Application of Fuzzy Set Theory and Multiobjective Decision Making in Project Portfolio Selection

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Abstract

Portfolio selection for strategic management is a crucial activity in many organizations, and it is concerned with a complex process that involves many decision-making situations. In the study, we propose a systematic approach that incorporates fuzzy set theory in conjunction with portfolio matrices to assist managers in reaching a better understanding of the overall competitiveness of their businesses' portfolios. We also present a multiobjective linear programming (MOLP), which helps to select strategic plans by using the result derived from the previous portfolio analysis and other financial data. The proposed approach has the advantage of dealing with the uncertainty problem of linguistic terms, providing a technique that presents the diversity of confidence level and optimism level of decision makers. Furthermore, solving MOLP by using fuzzy programming offers an effectively quantitative method for managers to balance the satisfaction of multiple objectives and allocate constrained resources optimally among proposed strategies. An illustration from a real-world situation demonstrates the approach. Although a particular portfolio matrix model was adopted in our research, the procedure proposed here can be modified to incorporate other portfolio matrices.

Keywords: Multiple objective decision making, Project portfolio selection, Fuzzy programming

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Introduction

Project portfolio selection is the process of determining appropriate courses of action or plan for achieving organizational objectives, and thus accomplishing the organizational purpose. The goal of selecting strategic plans is to identify the feasible strategic alternatives and select the best alternative. A diversified, multibusiness organization is a firm with several strategic business units (SBUs). A strategic business unit is a distinct business that has its own set of competitors and can be managed reasonably independently of other businesses within the organization. The advantages of organizing a firm into SBUs include the increment of autonomy and independence, and the improvement of operation efficiency within each SBU. However, the roots of a firm's competitive advantage derive from an ability to build the core competencies that spawn unanticipated products. The real sources of advantage exist in management's ability to consolidate corporate-wide technologies and production skills into competencies that empower individual business to adapt quickly to changing opportunities. Hence, to sustain a firm's competitive advantage, a leader should develop a corporate-wide strategic architecture that establishes objectives for competence building (Prahalad and Hamel, 1990). Therefore, in multibusiness organizations, the evaluation and selection of appropriate strategic plans that a firm will pursue involve the activities of using the corporate-level perspective to analyze the business strength/industry attractiveness of SBUs as well as the feasibility of strategic plans submitted by the SBUs. Before working out their final decision of selecting strategic plans, managers must consider several feasible alternatives and contemplate various factors behind each of them. Once the set of alternative solutions has been carefully evaluated, the next task is to rank the various alternatives and make a decision. The whole process from identifying the competitive position of SBUs to determining the suitable strategic plans is a very complicated task involving a structured evaluation procedure and experienced evaluators. Generally, strategic planning approaches with procedural structures are employed to guide managers in establishing each level of the strategic plan so a strategy can be completely assembled (Hax and Majluf, 1991; Archer and Ghasemzadeh, 1999; Ghasemzadeh and Archer, 2000).

However, in the aforementioned evaluation procedure, evaluators must confirm that all the information available or needed is brought to bear on the problem or issue at hand. As previous cases indicate (Ansoff and McDonnell, 1990; Chien, Lin, Tan and Lee, 1999; Jiang and Klein, 1999), identifying all relevant information for a decision does not mean that the decision makers have complete information; in most instances, information is incomplete. Decisions must be made with limited information since decision makers do not have full knowledge of the problem they face and cannot even determine a reasonable probability of alternative outcomes; thus they must make their decisions under a condition of uncertainty. In addition, many decisions in organizations, especially important decisions that have far-reaching effects on organizational activities and personnel, are made in groups. One drawback of group decisions is that not every member in the decision group has the same knowledge of the problem as others have. This means that evaluators will face a decision-making situation where evaluators possess different confidence levels for the particular problem to be dealt. Thus, the domain of strategic management has already been recognized as a field appropriate for the application of a fuzzy set theory, first, because of the fuzziness of main concepts and terms, and second, because of the contexts of strategic management that belong to the field of uncertainty and vagueness (Pap, Bosnjak and Bosnjak, 2000). Hence, in this study, we present a framework for incorporating fuzzy set theory into a portfolio analysis in order to provide a quantitative method for managers to deal with the problem of identifying the competitive position of SBUs and the feasibility of strategic plans. In this framework, we take advantage of the characteristics of the fuzzy set theory to handle the uncertainty problem indicated earlier, and to also consider the influence of different confidence levels of evaluators in selecting the suitable strategic plans. To accomplish this purpose, three fuzzy concepts are employed in this paper: linguistic variables, fuzzy numbers and fuzzy weighted average.

After identifying the competitive position of SBUs and the feasibility of strategic plans submitted by SBUs, a firm needs to select the most suitable strategic plans. In general, there is a trade-off between investment cost and financial potential in selecting a strategic: the less expensive a project, the less its return may be. For a manager, finding the optimal decision is difficult and time-consuming considering the numbers of permutations involved. Decision-making problems in areas such as research and development project selection, resource allocation, capital budget and scheduling are most often formulated as assignment problems with objective functions in zero-one variables. A zero-one integer linear programming model has been proposed as a tool to select an optimal project portfolio, based on the organization's objectives and constrains such as resource limitations and interdependence among projects (Burn, Liu and Feng, 1996; Ghasemzadeh, Archer and Iyogun, 1999). Thus, in the paper, to simplify the solution procedure, the project portfolio selection problem is formulated as a multiobjective linear programming (MOLP) model. We use the GE matrix to express the competitive position of SBUs and use the 3Cs model to evaluate the feasibility of the strategic plans. The maximization of the analysis result of the GE matrix and 3Cs model is one objective of the MOLP model. In addition, with the help of a firm providing estimation of potential profit and implementation cost for each strategic plan, we formulate another objective of the MOLP model. Then, after constructing and solving MOLP model, one can obtain the strategic plans that best utilize a firm's annual budget to maximize the potential profit generated from implementing these strategic plans. The notion is that a strategic plan with higher score on the analysis of GE matrix, 3Cs model and potential profit will have a more competitive advantage for high returns and be more likely to be selected for implementation.

