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FUZZY AHP WITH MCDA TO CONSTRUCT THE ROADMAP OF R&D CONSORTIA IN TAIWAN'S M&S ENTERPRISES

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Summary: *While entering WTO, Taiwan has become one of the members in the international community of globalization. The medium & small enterprises (M&SE), which accounts for 98 % of Taiwan industries facing even more competition due to insufficient capital, human resources, and limited organization scale. To achieve competitive edges for the globalization requires efficiency in doing business and scale in industry development, M&SE should aggressively develop technical capabilities and synergy form strategic R&D consortia to effectively consolidate resources. In this study we established a hierarchical frame for evaluating the utility of R&D consortia. As a result, it comes up with five levels of structure and twenty evaluating principles for forming R&D consortia. Analysis Hierarchy Process (AHP) was applied to determine the weights of considered criteria. We also employed Fuzzy Multi-Criteria Data Analysis (Fuzzy MCDA) to derive the utility of each strategy. Finally, we summarized some findings of this study and provided some suggestions for development direction of M&S enterprise in near future.*

Keywords: Medium & Small Enterprises, R&D consortia, Analysis Hierarchy Process, Fuzzy Multi-Criteria Decision Making

1. Introduction

Over the past two decades R&D consortia with strategy alliance are increasingly taken into account in making decision for enhancing innovation and advantage competence. The competence-based perspective of the firm, which emphasizes the internal features of organizations, has developed in parallel with an impressive amount of literature dedicated to interfirm cooperation. Some of these works bring together the competence perspective and issues related to cooperation (Dierickx & Cool, 1989; Amit & Schoemaker, 1993; Doz & Hamel, 1998). In this study, we examine how research and development (R&D) cooperation can be used as a means for firms to jointly create new resources, such as products, patents, and prototypes, as well as scientific and technological competencies. We aim to understand the relationships between the characteristics of firms, how they create and utilize resources, their degree of

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involvement, and the roles they have when participating in an R&D effort.

In real world systems, strategy drawing up and searching alliance partners in R&D consortia development may essentially be conflict analyses characterized by sociopolitical, industrial environment, and economic value judgments. Several strategies should be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often inaccurate or uncertain. Due to lack of information, future states of the system might not be known completely. This type of uncertainty has been handled appropriately by probability theory and statistics. However, in many areas such as engineering, medicine, meteorology and manufacturing, human judgment, evaluation and decisions often employ natural language to express thinking and subjective preferences. In these natural languages, the meaning of a word might be well defined, but when using the word as a label for a set, the boundaries within which objects do or do not belong to the set become fuzzy or vague.

Human judgment of events may be significantly different based on individuals' subjective perceptivity or personality, even when using the same words. Triangular fuzzy numbers have been developed to appropriately express linguistic variables. In this paper a fuzzy hierarchical analytic process was used to determine the weights of criteria from subjective judgment, and a simple additive weighted (SAW) method were used to evaluate the performance of R&D consortia strategies for M&SE in Taiwan.

In the next section, we will discuss the R&D cooperation and resource creation for strategy alliance. The fuzzy hierarchical analysis approach and evaluation process is derived in Section 3. A fuzzy simple additive weighted method for evaluating R&D consortia development in Taiwan is presented in Section 4. Finally, some research findings conclusions are presented in Section 5.

2. R&D Cooperation And Resource Creation

Wernerfelt (1984), Prahalad and Hamel (1990), Sanchez et al. (1996) and Teece et al. (1997) have developed an innovative theoretical view of the firm based on resources and competencies. These earlier works address the firm's internal competencies and its capabilities to develop activities and enter new markets. Here we adopt the following definitions from the resource-based perspective and competencies:

(1) Resources are assets, either tangible (such as machines, processes, capital, etc.) or intangible (such as knowledge, brand names, technological know-how, or commercial contacts), that are possessed or controlled by the firm and that can be used to create future benefits for the firm.
(2) Competence is an ability to sustain and to coordinate the deployment of assets.
(3) Capabilities are repeatable patterns of action that employ the firm's assets and that involve individual and organizational knowledge, skills, and competencies.

