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A fuzzy decision support system for strategic portfolio management

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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 order to decide which of the proposed projects should be retained in the final project portfolio, numerous conflicting criteria must be considered. They include economic, personnel development, and corporate image. Although there are many studies available to assist decision-makers in doing the process of portfolio selection, there are no integrated frameworks that one can use to systematically do the portfolio selection. In addition, in most decision-making situations, decision-makers have to make decisions with incomplete information and under uncertain circumstances. These situations have been recognized by many researchers as a suitable field to use fuzzy set theory. Therefore, based on the concepts of decision support system (DSS), we developed an integrated framework that incorporates fuzzy theory into strategic portfolio selection. This framework provides managers with a flexible, expandable and interactive DSS to select projects for portfolio management. We used a real-world case to demonstrate the proposed approach.

Keywords: Strategic portfolio; Fuzzy weighted average; Fuzzy integer linear programming; Decision support system

1. Introduction

The selection of a strategic portfolio, which requires the consideration of corporation goals, resources, and constraints, is an important and challenging task. Usually, there are more projects available for selection than can be undertaken within the physical and financial constraints of a firm, so choices must be made in creating a suitable project portfolio [13]. In order to decide which of the proposed projects should be retained in the final project portfolio, a number of conflicting criteria must be taken into account. They include environmental advantages and disadvantages, tangible and intangible benefits, and risk level of the project portfolio. Several studies have been proposed to help organizations make good project selection decisions. Most of these studies have focused on the fields of R&D [3,6,23,28,33,34], information technology [21,22,24,27] and marketing [8,35]. In these studies, the methods of Analytic Hierarchy Procedure (AHP), scoring model, and portfolio

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matrices used in conjunction with optimization models are popular among decision makers to consider a broad range of quantitative and qualitative characteristics, as well as multiple objectives. The evaluation models found in present portfolio selection methods are mainly numerical, e.g., expressed with numbers between 0 to 100. The drawback of these studies is that decision makers generally have vague perceptions instead of clear knowledge about the evaluation criteria and are unable to provide exact numbers. To overcome the problem, some prior studies employed fuzzy theory to do the evaluation [7,23,27,31]. Of these, Coffin and Taylor [7] and Machacha and Bhattacharya [27] applied fuzzy logic to software product selection and R&D project selection, respectively; Kuchta [23] used fuzzy numbers to present the net present value and the resource utilization of individual projects; and Rasmy [31] constructed a fuzzy expert system to solve the multiobjective linear programming problem. However, in order to sustain a company's competitive advantage in today's increasingly challenging and turbulent environment, a leader must change his perspective from product-orientation or market-orientation to strategy-orientation when making project selection decisions. Existing studies generally concentrate on evaluating projects for their functional level, e.g., R&D or information technology, and neglect the demands of making the evaluation at a corporate level. Hence, a project selection method constructed with complete strategy-oriented evaluation and selection process will meet many firms' practical needs.

In diversified, multibusiness organizations, the evaluation and selection of the appropriate strategic plans that the firm will pursue involve the business strength/industry attractiveness analysis of the SBUs and the feasibility analysis of the strategic plans that are submitted by the SBUs. The process, from identifying the competitive position of SBUs and the feasibility of strategic plans to determining the suitable strategic plans, is a very complicated task that requires a structured evaluation procedure and experienced evaluators. However, in the evaluation process, evaluators must confirm that all the information available or needed is brought to bear on the problem or issue at hand. As previous cases indicated [1,5,21], the identification of all relevant information for a decision does not mean that the decision-makers have complete information; in most cases, information is incomplete. In addition, many decisions that have far-reaching effects on the organizational activities and personnel are made in groups. One problem of group decision-making is that every member has different amounts of information on the problems. This means that the situation where different decision-maker possesses different confidence level for the problem will occur. Therefore, the field of strategic management has been recognized as an appropriate field for the application of the fuzzy set theory, because of the fuzziness of the main concepts and terms, and the contexts of strategic management belong to the area of uncertainty and vagueness [30].

In this study, we have developed an integrated framework for strategic formulation to improve the process of project portfolio selection. The proposed approach takes advantage of the characteristics of some existing methods, which include portfolio matrix model, 3Cs model [15], fuzzy weighted average [10,25,26] and fuzzy integer linear programming [17,18]. These methods have sound theoretical bases and are commonly used because of their good decision support characteristics. In order to increase the user acceptability, we use a computer-based group decision support approach to project strategic formulation. According to Turban [36], "A decision support system is an interactive, flexible, and adaptable computer-based information system, specially developed for supporting the solution of a non-structured management problem in improving decision making. It utilizes data, provides an easy-to-use interface, and allows for the decision-maker's own insights." Based on Turban's key concepts of DSS [36], a Fuzzy Portfolio Selection System (FPSS) is developed in this paper to help managers systematically and scientifically make decision for strategic project portfolio.