2. Literature review

2.1. The portfolio matrix model

The entire thrust of the competitive analysis concept is based on the underlying assumption that corporate strategy starts with an analysis of competitive position. During the 1970s and early 1980s, a number of leading consulting firms developed the concept of portfolio matrix to help managers to reach a better understanding of the competitive position of the overall portfolio of businesses (Hax and Majluf, 1983). The most popular three portfolio matrices are: the growth-share matrix developed by the Boston Consulting Group pioneered this concept (Ansoff and McDonnell, 1990); the GE Multifactor Portfolio Matrix, developed jointly by General Electric and McKinsey and Company, which introduced multidimensional criteria in the external and internal dimensions; and the life-cycle matrix developed by Arthur D. Little, Inc., which contains a comprehensive methodology that leads to a wide array of broad action programs to support the desired strategic thrust of each business (Rowe, Mason and Dickel, 1994). The portfolio matrix has been proved to be a powerful tool for companies to analyze products or strategic business units and to provide strategic directions (Rowe, Mason and Dickel, 1994). However, as indicated earlier, the fact that evaluators seldom have complete information to make decisions will result in feeling of uncertainty during the decision making process. In addition, the evaluation models found in the classical portfolio matrix are mainly expressed numerically between 0 and 100. Under many circumstances, crisp data is inadequate in modeling real-life situations. Since human judgments including preferences are often vague, which make it difficult for human to do the estimation with an exact numerical value, the major problem with humans using the classical portfolio matrix is in precisely determining the numerical value of the criterion (Bohanec, 1995; Pap, Bosnjak and Bosnjak, 2000). To remedy this shortcoming, a more realistic approach may be to use linguistic assessments instead of numerical indicators, meaning that the ratings and weights of the criteria in the problem are evaluated by means of linguistic variables (Bellman and Zadeh, 1970; Herrera, H-V., and Verdegay, 1996).

In the example of this paper, the top-managers of a cooperative company chose the GE portfolio matrix as a tool to position the competitive situation of their four strategic business units. Therefore, in this paper, we adopt the GE portfolio matrix as our portfolio model to demonstrate the use of fuzzy set theory to position strategic business units. The GE Multifactor Portfolio Matrix is a nine-cell matrix, originally used by GE to analyze its own business portfolio (Fig.1). This tool helps managers understand the competitive position of SBUs and develop an organizational strategy based primarily on industry attractiveness (IA) and business strength (BS). Each SBU is plotted on a matrix of two dimensions: industry attractiveness and business strength. The former is a subjective assessment based on external factors, uncontrollable by the firm, that are intended to capture the industry and the competitive structure on which the business operates. The latter is a subjective assessment based on the critical success factors, largely controllable by the firm, defining the competitive position of a business within its industry. Each of these two dimensions is actually a composite of various factors. For example, industry attractiveness might be determined by factors such as the number of competitors in an industry, the rate of industry growth, the barriers in leaving or entering an industry; while business strength might be determined by factors like the solidity of a company's financial position, its advantageous bargaining position over suppliers, and its high level of technology use. There are some useful implications that emerge from the current and future positions of the business unit in this matrix (Hax, 1991). One of the implications is to manage the different business portfolios of a firm. The notion behind this is that each business does not equally deserve the scarce resources of a firm. Hence, different priorities of investing should be derived to recognize the distinct potentials of these businesses. That means selecting strategic plans submitted by different SBUs are implied by where these SBUs fall on the matrix (see Fig. 1).

Business Strength \ Industry Attractiveness	High	Medium	Low
High	Investment and growth	Selective growth	Selectivity
Medium	Selective growth	Selectivity	Harvest/Divest
Low	Selectivity	Harvest/Divest	Harvest/Divest

Fig. 1 Industry Attractiveness vs. Business Strength Matrix

Besides considering the competitive of the business portfolio, managers also need to consider whether the businesses have the capabilities and resources necessary to implement the strategic plan. In addition, they must be sure that the plans will not threaten the attainment of other organizational goals. Therefore, for the purpose of selecting the strategic plans submitted by the same strategic business unit, a set of criteria is also needed to differentiate the most feasible strategic plan from the others. Thus, in the example of this paper, the top-managers of the cooperative company chose the 3Cs model (Hatten and Rosenthal, 1999) to assess the feasibility of strategic plans. The 3Cs model, presented by Hatten and Rosenthal (1999) is concerned with the business' customer relations, process capabilities, and functional competencies that constitute the resource platform for a business's future strategies and determine the feasibility of its plans. Trust, integrity and reciprocity define customer relations. Process capabilities are the physical capabilities to do things and are measures of the performance of business processes along dimensions defined by customers' needs and expectations (time, cost, quality, functionality, flexibility and acuity). Knowing how to do things constitutes functional competencies which are measures of the organization's potential to conduct business state-of-the-art in both the firm's input markets (labor, capital, information and technology) and its output markets with its customers. Thus, the formulation and selection of business strategy is based on the strengths of the firm's customer relationships, the depth of its competencies, and the capacity of its capabilities. Under this concept, a selected strategic plan must be congruent with the requirement of meeting customers' needs as well as with the competencies and capabilities of the business.

2.2. The fuzzy approaches

The first publication of fuzzy set theory was made by Zadeh (1965). The fuzzy set theory provides a strict mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied (Zimmermann, 1991). It can also be considered as a modeling language well suited for situations in which fuzzy relations, criteria, and phenomena exist. When performing an evaluation, an individual may have a vague knowledge about the rating and/or importance of criteria, and cannot estimate their values with an exact numerical number. Then linguistic assessments may be used, so that variables participating in the problem are assessed by means of linguistic terms (Delgado, Verdegay and Vila, 1993; Herrera, H-V. and Verdegay, 1996). A linguistic variable is a variable whose values are not numbers but words or phrases in a natural or synthetic language. Herein, linguistic variables represent the relative importance and appropriateness of each evaluation criteria perceived by the decision makers, and then are replaced by suitable triangular fuzzy numbers used for arithmetic operation. The basic definitions of the fuzzy set theory, which are necessary for the understanding of the paper are stated in Appendix 1.

When the environment is vague, the rating criteria and their corresponding importance weights are often evaluated in fuzzy numbers (Liou and Wang, 1992). In order to obtain the weighted sum of those criteria evaluated by fuzzy number in terms of rating and importance, we use a fuzzy weighted average for the calculation. There have been several researches involved in the field of fuzzy weighted average. Dong and Wong (1987) addressed the computational aspect of the extension principle when the principle is applied to the weighted average operations in risk and decision analysis. Their computational algorithm is based on the α-cut representation of fuzzy sets and interval analysis. Liou and Wang (1992) suggested a modification on the fuzzy weighted average method developed by Dong and Wong (1987). The modification obtained similar computation results but required less evaluation and computations. The algorithm provided by Dong and Wong (1987) requires $O(2^n)$ comparisons and arithmetic operations, whereas the algorithm provided by Liou and Wang (1992) needs only $O(n^2)$ comparisons and arithmetic operations. Lee and Park (1997) proposed an efficient algorithm, named the efficient fuzzy weighted average (EFWA), to compute a fuzzy weighted average, which was an improvement over the previous works by reducing the number of comparisons and arithmetic operations to (n log n). We adopted the EFWA algorithm to do the calculations in the current work. The definitions relating to the EFWA are mostly from Lee and Park (1997), as in Appendix 2. See the studies proposed by Dong & Wong (1987), Liou &Wang(1992), and Lee & Park (1997) for a more complete and through definition. We illustrate this algorithm by applying it to the example of this paper.