In recent years, alliances and collaborations have grown to become an important research topic. Three main types of studies exist on this subject matter:

(1) Motivations, objectives sought, and forms adopted (Contractor & Lorange, 1988; Hagedoorn, 1993; Smith et al., 1995) in a cooperation.
(2) Partner characteristics leading to the choice of an alliance. Resource exchange and the type of resources that can be accessed are of central concern in these studies (Harrigan, 1986; Oliver, 1990).
(3) The interactive nature of cooperation between firms (Kumar & Nti, 1998; Ring & Van de Ven, 1994)

Numerous authors developed the argument that firms use cooperation to acquire or to create new resources (Hamel, 1991; Kogut, 1988; Kogut & Zander, 1993; Pisano, 1990). They confirm the need for firms to widen their bases of competencies in order to create a competitive advantage, especially through technological innovation. These studies show that interfirm cooperation has three main strategic roles:

(1) It is a means to combine tacit and/or complementary competencies.
(2) It is an organizational tool to acquire or exchange resources and information without irreversible involvement and to enhance learning.
(3) It serves as a strategic instrument used to create value and to accelerate the firm's adaptation to its environment.

Motives for participating in cooperative R&D ventures are largely determined by the characteristics of the R&D projects pursued. R&D cooperation can eliminate wasteful duplication of effort and can also improve efficiency in the overall R&D process by coordinating individual projects and by disseminating knowledge (Katz & Ordover, 1990). In the case of activities with weak property rights, a cooperative R&D agreement can serve as a mechanism to internalize spillover, leading thus to greater R&D incentives for both parties (Teece, 1986). The resource-based perspective suggests that both the heterogeneity and complementarities of participants' capabilities can often incite firms to cooperate for R&D.

An R&D consortium can be viewed as an inter-organizational relationship in which firms maintain their autonomy but are involved in a bilateral dependency (Williamson, 1991). Here, we define an R&D consortium as a group of firms linked by a cooperation agreement and conducting R&D together. It is comprised of three characteristics:

(1) It is an organization that is not completely detached from its parent companies, either strategically or legally (Osborn & Baughn, 1990).
(2) Its scope changes over time, as certain members leave and others join (Evan & Olk, 1990).
(3) It can either be a research joint venture with shared common facilities or may have a more decentralized organization (Ouchi & Bolton, 1988).

Characterized by a network organization, R&D consortia do not possess a centralized, or common, research facility. As a result, resources and competencies are more or less disseminated among partners. However, even in such a decentralized organization, consortia members usually expect a minimum return on investment, may it be the perception of being on the leading edge of technology or, in a more tangible way, the creation of new products, processes, patents, or licenses. It is therefore worthwhile to identify the elements that influence the creation of new resources linked to the characteristics of the firms themselves and to those of the organization of the R&D consortium (Khanna et al., 1998).

3. Fuzzy Hierarchical Analysis Approach and Evaluation Process

Traditional evaluation methods usually take the minimum cost or the maximized benefit as their single index of measurement criteria, although these approaches may not be sufficient for the increasingly complex and diversified decision-making environment. Here we utilize a fuzzy hierarchical analytic process into four stages. First, the evaluation group will be defined after identifying the problem. We consider critical criteria from various points of view based on responsibility and effect for enterprise sustainable development planning. We also consider available strategies to validate the meaning of sustainable development. The hierarchical system for our problem is then set up in this stage.

Secondly, determine the weights of criteria as well as fuzzy set theory is introduced to determine performance values of strategies. Thirdly, fuzzy MCDM method was selected to evaluating the strategies, which method derive synthetic value of each strategy using by aggregating the weights with performance value with respect to considered criteria. Fourth and finally, decision makers decide on the best strategy based on the final synthetic value.

3.1 Building A Hierarchical System For Evaluation

The evaluators must establish a hierarchical system for analysis and evaluation in the multiple criteria decision-making problem. Keeney and Raiffa (1976) suggest that five principles must be followed when criteria are being formulated: (1) Completeness, (2) Operationality, (3) Decomposability, (4) Nonredundancy, and (5) Minimum size.

Following the assumption of problem description, we establish the hierarchical frame using a literature survey and group conferencing for scenario writing and brainstorming, as shown in Fig.1. Phase 1 includes setting our goal for strategy development. We consider five aspects for achieving goals in Phase

2, including enterprise strategy planning, consortia partner selecting, alliance interface management, regulation completeness, and government incentive policy for consortia development. Furthermore, we consider twenty criteria with respect to these dimensions we consider, as evaluated and listed in Phase 3. All criteria are measured by evaluators using their individual subjective judgment. Finally, ten feasible sustainable development strategies selected are listed in Phase 4.