2. The conceptual framework

Conceptually, our approach for project portfolio selection in the group decision support system is a three phase process: (1) pre-evaluation, (2) preference elicitation, and (3) data analysis and reporting. The pre-evaluation phase encompasses four basic activities: (1) discussing and selecting the alternatives for evaluation; (2) setting strategic focus and resource constraints; (3) deciding the portfolio matrix and the corresponding evaluation criteria; and (4) deciding the type of the fuzzy integer linear programming model and the relative importance of coefficients. The four activities are common to any group decision-making process, and are well discussed in the literature [12,21,22].

The preference elicitation phase is consisted of two activities: (1) collecting the individual confidence level, and the definition of the linguistic variables and the corresponding triangular fuzzy numbers; and (2) deriving the scores of weighing the criteria and rating the alternatives. The first activity is the basic preparation step for the utilization of the fuzzy set theory to deal with the uncertainty problem of linguistics and the problem of the decision-makers' different confidence levels. The confidence level that is provided by an individual decision-maker implies how confident he/she is in weighing the criteria and rating the alternatives (see Appendix A). In practice, the confidence levels of different managers toward one strategic plan might vary [20]. Sometimes there are experienced managers in a decision group, such as a project manager who is familiar with the field of the strategic plan, or some managers who have more experience with evaluation than others, thus the final evaluation result is influenced by these managers with different confidence levels. The second activity of the preference elicitation phase is common in group decision-making situations, which is generally supported by most DSS environments.

The third phase, which is the calculation process, includes data analysis and reporting. This phase employs two algorithms, one is the fuzzy weighted average for identifying the competitive advantage of SBUs and the feasibility of strategic plans, and the other is the fuzzy integer linear programming for selecting the optimum strategic plans.

2.1. The portfolio matrix model

During the 1970s and early 1980s, a number of leading consulting firms developed the concept of portfolio matrix to help managers better understand the competitive position of the overall portfolio of businesses, suggest strategic alternatives for each of the businesses, and develop priorities for resource allocation [16]. One of the most popular portfolio matrices is the GE Multifactor Portfolio Matrix that developed jointly by General Electric and McKinsey and Company (Fig. 1). This tool helps managers understand the competitive position of SBUs based primarily on industry attractiveness (IA) and business strength (BS). Industry attractiveness is a subjective assessment based on external factors, which is uncontrollable by the firm. Business strength is a subjective assessment based on the critical success factors, which is largely controllable by the firm. Each of these two dimensions is a composite of various factors. For example, industry attractiveness might be determined by factors such as the number of competitors in an industry, and the rate of industry growth; while business strength can be determined by factors like the solidity of a company's financial position, and its advantageous bargaining position over suppliers.

2.2. The feasibility analysis of strategic plans

Besides considering the competitiveness of the business portfolio, managers also need to consider whether the businesses have the capabilities and resources that are necessary for the implementation of 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

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.

the same strategic business unit, a set of criteria is also needed to differentiate the most feasible strategic plan from the others. The 3Cs model, which is presented by Hatten and Rosenthal [15], 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 the customer relations. Process capabilities are the physical capabilities to do things and are measures of the performance of business processes along dimensions that are 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 one organization's potential to conduct business that is state-of-the-art in both the firm's input markets (labor, capital, information and technology) and its output markets with customers. Thus, a business strategy is based on the strengths of a firm's customer relationships, the depth of its competencies, and its capabilities. Under this concept, a selected strategic plan must be congruent with the requirement for meeting customers' needs as well as with the competencies and capabilities of the business.

2.3. Fuzzy weighted average

The initial publication of fuzzy set theory was by Zadeh [37]. Fuzzy set theory provides a strict mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied [38]. It can also be considered as a modeling language that is well suited for situations that contains fuzzy relations, criteria and phenomena. The portfolio matrix and 3Cs model have been proved to be a useful tool to companies for analyzing strategic business units and projects, and providing strategic directions [15,32]. However, as indicated earlier, the fact that evaluators seldom have the complete information to make the decisions will result in evaluators' uncertainty during the decision-making process. Since human judgments and preferences are often vague and difficult to be estimated with an exact numerical value, the main problem with the usage of the classical portfolio matrix is the precise determination of the numerical value for the criteria [3,30]. To remedy this shortcoming, the linguistic assessments instead of numerical indicators can be used, which means that the ratings and weights of the criteria in the problem are presented through the means of linguistic variables [2,9,19]. 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 operations. The basic definitions of the fuzzy set theory, which are necessary for this paper, are presented in Appendix A.