2.3. Fuzzy Programming

In 1978, Zimmermann (1978) first introduced the fuzzy set theory into multiobjective linear programming (MOLP) problem. He considered multiobjective linear programming problem with fuzzy goals. Following the fuzzy decision proposed by Bellman and Zadeh (1970) together with linear membership functions, he proved that there exists an equivalent linear programming problem. Since then, many fuzzy programming techniques have been developed for solving multiobjective linear programming problems to obtain the best-compromise solution (Lai and Hwang, 1994). The fuzzy feature of this approach lies in the fact that objective functions of the MOLP problem are considered as fuzzy constraints of its equivalent single-objective linear programming (LP) problem. A fuzzy constraint is modeled as membership function that represents the degree of satisfaction of the objective function. The value of the membership function of an objective function is usually assumed to increase linearly from 0 (for solutions at the least satisfactory value) to 1(for solutions at the most satisfactory value).

The objective function of the equivalent LP problem is to maximize the overall satisfactory level of compromise between objectives, which is defined by the interaction of membership functions of objective functions of the original MOLP problem. Zimmermann (1978) first use the max-min operator of Bellman and

Zadeh (1970) to aggregate the membership functions of an LP problem (transformed from all the objective functions of a MOLP problem) for making best-compromise decisions that satisfy both the objectives and constraints of the MOLP problem. The drawback of this operator is that it cannot guarantee a nondominated solution and is not completely compensatory (Lee and Li, 1993). To overcome this drawback, we use the augmented max-min approach proposed by Lai and Hwang (1994), which is an extension of Zimmermann's approach. The augmented max-min approach can provide full compensation between aggregated membership functions of objective functions and ensure a nondominated solution. The algorithm for solving the MOLP problem by using augmented max-min approach is given in Appendix 3.

With fuzzy programming, MOLP problems can be solved easily as LP problems. In addition, one advantage of applying this approach to solve the project portfolio selection problem is that the best-compromise solution will not be affected by the units used for measuring the value of the objectives.

3. Model formulation

3.1. The model

In the example of the paper, the following assumptions and model are made based on the consideration of top-managers of the cooperative firm. Three basic assumptions are stated as follows:

1. Two parameters, investment cost and expected profit, are considered to evaluate the financial feasibility of strategic plans.
2. All strategic plans are independent of one another.
3. Each SBU can only implement one strategic plan a year.

The MOLP model proposed includes the following notations:

r_{ij} : Unity if the *j*th strategic plan is implemented at the *i*th SBU; otherwise it is 0

P_{ij} : Anticipated profit resulted from implementing the *j*th strategic plan at the *i*th SBU

C_{ij} : Required cost of implementing the *j*th strategic plan at the *i*th SBU

U_i : Upper limit on the total investment amount budgeted to the *i*th SBU of the firm

B : Overall investment budget of the firm for the year

I_i : Industry attractiveness of the *i*th SBU

A_i : Competitive advantage of the *i*th SBU

F_{ij} : Feasibility of *j*th strategic plan at the *i*th SBU

Under the consideration of the cost requirement, a strategic plan with the greater potential payoff and the higher score in the analysis of industry attractiveness, business strength and the feasibility implies a higher priority of the alternative to be selected. The MOLP model can then be stated as follows:

Maximize $$Z_1 = \sum_i \sum_j r_{ij}(w_A A_i + w_I I_i + w_F F_{ij}) \tag{1}$$

Maximize $$Z_2 = \sum_i \sum_j r_{ij} P_{ij} \tag{2}$$

Subject to $$\sum_j r_{ij} C_{ij} \le U_i \quad , \quad \text{for all } i \tag{3}$$

$$\sum_i \sum_j r_{ij} C_{ij} \le B \tag{4}$$

$$\sum_j r_{ij} = 1 \quad , \text{for all } i \tag{5}$$

$$r_{ij} = 0,1 \quad \text{for all } i, j \tag{6}$$

The objective function, equation (1), is to maximize the total scores of industry attractiveness, business strength and feasibility. The objective function, equation (2), is to maximize the total profit on investment. These w_A, w_I, w_F ($w_A + w_I + w_F = 1$) denote, respectively, the importance of A, I, F to the objective, and are determined by the evaluators. Constraint equations (3) and (4) ensure the budget limits for the *i*th SBU and the entire firm, respectively. Meanwhile, constraint equation (5) guarantees that each SBU will be assigned exactly one strategic plan to implement. Finally, constraint equation (6) specifies the integrality restriction on the values of the decision variables r_{ij}.

3.2. The procedure of the proposed approach

In this article we describe the procedure of selecting the best strategic plans by means of a portfolio matrix, 3Cs model, fuzzy set theory and MOLP through the following steps:

Step 1: Determine two sets of criteria, one regarding the internal and external factors of assessing the competitive position of SBUs, the other evaluating the feasibility of strategic plans;

Step 2: Define the linguistic variables and corresponding triangular fuzzy numbers that are used to represent the ratings of internal and external factors, feasibility factors and the importance of these factors (e.g. low, medium, high, etc.);

Step 3: Evaluate SBUs based on internal and external factors, strategic plans on the feasibility factors and the importance of these factors;

Step 4: Determine the degree of confidence α-value on each evaluator and calculate the weighted scores of those criteria by using the Efficient Fuzzy Weighted Average (EFWA);

Step 5: Determine optimistic level under consideration and use the average method to aggregate weighted scores assessed by evaluators;

Step 6: Apply financial information in terms of profitability and implementation cost of strategic plans, and the result obtained in previous step to the MOLP, which assist in selecting the best strategic plans for utilizing the firm's resources and having the potential of higher financial return.

Fig. 2 describes the procedure in a flow chart.

4. Example

To evaluate the applicability of the proposed approach, we implemented them in a strategic planning project for a food corporation in Taiwan. Top management of the firm was very concerned with the issue of effectively allocating the firm's annual budget to the proposed strategic plans provided by the SBUs. The firm runs four SBUs. The first (SBU 1) identified four alternative strategic plans, the second (SBU 2) identified two, the third (SBU 3) prepared three, and the fourth (SBU 4) submitted two alternative strategic plans.