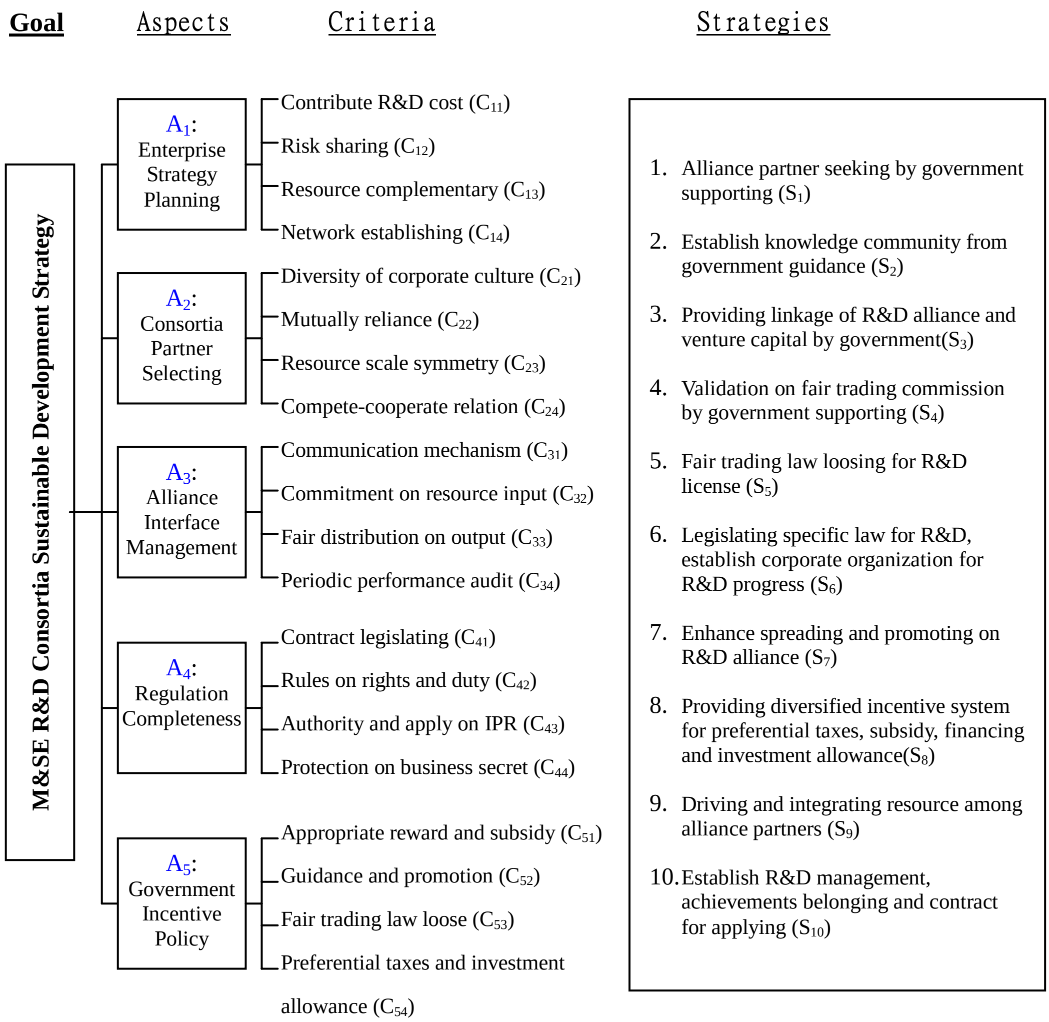

FIG. 1 Hierarchy frame for R&D consortia development strategy evaluation

3.2 Determining The Fuzzy Criteria Weights

Because the effects on evaluation from criteria are instinct with variance, we cannot assume that each considered criterion is of equal importance. There are many methods that can be employed to determine weights (Hwang and Yoon, 1981), such as the eigenvector method, weighted least square method, entropy method, AHP, etc. The selection of method depends on the nature of the problems, we utilize the fuzzy AHP approach to determine the criteria weights used in this paper.

AHP was originally proposed by Saaty in 1971, and this approach is now widely used in many fields, such as economic planning, portfolio selection, and benefit/cost analysis by government agencies for resource allocation, etc (Saaty, 1980). Subsequently, Buckley (1985) investigated fuzzy weights and fuzzy utility for AHP technique, extending AHP by the geometric mean method to derive the fuzzy weights. He considered a fuzzy positive reciprocal matrix $\tilde{A} = [\tilde{a}_{ij}]$, where $\tilde{a}_{ij}$ represents the value of subjective judgment by the j-th evaluator corresponding to the i-th criterion. Buckley (1985) defined the fuzzy geometric mean $\tilde{r}_i$ and fuzzy weights $\tilde{w}_i$ of the i-th criterion from m evaluators as follows.

