0.591	0.795	0.883
PDI	0.201	0.283	0.474	0.254	0.411	0.521	0.433	0.608	0.755	0.508	0.697	0.799
CII	0.133	0.245	0.301	0.312	0.466	0.601	0.403	0.552	0.705	0.601	0.754	0.885
ESC	0.224	0.295	0.465	0.265	0.405	0.515	0.465	0.595	0.785	0.528	0.705	0.821
IRD	0.303	0.483	0.613	0.348	0.482	0.626	0.568	0.815	0.893	0.141	0.214	0.394
ECR	0.244	0.401	0.491	0.463	0.668	0.835	0.488	0.627	0.749	0.241	0.313	0.494
NUP	0.362	0.486	0.641	0.333	0.512	0.665	0.621	0.774	0.886	0.133	0.225	0.281
QUP	0.265	0.445	0.515	0.465	0.565	0.725	0.528	0.705	0.821	0.244	0.345	0.485
ROI	0.402	0.564	0.686	0.588	0.795	0.863	0.172	0.264	0.425	0.273	0.413	0.564
DRR	0.453	0.621	0.778	0.489	0.667	0.729	0.241	0.283	0.496	0.224	0.401	0.514
PRF	0.398	0.512	0.655	0.641	0.784	0.915	0.123	0.215	0.291	0.362	0.486	0.621
POG	0.465	0.595	0.785	0.528	0.705	0.821	0.224	0.295	0.465	0.265	0.405	0.515

implying that this partner must have the potential to satisfy the motivations that the company is pursuing in the near future.

It is obvious that to select an adequate partner is important for ensuring the success of setting a strategic alliance. Unfortunately, to select an adequate partner is not an easy task. It should be considered in every respect. As we can see, the intensities of the motivations in this case could be considered as the "priority" of the motivations that the company may want to pursue, based on the perception of the committee. The composite relative weight of criterion indicates the relative importance of the criterion among the evaluation model. The calculation process could be viewed as the deliberation of committee of the whole. It is a recursive procedure until the intensities and composite relative weights comply with the enterprise's development policy. At the same time, based on the model development procedure and the brief discussion doing in the previous paragraph, to track the performance of each candidate on each criterion is possible. Although the suitable indices of the candidate partners can be used as a basis for partner selection, to conduct a comprehensive analysis of the performance of these candidates on each criterion is necessary before a final decision is made.

6. Conclusions

When an enterprise has resolved to form a strategic alliance, it should then carefully select the partner in order to ensure success. The top managers of an enterprise may have multiple motivations for establishing an alliance but with different priorities in mind, thus affecting the weighting of criteria for evaluating the suitability of candidate partners.

In the earlier phase of the partner selection process, each member of the committee must realize the intensity of different motivations and gain a consensus. After that, the consensus on priorities of the motivations must be integrated into the weighting process for major criteria. The composite fuzzy relative weights of criteria are then reserved to evaluate the performance of candidate partners afterwards. The latter phase of the selection process involves evaluation of the sub-criteria. The relative weights of importance for each group of those measurable sub-criteria are set with respect to the criterion from which the particular group of sub-criteria developed. To increase the consistency of judgment, we suggest the pair-wise comparison approach for comparing the level of performance for the candidate partners. This is particularly

Table 9
Composite weighted performance evaluation for the candidate partners.

	Candidate 1			Candidate 2			Candidate 3			Candidate 4		
	C_{q11}	C_{q12}	C_{q13}	C_{q21}	C_{q22}	C_{q23}	C_{q31}	C_{q32}	C_{q33}	C_{q41}	C_{q42}	C_{q43}
Organization compatibility (0.195)	0.166	0.439	0.725	0.251	0.59	0.975	0.33	0.748	1.110	0.103	0.278	0.545
Defuzzified score		0.443			0.605			0.63			0.308	
Normalized score		0.223			0.305			0.317			0.155	
Technology capability (0.296)	0.106	0.279	0.529	0.167	0.455	0.73	0.255	0.601	0.964	0.332	0.769	1.11
Defuzzified score		0.304			0.451			0.707			0.737	
Normalized score		0.138			0.205			0.321			0.335	
Resource for R&D (0.312)	0.193	0.472	0.762	0.271	0.608	0.995	0.365	0.758	1.136	0.128	0.3	0.584
Defuzzified score		0.476			0.625			0.753			0.338	
Normalized score		0.217			0.285			0.344			0.154	
Financial condition (0.197)	0.291	0.588	0.95	0.394	0.768	1.109	0.124	0.273	0.542	0.2	0.442	0.732
Defuzzified score		0.61			0.757			0.313			0.458	
Normalized score		0.285			0.354			0.146			0.214	
Suitability index		0.208			0.279			0.293			0.22	

meaningful when evaluating companies with closer levels of performance or when every candidate company has its own merits in particular sub-criteria. Finally, the suitability index for each candidate partner is available by synthesizing the performance of each candidate company on each group of sub-criteria with its corresponding criterion. Although the multiplication of two triangular fuzzy numbers may be tedious, in practice, an approximation triangular form for the non-triangular fuzzy number is advised for simplifying the calculation.

The relative intensities and weights are calculated from the pair-wise comparison of motivations and criteria considering their “super-criteria”, the decision-maker should assure the output of each step coincide with the initial policy set for enterprise. We claim that the relative weights of criteria are affected by motivations. If the calculated intensities of the motivations coincide with the enterprise policy, the relative weights of the criteria calculated based on the motivations will be used in the subsequent procedure; otherwise, if there is a misunderstanding existing in committees, the relative weights of the criteria that calculated based on these motivations may be twisted. The subsequent processes could be errors in calculation. Consequently, they will make a wrong decision and select an improper partner. In such a case, the intensities of the motivations should be considered again by the committees and the above procedure should be repeated. Based on this iterative review approach, a proper weight setting for these criteria is available and will comply with the original motivation for establishing the strategic alliance. This is essential for selecting an appropriate partner for establishing an alliance that matches the original strategic consideration of the company.

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