In order to collect the data that reflected the managers' strategy evaluation process accurately, we did the following preparatory activities in order: (1) explained the purpose of this research and the concepts of the portfolio matrix, 3Cs model, fuzzy set theory and MOLP to the managers who would participate in this study; (2) collected the important factors from several strategic planning cases, and consulted with the managers of different departments in the company for their opinions, which would help the managers to identify the relevant internal and external factors of positioning the SBUs, as well as the feasibility factors of strategic plans; (3) conducted a focus group including 10 managers and 3 experts in strategic planning to select these factors as follows: a. The assessment of the internal factors of SBUs involves a structure that evaluates the management, manufacturing, R&D and engineering and marketing. b. The assessment of the external factors of SBUs involves the competitive, economic and government, social and market factors. c. The assessment of the feasibility of strategic plans is

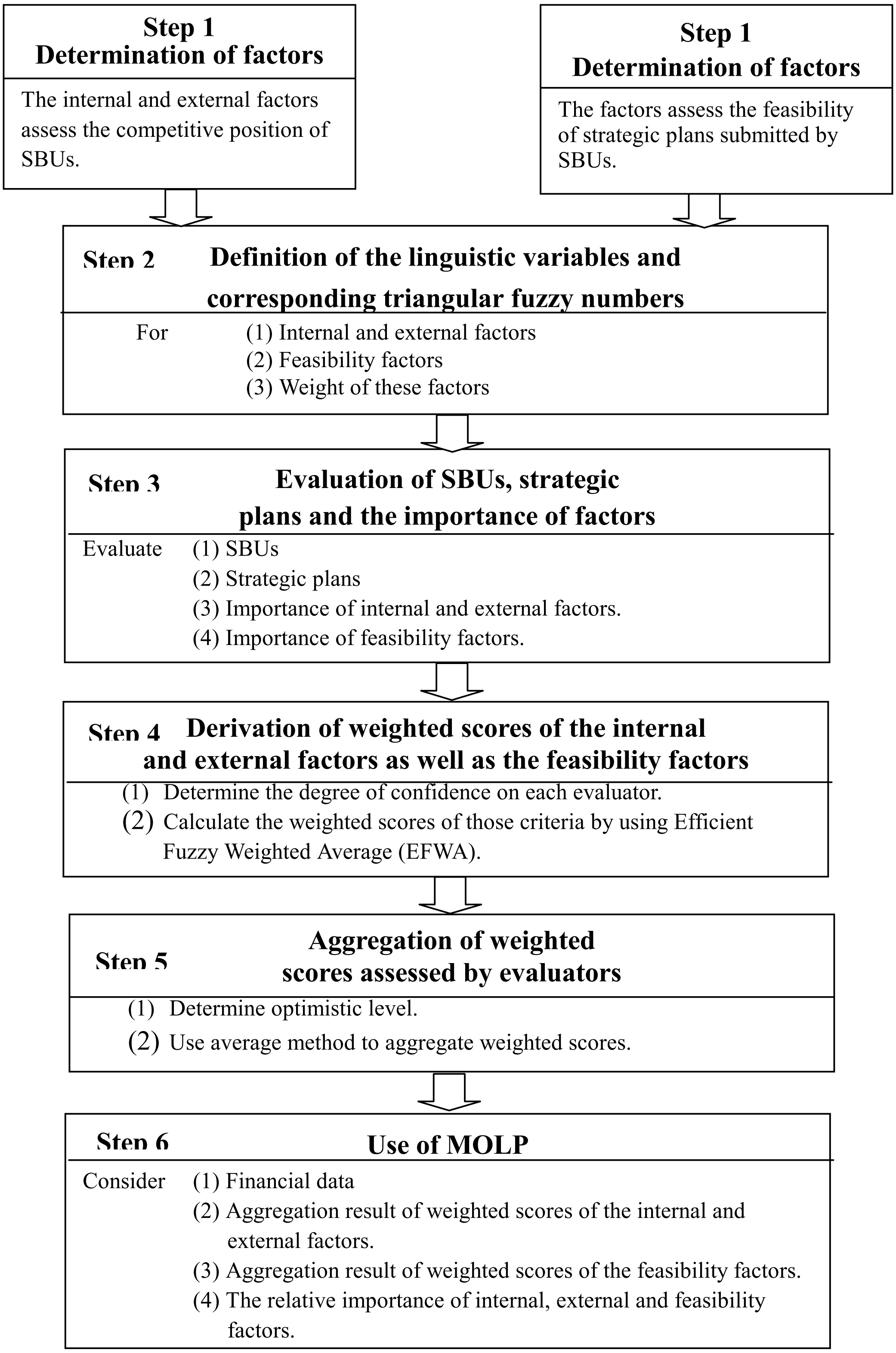

Fig. 2. Flow chart of the proposed procedure

relative to the customer relation, businesses' capabilities and competencies (shown in Tables 1 and 2). (4) developed the questionnaires based on those factors shown in Tables 1 and 2, the three top-level managers were invited to fill out the questionnaires.

Table 1. Criteria structure related to GE matrix

GE Matrix			
Business Strength		Industry Attractiveness	
Manufacturing	Location and number of plants, Sizes of plants, Ages of plants, Automation level	Market factors	Captive markets, industry Profitability
Marketing	Procurement, Brand loyalty, Business image	Competitive factors	Barriers to exit, Barriers to entry, Availability of substitutes
R&D and engineering	Human resource, Patents	Economic and Governmental factors	Inflation, Wage level, Legislation, Taxation
Management	Management competence, Planning and control systems, Financial strength	Social factors	Ecological impacts, Consumer protection, Degree of unionization

Table 2. Criteria structure related to the 3Cs model

3Cs model	
Customer relation	Customer preference, reciprocity, loyalty
Capabilities	Time, cost, quality, functionality, flexibility and acuity
Competencies	Labor, capital, information and technology

4.1. Implementing procedure and result

The implementing procedure of the example of this study are summarized below:

1. The three managers defined the linguistic variables and triangular fuzzy numbers for ‘internal factors’, ‘external factors’, ‘feasibility factors’ and ‘weights’ (shown in Table 3).