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{im})^{1/m};\ \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1};\ \forall i \qquad (1)$$

where $\oplus$ and $\otimes$ represent the addition and multiplication operations of fuzzy numbers, respectively.

Following Bellman and Zadeh (1970) described the decision-making method under fuzzy environments, an increasing number of studies have dealt with uncertain problems by applying fuzzy set theory. In addition, it is very difficult for conventional quantification to express reasonably those situations that are overly complex or hard to define (Zadeh, 1975). Thus, using a linguistic variable is a variable whose values are words or sentences in natural language that is necessary in such situations. We use this kind of expression to compare two considered criteria in a fuzzy environment as "absolutely important", "very strongly important", "essentially important", "weakly important", and "equally important" on a five level scale. The use of linguistic variables is currently widespread and the linguistic effect values of strategies found in this paper are primarily used to assess the linguistic ratings given by evaluators. This paper employs a triangular fuzzy number to express the membership functions of above expression values on a five level scale (Table 1 and Fig.2).

TABLE 1. Fuzzy scale and linguistic expression of relative importance between two criteria

Intensity of fuzzy scale	Definition of linguistic variables
$\tilde{1} = (1,1,3)$	Two criteria have equally important.
$\tilde{3} = (1,3,5)$	One criterion is weakly important than the other one.
$\tilde{5} = (3,5,7)$	One criterion is essentially important than the other one.
$\tilde{7} = (5,7,9)$	One criterion is very strongly important than the other one.
$\tilde{9} = (7,9,9)$	One criterion is absolutely important than the other one.
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	Intermediate values between two adjacent judgments.

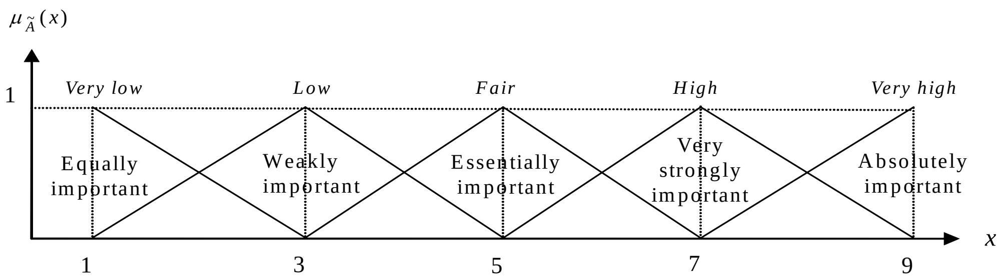

FIG. 2 Membership Functions For The Five Levels Scale Of Linguistics Variables

In order to integrate the weighting by group decision through individual subjective judgment, in this study we exploit triangular fuzzy number to express the aggregated weights of *j-th* criterion as follows:

$$\tilde{w}_j = \left(l_j, m_j, u_j\right) \qquad (2)$$

where

$$l_j = \min_k \left\{ w_j^k \middle| k = 1,\dots,m \right\};\ m_j = \left(\sum_{k=1}^{m} w_j^k \right) \Big/ m;\ u_j = \max_k \left\{ w_j^k \middle| k = 1,\dots,m \right\}$$

3.3 Obtaining The Synthetic Value

Each strategy can be evaluated for its each attribute value using the linguistics variables of five scales in "Worse", "Bad", "Excellent", "Good" and "Medium". Each linguistic variable can be further presented in the scales of 0 ~ 100 points. It can be assumed that evaluation expert k has his fuzzy judgment values of $\tilde{E}_{ij}^{k}$ for the criterion j under strategy i, and all the items to be evaluated is defined as S set.

$$\tilde{E}_{ij}^{k} = \left(LE_{ij}^{k}, ME_{ij}^{k}, UE_{ij}^{k}\right), \quad j \in S \tag{3}$$

Each expert has his different academic and business careers, so as his objective understanding on the linguistic variables. This study used the average number to integrate the fuzzy judgment values given by m experts. The average number of equation (3) can be calculated as:

$$\tilde{E}_{ij} = (1/m) \odot \left(\tilde{E}_{ij}^{1} \oplus \cdots \oplus \tilde{E}_{ij}^{m}\right) \tag{4}$$

where $\odot$ and $\oplus$ are defined in the multiplication and addition property of fuzzy numbers and $\tilde{E}_{ij}$ is the average fuzzy value given by the decision maker. Its triangular membership function is shown below:

$$\tilde{E}_{ij} = \left(LE_{ij}, ME_{ij}, UE_{ij}\right), \quad j \in S \tag{5}$$

where $\tilde{E}_{ij}$ can be solved using the equations proposed by Buckley (1985):

$$LE_{ij} = (1/m) \times \left(\sum_{k=1}^{m} LE_{ij}^{k}\right); \; ME_{ij} = (1/m) \times \left(\sum_{k=1}^{m} ME_{ij}^{k}\right); \; UE_{ij} = (1/m) \times \left(\sum_{k=1}^{m} UE_{ij}^{k}\right)$$