Table 3. Membership functions for linguistic values

Linguistic values	Fuzzy numbers		
	Manager 1	Manager 2	Manager 3
Very low	(0,0,3)	(0,0,1)	(0,0,2)
Low	(0,3,5)	(0,1,5)	(0,2,5)
Medium	(3,5,9)	(1,5,9)	(2,5,8)
High	(5,9,10)	(5,9,10)	(5,8,10)
Very high	(9,10,10)	(9,10,10)	(8,10,10)

2. The three managers evaluated the importance of each factor, and SBUs on internal and external factors, as well as strategic plans on the feasibility factors.
3. Owing to the first time using the approach, the three managers decided to simplify the arithmetic process of EFWA by using confidence level $\alpha = 0$ to calculate the weighted scores of those criteria. Taking Manager 1 as an example. Manager 1 evaluated strategic plan 2 submitted by SBU3 on the feasibility factors. The feasibility factors are customer relations, capabilities, and competencies. The evaluation result, presenting in linguistic values, of the

feasibility factors and their corresponding importance are medium/medium/very high and high/medium/medium, respectively. We replace the linguistic values with triangular fuzzy number based on (Table 3) constructed by 3 top-managers. The computational procedure of EFWA for the example is shown in Appendix 2. Accordingly, the interval for confidence level $\alpha = 0$ is [3.818,9.529]. The process is repeated to calculate the weighted scores of Manager 1 evaluating other strategic plans submitted by all other SBUs on internal, external and feasibility factors, which are shown in Table 4.

Table 4. Calculation results for manager 1 (α=0, α is called confidence level which represents the degree of confidence of a decision maker); a: Business Strength, i: Industry Attractiveness, f: Feasibility

	SBU1			SBU2			SBU3			SBU4		
	a	i	f	a	i	f	a	i	f	a	i	f
Strategic Plan 1	(2.9,4.7)	(4.1,5.8)	(3.7,4.1)	(2.7,5.1)	(6.7,7.8)	(5.6,7.9)	(4.3,6.2)	(5.3,6.9)	(2.5,6.4)	(8.7,9.1)	(3.5,7.1)	(3.5,7.1)
Strategic Plan 2	(2.9,4.7)	(4.1,5.8)	(3.9,5.2)	(2.7,5.1)	(6.7,7.8)	(3.2,5.6)	(4.3,6.2)	(5.3,6.9)	(3.8,9.5)	(8.7,9.1)	(3.5,7.1)	(3.7,7.1)
Strategic Plan 3	(2.9,4.7)	(4.1,5.8)	(4.8,6.3)				(4.3,6.2)	(5.3,6.9)	(3.8,8.1)			
Strategic Plan 4	(2.9,4.7)	(4.1,5.8)	(5.3,6.9)									

4. Repeat the aforementioned process for confidence level $\alpha = 0$ to obtain the weighted scores results of the other 2 managers, then discuss with the managers to determine the optimistic level, and then aggregate these 3 managers results.

5. With the aggregation result of weighted scores and information of the profitability/implementing cost estimates provided by the managers of the SBUs, we construct a MOLP. Then, we use fuzzy programming to solve the MOLP. Table 5 illustrates how the best-compromise solution of the MOLP model (maximizing Z_1 and Z_2) is obtained by making trade-offs between the optimal solutions for the two single-objectives, respectively. From the aspect of maximizing the total scores of industry attractiveness, business strength and feasibility, we obtain the solution $r_{12} = r_{21} = r_{32} = r_{41} = 1$, all other $r_{ij}'s = 0$. This implies that with the combination of SBU1 adopting its second strategic plan, SBU2 adopting its first strategic plan, SBU3 adopting its second strategic plan and SBU4 adopting its first strategic plan, the company can obtain the project portfolio with the maximization of total scores of industry attractiveness, competitive advantage and feasibility ($Z_1 = 52$). However, the result provides the optimal solution for the objective function Z_1, but not Z_2. In the case of maximizing the total profit on investment, we obtained the solution: $r_{11} = r_{21} = r_{32} = r_{42} = 1$, all other $r_{ij}'s = 0$. The result satisfies Z_2, but not Z_1. In an attempt to make trade-offs between these two conflicting objectives, we apply fuzzy programming to derive the best-compromise solution. The best-compromise solution is *r*14=*r*22=*r*31=*r*42=1, all other $r_{ij}'s = 0$ with optimal effect of the balance of Z_1= 40 and Z_2= 30 where the overall satisfactory level is 0.94.

Table 5. Optimal solution of the MOLP model ($\alpha = 0$)

	r_{11}	r_{12}	r_{13}	r_{14}	r_{21}	r_{22}	r_{31}	r_{32}	r_{33}	r_{41}	r_{42}	Z_1	Z_2
Maximizing the total scores of industry attractiveness, business strength and feasibility (Z_1)	0	1	0	0	1	0	0	1	0	1	0	52	19
Maximizing the total profit on investment (Z_2)	1	0	0	0	1	0	0	1	0	0	1	35	36
Maximizing Z_1 and Z_2	0	0	0	1	0	1	1	0	0	0	1	40	30

5. Discuss and Conclusion

In the above example, we use confidence level $\alpha = 0$ to calculate the weighted scores of those criteria. However, it should be noted that the confidence levels of different managers to a strategic plan may not be the same. Sometimes there are experienced managers in a decision group, such as the project manager who is familiar with the field of certain strategic plan, or some managers more experienced with evaluation than others, thus the final evaluation result is influenced by these managers with different confidence levels. Hence, under this concept, the three managers provide their own confidence levels toward different strategic plan (show in Table 6) and we recalculate the whole arithmetic processes of EFWA. Then, we obtain the optimal solution is $r_{13} = r_{22} = r_{32} = r_{42} = 1$, all other $r_{ij}'s = 0$ with optimal effect of the balance of Z_1 = 42 and Z_2 = 28 where the overall satisfactory level is 0.93. Comparing the result with previous result, we found that evaluations made by managers with different confidence levels toward certain strategic plans will lead to a different results from those made by managers with the same confidence levels. In practice, top managers will encounter plan selection situations with which he/she is not familiar. Hence, a good method to deal with this problem would be to consider the diversity of the confidence level of managers. The procedure we provided in this paper takes the above concept into account to increase the contribution of the evaluation result provided by experienced managers, but decreasing the influence of the managers with less experience to the final result.

Table 6. Confidence levels of 3 managers to the strategic plans
(M1: Manager1; M2: Manager 2; M3: Manager3)

	SBU1			SBU2			SBU3			SBU4		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Strategic Plan 1	0.5	0.8	0.5	0.8	0.6	0.8	0.9	0.8	0.6	0.8	0.8	0.6
Strategic Plan 2	0.8	0.5	0.8	0.8	0.5	0.6	0.5	0.6	0.8	0.6	0.9	0.5
Strategic Plan 3	0.8	0.8	0.6				0.6	0.6	0.6			
Strategic Plan 4	0.5	0.6	0.6									

After calculating the weighted sum of score by using the EFWA, we derived the result presented in a triangular fuzzy number. The next step is to decide the optimistic level to transfer triangular fuzzy number into crisp numbers for the following arithmetic processes-aggregation of weighted scores and MOLP. The optimistic level is an attitude a decision maker possesses toward how things go. For example, a result of previous example, presenting in triangular fuzzy number, is (3.818, 5.432, 9.529). If a decision maker has an optimistic attitude, the biggest value he will choose is 9.525. If a decision maker has a pessimistic attitude, the smallest value he will choose is 3.818, whereas a manager with a medium attitude will choose 5.432. In this case, the three managers showed the same optimism level-medium attitude. However, in other decision-making cases, the situation owning different levels of optimism within decision makers will probably occur, which will lead to a different final selecting result. Therefore, just like the function of the confidence level, the optimism level is viewed as a factor to express the diversity of the managers' attitude towards the whole situation instead of seeing them as all equal. In addition, at the step of using MOLP to select the most suitable strategic plans, the different proportion of these values w_A, w_I, w_F in objective will also affect the final selecting result. These values w_A, w_I, w_F presenting, respectively, the importance of A, I, F on selecting strategic plans vary somewhat from industry to industry, or firm to firm, determined by the evaluators. In this case, managers assign w_A, w_I, w_F as 0.3,0.3,0.4, respectively.

The top managers of the company were very pleased and totally agreed with our recommendations. Furthermore, by using the proposed approach, we reduced the decision-making time for evaluation and selection of strategies from the normal two-month period to only twelve business days, a dramatic savings in time that the top managers had previously considered impossible. In addition, the top managers also felt that the proposed approach was a practical tool selecting strategies, considering the uncertainty problem of linguistic factors, as well as the diversity of the confidence level and optimism level of the evaluators. Finally, the proposed approach earned the confidence of top managers and will be implemented by the company to conduct its annual strategic planning in the future.

In this paper, we incorporated fuzzy theory into the GE matrix to assist managers in evaluating the strategic positions of the SBUs in a firm. Also, in order to differentiate the optimal strategic plan from others submitted by the same

SBU, another set of evaluation criteria was used by means of fuzzy theory to compare these strategic plans on the basis of 3Cs model-customer relations, capabilities, and competencies. Then, with the analysis result from the GE matrix, 3Cs model and financial estimated information, we constructed and solved a MOLP model to determine the strategic plans that best utilizes a firm's annual budget to maximize the potential profit generated from implementing these strategic plans. The actual implementation of the proposed approach to a strategic planning project undertaken by a major food company in Taiwan confirmed the efficiency of the approach in assessing and selecting strategic plans.

The advantages of the proposed approach can be addressed in the following ways: 1. The proposed approach is a complete procedure for managers selecting strategic plans by appropriately considering the industry attractiveness/business strength of SBUs, the feasibility and financial potential of strategic plans. 2. Through the use of fuzzy set theory, this approach helps to deal with the uncertainty problem of linguistic terms, providing a technique with the characteristic of presenting the diversity of confidence level and optimism level of evaluators when facing different SBUs and strategic plans. 3. In this paper, we also describe the process of selecting plans by means of a MOLP, which appears to be an effectively quantitative method for managers to select strategic plans using multiple objectives. 4. The approach dramatically reduced the time spent for the evaluation and selection of strategies. Although we adopted the GE matrix as the portfolio model in evaluating the strategic positions of the SBUs and the 3Cs model in assessing the feasibility of strategic plans, our approach can also work with other evaluation measures.

Appendix 1. The basic definitions of the fuzzy set theory

Dubois and Prade (1978) defined fuzzy number and described its meaning and features. A fuzzy number $\widetilde{A}$ is a fuzzy set which membership function is $\mu_{\widetilde{A}}(x): R \rightarrow [0.1]$, and its characteristic is:

(1) $\mu_{\widetilde{A}}(x): R \rightarrow [0.1]$ is continuous;

(2) $\mu_{\widetilde{A}}(x): R \rightarrow [0.1]$ is a convex fuzzy set;

(3) It exists exactly $x_o \in R$ with $\mu_{\widetilde{A}}(x_0) = 1$

A triangular fuzzy number $\widetilde{A} = (l, m, u)$ can conform to the above-mentioned terms (see Fig. 3). In practice, the value u is treated as an optimistic estimate which is intended to be the unlikely but possible value if everything goes well. The value m is the most likely estimate, intended to be the most realistic value. The value l is a pessimistic estimate, which is intended to be the unlikely but possible value if everything goes badly. The membership function of $\widetilde{A}$ is expressed as:

$$\mu_{\widetilde{A}}(x) = \begin{cases} \dfrac{(x-1)}{m-l}, & 1 \le x < m, \\ \dfrac{(x-u)}{m-u}, & m \le x \le u, \\ 0, & \text{others,} \end{cases}$$

The α -cut set of a fuzzy number $\widetilde{A}_\alpha = \{x \mid \mu_{\widetilde{A}}(x) \ge \alpha\}$ $\alpha \in \{0,1\}$, is expressed as $(l^\alpha, m^\alpha, u^\alpha)$. The confidence interval of $\widetilde{A}_\alpha$ at α -level can also be stated $\widetilde{A}_\alpha = [a_1^\alpha, a_2^\alpha]$. a_1^α and a_2^α mean the upper and lower boundaries of confidence interval.

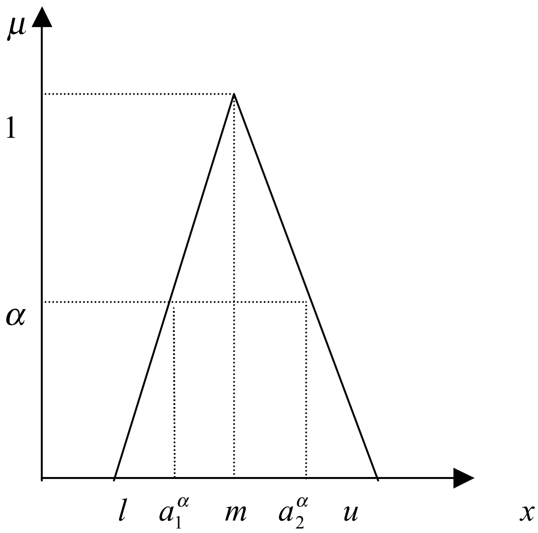

Fig. 3. Triangular fuzzy number

Appendix 2. The procedure of the EFWA

Suppose x_i and w_i, i= 1,2,…,n, has the corresponding interval [a_i, b_i] and [c_i , d_i] with $c_i \le 0$, respectively. Lee and Park (1997) proposed the following steps to calculate fuzzy weighted average:

1.Sort a's in nondecreasing order. Let ($a_1, a_2, \cdots a_n$) be the resulting sequence. Let *first* =1 and *last* = n.