The weightings and the fuzzy values for each strategy can be integrated through the fuzzy set theory operations to calculate an overall fuzzy judgment values. Based on AHP developed weightings $\tilde{\boldsymbol{w}}$ from the weighting vector, the fuzzy performance matrix $\tilde{\boldsymbol{E}}$ is also developed from the fuzzy values of each strategy with respect to n criteria:

$$\tilde{\boldsymbol{w}} = \left(\tilde{w}_1, \cdots, \tilde{w}_j, \cdots \tilde{w}_n\right)^{t} \tag{6}$$

$$\tilde{\boldsymbol{E}} = \left[\tilde{E}_{ij}\right] \tag{7}$$

The overall fuzzy judgment matrix $\tilde{\boldsymbol{R}}$ can then be developed from both weighting vector and fuzzy decision matrix as shown below:

$$\tilde{\boldsymbol{R}} = \tilde{\boldsymbol{w}} \Leftrightarrow \tilde{\boldsymbol{E}} \tag{8}$$

where "$\Leftrightarrow$" includes the operations of fuzzy multiplication and fuzzy addition. The overall fuzzy judgment matrix can be illustrated below:

$$\tilde{\boldsymbol{R}}_i = \left(LR_i, MR_i, UR_i\right) \quad \forall i \tag{9}$$

where

$$LR_i = \sum_{j=1}^{n} l_j \cdot LE_{ij}; \; MR_i = \sum_{j=1}^{n} m_j \cdot ME_{ij}; \; UR_i = \sum_{j=1}^{n} u_j \cdot UE_{ij}$$

On the other hand, the result of fuzzy synthetic decisions reached by each alternative is a fuzzy number. Therefore, it is necessary that the nonfuzzy ranking method for fuzzy numbers be employed during the comparison of the strategies. Methods of such defuzzified fuzzy ranking generally include mean of maximal, center of area (COA), and α -cut, three kinds of method (Zhao and Govind, 1991; Opricovic & Tzeng, 2003). Utilizing the COA method to determine the best nonfuzzy performance (BNP) value is a simple and practical method, and there is no need to introduce the preferences of any evaluators. The BNP value of the triangular fuzzy number (LR_i, MR_i, UR_i) can be found by the following equation:

$$BNP_i = \left[\left(UR_i - LR_i\right) + \left(MR_i - LR_i\right)\right] / 3 + LR_i \quad \forall i \tag{10}$$

For those reasons, the COA method is used in this paper to rank the order of importance of each criterion. According to the value of the derived BNP, the evaluation of each R&D consortia development strategy can then proceed.

4. Illustrative Example

In this section we take an illustrative example for evaluating R&D consortia development strategy to demonstrate that these methods of fuzzy MCDM to be appropriate on realm problems.

4.1 Calculating The Weights of Considered Criteria

Firstly, we establish the hierarchy frame for sustainable development planning, as shown in Fig.1, where the preliminary classification consists of five aspects corresponding to twenty criteria selected. We also take ten feasible strategies to confirm the meaning of sustainable development.

Secondly, we have 26 evaluators including staff from the government sector who are in charge of R&D consortia, academic experts, and M&SE managers who engage in R&D department and strategy alliance. We integrate their subjective judgments to develop the fuzzy criteria weights with respect to aspects by the fuzzy geometric mean method as Eq.(1). We further derive the final fuzzy weights and nonfuzzy BNP values corresponding to each criterion, as shown in Table 2.