2.Let $\delta - threshold = \lfloor (first + last) / 2 \rfloor$. For each $i = 1,2,\cdots,\delta - threshold$, let $e_i = d_i$, and for each $i = \delta - threshold + 1,\cdots,n$, let $e_i = c_i$. For an n-tuple $S=(e_1,e_2,\ldots,e_n)$, evaluate $\delta_{S_{\delta-threshold}}$ and $\delta_{S_{(\delta-threshold+1)}}$.

$$\delta_{s_i}=\frac{(a_1-a_i)e_1+(a_2-a_i)e_2+\cdots+(a_n-a_i)e_n}{e_1+e_2+\cdots+e_n}$$

3.If $\delta_{S_{\delta-threshold}}>0$ and $\delta_{S_{(\delta-threshold+1)}}\le 0$ then $L=f_L(e_1,e_2,\ldots,e_n)=a_1+\delta_{s_1}=a_2+\delta_{s_2}=\cdots=a_n+\delta_{s_n}$ and goto Step 4; otherwise execute the following step.

3.1 If $\delta_{S_{\delta-threshold}}>0$, then *first* = $\delta-threshold+1$; otherwise *last* = $\delta-threshold$, and goto Step2.

4.Sort *b*'s in nondecreasing order. Let ($b_1,b_2,\ldots,b_n$) be the resulting sequence. Let $first=1$ and $last=n$.

5.Let $\xi-threshold=\lfloor (first+last)/2\rfloor$. For each $i=1,2,\cdots,\xi-threshold$, let $e_i=c_i$ and for each $i=\xi-threshold+1,\cdots,n$, let $e_i=d_i$. For an n-tuple $S=(e_1,e_2,\cdots,e_n)$, evaluate $\xi_{S_{\xi-threshold}}$ and $\xi_{S_{(\xi-threshold+1)}}$. $\xi_{s_i}=\dfrac{(b_1-b_i)e_1+(b_2-b_i)e_2+\cdots+(b_n-b_i)e_n}{e_1+e_2+\cdots+e_n}$

6.If $\xi_{S_{\xi-threshold}}>0$ and $\xi_{S_{(\xi-threshold+1)}}\le 0$ then $U=f_U(e_1,e_2,\ldots,e_n)=b_1+\xi_{s_1}=b_2+\xi_{s_2}=\cdots=b_n+\xi_{s_n}$ and stop; otherwise execute the following step.

6.1If $\xi_{S_{\xi-threshold}}>0$ then *first* = $\xi-threshold+1$; otherwise *last* = $\xi-threshold$, and goto Step 5.

The arithmetic procedure of the proposed example:

Step 1:

For confidence level $\alpha = 0$, the intervals of x_i and w_i are

$[a_1 = 3, b_1 = 9]$, $[a_2 = 3, b_2 = 9]$, $[a_3 = 9, b_3 = 10]$

$[c_1 = 5, d_1 = 10]$, $[c_2 = 3, d_2 = 9]$, $[c_3 = 3, d_3 = 9]$

Respectively for $i = 1,2,\cdots,5$.

Step 2:

$(a_1, a_2, a_3) = (3,3,9)$

$first = 1, \quad last = 3.$

Step 3:

$$\delta - threshold := \left\lfloor \frac{(1+3)}{2} \right\rfloor = 2$$

$$S = (10,9,3)$$

$$\delta_{S_2} = \frac{(3-3)\cdot 10 + (3-3)\cdot 9 + (9-3)\cdot 3}{10+9+3} = 0.818$$

$$\delta_{S_3} = \frac{(3-9)\cdot 10 + (3-9)\cdot 9 + (9-9)\cdot 3}{10+9+3} = -5.182$$

Step 4:

Since $\delta_{S_2} > 0$ and $\delta_{S_3} \le 0$

$$L = f_L(d_1, d_2, c_3) = a_2 + \delta_{S_2} = 3 + 0.818 = 3.818$$

Min f_L is 3.818 and go to Step 4.

Step 5:

$$(b_1, b_2, b_3) = (9,9,10)$$

$$first = 1, \quad last = 3.$$

Step 6:

$$\xi - threshold := \left\lfloor \frac{(1+3)}{2} \right\rfloor = 2$$

$$S = (5,3,9)$$

$$\xi_{S_2} = \frac{(9-9)\cdot 5 + (9-9)\cdot 3 + (10-9)\cdot 9}{5+3+9} = 0.529$$

$$\xi_{S_3} = \frac{(9-10)\cdot 5 + (9-10)\cdot 3 + (10-10)\cdot 9}{5+3+9} = -0.47$$

Step 7:

Since $\xi_{S_2} > 0$ and $\xi_{S_3} \leq 0$

$$U = f_U(c_1, c_2, d_3) = b_2 + \xi_{S_2} = 9 + 0.529 = 9.529$$

Max f_U is 9.529 and stop.

Appendix 3. Solution procedure for solving the MOLP model

Step 1: Construct the payoff table of the positive-ideal solution, as shown in Table 7. In Table 7, for the objective function Z_1, x_1^* is the feasible and optimal solution, and U_1 and L_1 are the upper and lower bounds of the solution set. x_2^* is the feasible and optimal solution, and U_2 and L_2 are the upper and lower bounds of the solution set for the objective function Z_2.

Step 2: Construct the membership functions $\mu_1(x)$ and $\mu_2(x)$ for the two objective functions Z_1 and Z_2, respectively by

$$\mu_1(x)=\begin{cases}1 & \text{if} \quad Z_1 \le L_1, \\ 1-\dfrac{Z_1-L_1}{U_1-L_1} & \text{if} \quad L_1 < Z_1 < U_1, \\ 0 & \text{if} \quad Z_1 \ge U_1,\end{cases} \tag{8}$$

$$\mu_2(x)=\begin{cases}1 & \text{if} \quad Z_2 \le L_2, \\ 1-\dfrac{Z_2-L_2}{U_2-L_2} & \text{if} \quad L_2 < Z_2 < U_2, \\ 0 & \text{if} \quad Z_2 \ge U_2,\end{cases}$$

(9)

Step 3: Obtain the single-objective LP model by aggregating $\mu_1(x)$ and $\mu_2(x)$ using the augmented max-min operator as

Maximize $$\alpha+\frac{\delta(\mu_1(x)+\mu_2(x))}{2} \tag{10}$$

Subject to $$\alpha \le \mu_1(x), \quad x \in X, \tag{11}$$

$$\alpha \le \mu_2(x), \quad x \in X, \tag{12}$$

Objective function (1)-(2),

Constraints (3)-(7),

Where X represent the feasible space, and α is the overall satisfactory level of compromise (to be maximized) and δ is a small positive number. A nondominated solution is always generated when α is maximized. This is because the averaging operator used in the objective function (10) for $\mu_1(x)$ and $\mu_2(x)$ is completely compensatory (for more detail, see Chang, Yeh, and Shen, 2000).