TABLE 2. Criteria weights for evaluating sustainable development strategy

	Group 1 (n=6)					Group 2 (n=5)					Group 3 (n=15)					Whole Participants (n=26)			
	Local weight	Global weight	Rank	Std.	CV*	Local weight	Global weight	Rank	Std.	CV*	Local weight	Global weight	Rank	Std.	CV*	Global weight	Rank	Std.	CV*
A1	*0.179*		*3*	0.200	**0.907**	*0.379*		*1*	0.260	**0.671**	*0.253*		*2*	0.214	**0.829**	***0.260***	*2*	0.219	**0.798**
C11	0.096	0.017	19	0.038	0.430	0.118	0.045	8	0.075	0.600	0.198	0.050	7	0.159	0.748	0.041	9	0.136	0.814
C12	0.159	0.028	12	0.232	1.051	0.294	0.111	2	0.179	0.583	0.128	0.032	15	0.113	0.804	0.047	8	0.166	0.867
C13	0.525	0.094	4	0.137	0.298	0.460	0.174	1	0.103	0.242	0.455	0.115	2	0.169	0.385	0.122	2	0.147	0.333
C14	0.221	0.039	7	0.145	0.624	0.128	0.048	6	0.102	0.712	0.219	0.055	6	0.100	0.478	0.050	6	0.112	0.552
A2	*0.349*		*1*	0.165	**0.504**	*0.192*		*2*	0.058	**0.353**	*0.287*		*1*	0.157	**0.579**	***0.283***	*1*	0.151	**0.573**
C21	0.085	0.030	11	0.085	0.843	0.085	0.016	18	0.054	0.593	0.092	0.026	16	0.043	0.485	0.025	16	0.055	0.594
C22	0.583	0.203	1	0.076	0.139	0.479	0.092	3	0.095	0.205	0.485	0.139	1	0.173	0.358	0.145	1	0.142	0.289
C23	0.120	0.042	6	0.065	0.517	0.139	0.027	17	0.084	0.543	0.115	0.033	14	0.085	0.699	0.034	14	0.079	0.610
C24	0.212	0.074	5	0.120	0.522	0.296	0.057	5	0.098	0.336	0.308	0.089	4	0.152	0.495	0.079	4	0.136	0.474
A3	*0.275*		*2*	0.115	**0.467**	*0.173*		*3*	0.027	**0.194**	*0.222*		*3*	0.154	**0.679**	***0.224***	*3*	0.132	**0.615**
C31	0.403	0.111	2	0.237	0.581	0.259	0.045	7	0.266	0.901	0.168	0.037	11	0.150	0.897	0.056	5	0.213	0.863
C32	0.126	0.035	10	0.031	0.278	0.211	0.036	14	0.130	0.614	0.205	0.045	8	0.143	0.678	0.041	10	0.127	0.677
C33	0.380	0.104	3	0.213	0.545	0.347	0.060	4	0.167	0.507	0.436	0.097	3	0.178	0.454	0.091	3	0.179	0.470
C34	0.092	0.025	14	0.067	0.731	0.183	0.032	15	0.064	0.393	0.191	0.042	9	0.212	0.926	0.036	12	0.173	0.939
A4	*0.102*		*4*	0.095	**0.856**	*0.165*		*4*	0.222	**0.990**	*0.103*		*5*	0.096	**0.900**	***0.115***	*5*	0.131	**1.002**
C41	0.195	0.020	18	0.309	1.154	0.225	0.037	12	0.048	0.210	0.148	0.015	20	0.148	0.850	0.021	18	0.183	0.885
C42	0.213	0.022	17	0.184	0.875	0.258	0.043	9	0.016	0.062	0.154	0.016	19	0.089	0.563	0.022	17	0.113	0.600
C43	0.239	0.024	15	0.112	0.531	0.258	0.043	9	0.016	0.062	0.349	0.036	13	0.154	0.465	0.035	13	0.136	0.471
C44	0.353	0.036	9	0.185	0.596	0.258	0.043	9	0.016	0.062	0.349	0.036	12	0.168	0.499	0.037	11	0.154	0.488
A5	*0.096*		*5*	0.062	**0.651**	*0.091*		*5*	0.050	**0.603**	*0.135*		*4*	0.121	**0.881**	***0.117***	*4*	0.100	**0.852**
C51	0.262	0.025	13	0.243	0.883	0.338	0.031	16	0.106	0.322	0.281	0.038	10	0.200	0.663	0.034	15	0.191	0.634
C52	0.090	0.009	20	0.024	0.315	0.105	0.010	20	0.038	0.367	0.133	0.018	18	0.096	0.718	0.014	20	0.079	0.683
C53	0.239	0.023	16	0.173	0.735	0.150	0.014	19	0.102	0.602	0.153	0.021	17	0.141	0.868	0.020	19	0.140	0.777
C54	0.408	0.039	8	0.206	0.499	0.407	0.037	13	0.154	0.386	0.433	0.058	5	0.189	0.470	0.050	7	0.180	0.445

From Table 2, the first five important criteria in R&D consortia development planning are Mutually reliance (C_{22}), Resource complementary (C_{13}), Fair distribution on output (C_{33}), Compete-cooperate relation (C_{24}) and Communication mechanism (C_{31}); whereas the three least unimportant criteria are Guidance and promotion from government (C_{52}), Fair trading law loose from government (C_{53}), and Contract legislating by public sectors (C_{41}).

4.2 Determining The Performance Matrix

To determine the performance value of each strategy, the evaluators can define their own individual subjective judgments within a fuzzy scale. Let $\tilde{h}_{ij}^{\ k}$ represent the fuzzy evaluated score of the *i*-th strategy under the *j*-th criterion by the *k*-th evaluator. Since the perception of each evaluator varies according to individual experience and knowledge, we select the fuzzy geometric mean method to integrate the fuzzy evaluated score $\tilde{h}_{ij}$ from *m* evaluators, the formula shown as following,

$$\tilde{h}_{ij} = \left(\tilde{h}_{ij}^{1} \otimes \tilde{h}_{ij}^{2} \otimes \cdots \otimes \tilde{h}_{ij}^{m}\right)^{\frac{1}{m}} \tag{11}$$

Furthermore, we use the centroid method to compute the BNP values of whole group from fuzzy evaluated score $\tilde{h}_{ij}$, as shown in Table 3.

TABLE 3. BNP values of fuzzy performance score with respect to criteria

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42	C43	C44	C51	C52	C53	C54
S1	47.06	48.41	61.53	59.59	48.18	50.23	55.55	59.10	57.15	57.28	52.03	51.35	55.74	57.12	54.04	46.67	50.94	64.17	54.78	57.99
S2	45.10	44.61	55.73	59.47	52.24	50.74	52.69	57.76	64.14	49.97	48.31	48.44	44.78	44.33	47.35	39.72	42.35	54.27	41.10	44.46
S3	63.43	61.55	57.22	56.01	36.32	51.71	51.06	55.36	51.47	58.59	51.71	49.14	49.36	49.10	50.90	46.73	56.99	62.05	43.18	46.79
S4	31.18	50.90	34.94	34.54	26.54	31.86	27.05	43.21	36.35	38.91	38.18	31.15	46.09	42.18	42.24	39.42	35.94	50.19	66.67	40.74
S5	52.53	55.92	51.97	48.21	30.32	37.76	42.31	55.06	42.44	44.42	45.68	36.15	44.74	42.44	43.14	39.74	47.09	55.81	78.33	47.03
S6	74.89	72.18	68.72	61.74	53.56	54.08	51.41	62.99	61.47	64.10	60.62	59.94	71.13	66.19	69.33	69.97	75.42	71.83	68.01	67.28
S7	43.04	45.24	52.92	59.24	43.91	45.00	45.71	58.69	54.68	51.86	40.26	41.60	46.35	50.13	49.29	38.21	49.17	70.51	50.90	48.72
S8	79.04	69.24	57.28	46.06	42.05	40.45	53.14	56.67	51.35	71.90	54.14	53.65	55.17	52.03	50.29	47.41	79.10	73.46	47.82	77.56
S9	59.96	64.39	62.98	62.67	59.04	62.92	59.08	66.19	71.35	66.79	64.23	61.60	61.77	60.17	64.55	55.38	58.65	69.78	51.15	50.64
S10	48.67	60.11	53.91	48.21	56.58	62.60	54.85	63.24	64.87	66.58	71.58	60.96	76.35	73.46	75.38	72.76	50.90	59.72	51.83	44.62

4.3 Aggregating The Final Synthetic Utilities For Each Strategies

Here we employ the simple additive weighted (SAW) method to derive the synthetic value of each strategy with respect to considered criteria, as shown in Table 4.