Solving the above single-objective LP model using LINDO (1991), a commercial mathematic programming software.

Table 7. Payoff table of positive-ideal solution

	Z_1	Z_2	x
Max Z_1	$Z_1(x_1^*)$	$Z_2(x_1^*)$	x_1^*
Max Z_2	$Z_1(x_2^*)$	$Z_2(x_2^*)$	x_2^*
	$U_1 = Z_1(x_1^*)$	$U_2 = Z_2(x_2^*)$	
	$L_1 = Z_1(x_2^*)$	$L_2 = Z_2(x_1^*)$	

References

Ansoff, H.I., and E.J. McDonnell. Implanting Strategic Management. Pretice-Hall. 1990.

Archer, N.P., and F. Ghasemzadeh. An integrated framework for project portfolio selection. International Journal of Project Management. 17(4), 1999:207-216.

Bellman, R.E., and L.A. Zadeh. Decision-making in a fuzzy environment. Management Science. 17(4), 1970:141-164.

Bohanec, M. Knowledge-based portfolio analysis for project evaluation. Information and Management. 28, 1995:293-302.

Burn, S.A., L. Liu, and C.W. Feng. The LP/IP hybrid method for construction time-cost trade-off analysis. Construction Management and Economics; London. 14, May 1996:265-277.

Chang, Y.H., C.H. Yeh, and C.C. Shen. A multiobjective model for passenger train services planning: application of Taiwan's high-speed rail line. Transportation Research. 34, 2000:91-106.

Chien, T.W., C. Lin, B. Tan, and W.C. Lee. A neural networks-based approach for strategic planning. Information & Management. 35, 1999:357-364.

Delgado, M., J.L. Verdegay, and M.A. Vila. Linguistic decision making models. Internet. J. Intelligent Systems. 7,1993:479-492.

Dong, W.M., and F.S. Wong. Fuzzy weighted average and implementation of the extension principle. Fuzzy Sets and System. 21, 1987:183-199.

Dubois, D., and H. Prade. Operation on fuzzy numbers. International Journal of Systems Service. 9, 1978:613-626.

Ghasemzadeh, F., and N.P. Archer. Project portfolio selection through decision support system. Decision Support Systems. 29, 2000: 73-88.

Ghasemzadeh, F., N. Archer, and P. Iyogun. A zero-one model for project portfolio selection and scheduling. The Journal of the Operational Research Society;

Oxford. 50, Jul 1999:745-755.

Hatten, K.J., and S.R. Rosenthal. Managing the process-centred enterprise. Long Range Planning. 32(3), 1999:293-310.

Hax, A.C., and N.S. Majluf. The use of the industry attractiveness-business strength matrix in strategic planning. Interfaces. 13(2), 1983:54-71.

Hax, A.C., and N.S. Majluf. The Strategy Concept and Process. Pretice-Hall, New York. 1991.

Herrera, F.H., E. H-V., and J.L. Verdegay. A model of consensus in group decision making under linguistic assessments. Fuzzy Sets and Systems. 78, 1996:73-87.

Jiang, J.J., and G. Klein. Project selection criteria by strategic orientation. Information and Management. 36, 1999:63-75.

Lai, Y-L., and C-L. Hwang. Fuzzy Multiple Objective Decision Making: Methods and Applications. Springer, Berlin. 1994.

Lee, D. H., and D. Park. An efficient algorithm for fuzzy weighted average. Fuzzy Sets and Systems. 87, 1997:39-45.

Lee, E.S., and R.J. Li. Fuzzy multiple objective programming and compromise programming with pareto optimum. Fuzzy Sets and Systems. 53, 1993:275-288.

Liou, T.S., and M.J.J. Wang. Fuzzy weighted average: An improved algorithm. Fuzzy Sets and Systems. 49, 1992:307-315.

Pap, E., Z. Bosnjak, and S. Bosnjak. Application of fuzzy sets with different t-norms in the interpretation of portfolio matrices in strategic management. Fuzzy Set and Systems. 114, 2000:123-131.

Prahalad, C.K., and G. Hamel. The core competence of the corporation, Harvard Business Review, May, 1990: 79-91.

Rowe, A.J., R.O. Mason, and K.E. Dickel. Strategic Management. Addison Wesley. 1994.

Schrage, L. LINDO: An optimization Modeling System. Fourth, The Scientific Press, California. 1991.

Zadeh, L.A. Fuzzy set. Information and Control. 8(3), 1965:338-353.

Zimmermann, H.J. Fuzzy programming and linear programming with several objective functions. Fuzzy Sets and Systems. 1, 1978:45-55.

Zimmermann, H.J. Fuzzy Set Theory and Its Application, Kluwer Academic, Boston. 1991.

應用模糊理論及多目標決策於投資計畫組合之選擇

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摘 要

對於許多組織，投資計畫的選擇是一項重要的活動，它牽涉到很多決策的過程。本文提出一個整合方法，利用模糊理論結合投資組合矩陣及策略計劃可行性分析，提供經理人更了解公司事業組合之競爭能力，除此之外，多目標線性規劃的方法協助經理人利用投資組合矩陣分析、策略計劃可行性分析資料及其他財務資料，進一步的選出投資計畫。本文提出的整合方法優點在於以下: 1.模糊理論具有解決不確定性、能夠表達不同評估者不同信心程度及樂觀程度的特性; 2.利用模糊規劃的方法解決多目標線性規劃的問題，可以在滿足多目標之間，尋求平衡並找到最佳妥協點。最後，本文以實際的例子說明本方法的應用過程。雖然本文是以投資組合矩陣應用於實際例子，但其他的策略矩陣亦可以應用本文所提出之整合方法，有效率的進行策略決策。

關鍵詞：多目標決策，投資計畫的選擇，模糊規劃

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