TABLE 4. BNP value of Synthetic values of each strategy

	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42	C43	C44	C51	C52	C53	C54	Grand	Rank
S1	1.95	2.26	7.48	3.00	1.22	7.29	1.88	4.67	3.18	2.36	4.75	1.87	1.15	1.28	1.87	1.74	1.71	0.91	1.09	2.89	54.53	*5*
S2	1.87	2.08	6.77	3.00	1.32	7.36	1.78	4.57	3.57	2.06	4.41	1.76	0.92	0.99	1.64	1.48	1.42	0.77	0.82	2.21	50.80	*7*
S3	2.63	2.87	6.95	2.82	0.92	7.50	1.73	4.38	2.86	2.41	4.72	1.79	1.02	1.10	1.76	1.75	1.91	0.88	0.86	2.33	53.18	*6*
S4	1.29	2.37	4.25	1.74	0.67	4.62	0.92	3.42	2.02	1.60	3.49	1.13	0.95	0.94	1.46	1.47	1.21	0.71	1.32	2.03	37.62	*10*
S5	2.18	2.61	6.32	2.43	0.77	5.48	1.43	4.35	2.36	1.83	4.17	1.31	0.92	0.95	1.49	1.48	1.58	0.79	1.56	2.34	46.35	*9*
S6	3.11	3.37	8.35	3.11	1.35	7.84	1.74	4.98	3.42	2.64	5.53	2.18	1.46	1.48	2.40	2.61	2.53	1.02	1.35	3.35	63.83	*1*
S7	1.78	2.11	6.43	2.98	1.11	6.53	1.55	4.64	3.04	2.14	3.68	1.51	0.95	1.12	1.71	1.43	1.65	1.00	1.01	2.43	48.79	*8*
S8	3.28	3.23	6.96	2.32	1.06	5.87	1.80	4.48	2.86	2.96	4.94	1.95	1.14	1.17	1.74	1.77	2.65	1.04	0.95	3.86	56.03	*4*
S9	2.49	3.00	7.65	3.16	1.49	9.13	2.00	5.23	3.97	2.75	5.86	2.24	1.27	1.35	2.24	2.07	1.97	0.99	1.02	2.52	62.39	*2*
S10	2.02	2.80	6.55	2.43	1.43	9.08	1.86	5.00	3.61	2.74	6.53	2.22	1.57	1.65	2.61	2.72	1.71	0.84	1.03	2.22	60.62	*3*

From Table 4, we conduct the preferred order of proposed strategies based on their final synthetic utility values as follows: $S_6 \succ S_9 \succ S_{10} \succ S_8 \succ S_1 \succ S_3 \succ S_2 \succ S_7 \succ S_5 \succ S_4$, where $A \succ B$ means that A is preferred to B.

From Table 4, it indicates that the first five favorite strategies for improving R&D consortia development are (1) Legislating specific law for R&D, establish corporate organization for R&D progress (S_6); (2) Driving and integrating resource among alliance partners (S_9); (3) Establish R&D management, achievements belonging and contract for applying (S_{10}); (4) Providing diversified incentive system for preferential taxes, subsidy, financing and investment allowance(S_8); and (5) Alliance partner seeking by government supporting (S_1).

5. Conclusions

Generally, sustainable development issues and fuzzy MCDM problems that are essentially conflict analyses are characterized by multi-dimension judgments. Several alternatives/strategies must be considered and evaluated in terms of many different criteria, resulting in a vast body of data that are often inaccurate or uncertain. In this study, we use the triangular fuzzy numbers to express linguistic variables that consider the possible fuzzy subjective judgment of the evaluators. Furthermore, the fuzzy geometric mean technique is an effective method to conduct the final fuzzy weights of each criterion.

In this paper, we propose a fuzzy hierarchical analytic process, which is an effective fuzzy method to derive the weight of considered criteria and the final synthetic utility values, and then rank the importance of the criteria as well as the sustainable development strategies. The results can provide some useful meaning for business practice; the findings of this study are summarized as follows:

(1) In pursuit of R&D consortia and evaluation, the major consideration for Medium & Small Enterprises goes to three categories, i.e., company strategic planning, selection of partners, and management of alliance interface. And then, secondary consideration goes to government policies and regulations.
(2) In pursuit of R&D consortia, the key points of consideration for Medium & Small Enterprises comprises four categories, i.e. mutual trust, mutual support of resources, equalization of business outcome, and the collaboratively competitive relationship, in which certain extent of consensus can be reached.
(3) While seeking for forming the alliance to consolidate resources and sharing risks in the midst of global competition and technology revolution, the Medium and Small Enterprises have to put more emphasis on two evaluating principles- "Communications Mechanism and System" and "Risk Sharing".
(4) There should be different evaluating principles for different industrial sectors. Similarly, considering different goals of R&D planning in terms of levels of innovation, technical complex, foresightedness, uncertainty, project duration, investment amount, and attribute of alliance members, there should also be varied extent of emphasis for evaluating principles.

In concluding, in order to progress the development of R&D consortia, the following activities have to be promoted:

(1) To draft R&D alliance related regulations, set up R&D organization, and ensure the development of a sound R&D alliance system;
(2) To have study groups taking lead to promote R&D activities and coordinate members of alliance;
(3) To help the industry draw out the general terms & conditions of contract in governing R&D management, outcome sharing, and methods of application;
(4) To provide multiform privilege and incentive systems;
(5) To make government assist the industry in finding suitable partners.

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