In order to obtain the weighted sum of those criteria that was evaluated by fuzzy number in terms of rating and importance, we use a fuzzy weighted average for the calculation [10,25,26]. There have been several previous studies on the fuzzy weighted average. Dong and Wong [10] 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 [26] suggested a modification of the fuzzy weighted average method that was developed by Dong and Wong [10]. This modification provided similar computational results but required less evaluation and computations. Lee and Park [25] proposed the efficient fuzzy weighted average (EFWA) for the computation of a fuzzy weighted average, which improved on the previous works by reducing the number of comparisons and arithmetic operations. We adopt the EFWA algorithm for the calculations in the current work [25]. The definitions relating to the EFWA are mostly from Lee and Park [25], Dong and Wong [10], and Liou and Wang [26].

2.4. Fuzzy integer linear programming

Generally, there is a trade-off between investment cost and financial potential in selecting a strategic plan; the less expensive projects will have lower returns. For a manager, finding the optimal decision is difficult and time-consuming due to 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 for selecting an optimal project portfolio, based on the organization's objectives and constraints, such as resource limitations and interdependence of projects [4,14]. In this study, we use the GE matrix to express the competitive position of SBUs, the 3Cs model to evaluate the feasibility of the strategic plans, and a proper estimation of the potential profit and implementation cost for strategic plans to present the financial potential of the strategic plans to earn fortune. Generally, a strategic plan with a higher score on the analysis of GE matrix, 3Cs model and financial potential will have more competitive advantage for high return and be more likely to be selected for implementation. Hence, by using the evaluation results of the GE matrix, 3Cs model and financial potential as the input data, we can construct and solve a mathematical programming to obtain an optimal project portfolio. However, the evaluation process implemented in the proposed approach and the way used to present the evaluation results are based on the fuzzy theory. Therefore, we adopt the fuzzy integer linear programming (FILP) to do the selection of an optimal project portfolio [18], see Appendix B. In FILP classification [17,18], we find that there are either fuzzy numbers as coefficients in the objective function or fuzzy numbers defining the set of constraints. In the current work, we use the FILP with fuzzy numbers as coefficients in the objective function.

The decision variables of the fuzzy integer linear programming model used in the paper are defined by:

$$r_{ij} = \begin{cases} 1 & \text{if the } j\text{th strategic plan is implemented at the } i\text{th SBU} \\ 0 & \text{otherwise} \end{cases}$$

for $i=1,\ldots,N$, where N is the total number of SBUs submitting strategic plans, and $j=1,\ldots,T$, where T is the total number of strategic plans submitted by the ith SBU.

The fuzzy integer linear programming model is given by:

$$\text{Maximize} \quad z = \sum_{i\in N}\sum_{j\in N} \tilde{c}_{ij} r_{ij} \tag{1}$$

$$\text{Subject to} \quad \sum_{i\in N}\sum_{j\in N} a_{ij} r_{ij} \le b, \tag{2}$$

where z is the value function to be maximized; and a_{ij}, $b \in \mathrm{R}$ are real coefficients. The $\tilde{c}_{ij}$ in the objective are fuzzy numbers, that is, $\tilde{c}_{ij} \in F(\mathrm{R})$, $F(\mathrm{R})$ being the set of real fuzzy numbers.

3. The decision support system

The portfolio selection prototype, an application within the group work environment discussed here, was developed using Visual Basic 6.0. The functional architecture of the application can be divided into four modules, as illustrated in Fig. 2: (1) process management module, (2) preference elicitation module, (3) optimal portfolio selection module, and (4) reporting module.

One function of the process management module is to collect the off-line information for the subsequent modules. The information includes the alternatives for evaluation, the required implementation time or cost and potential returns of alternatives, the resources a firm can provide, the portfolio matrix and the corresponding evaluation criteria, and the fuzzy integer linear programming model and the relative importance of coefficient. Several researchers have previously discussed the role of a facilitator in computer supported group processes [12,29]. The major functions of the facilitator include the preparation and setup of the strategic selection, the management of the group process, and promotion of effective task behaviors. Hence, the facilitator can assist in loading the aforementioned off-line information into the data files of the preference elicitation module through the interaction with the process management module. The other function of the process management module is to offer a facilitator access to make orders to preference elicitation mod-

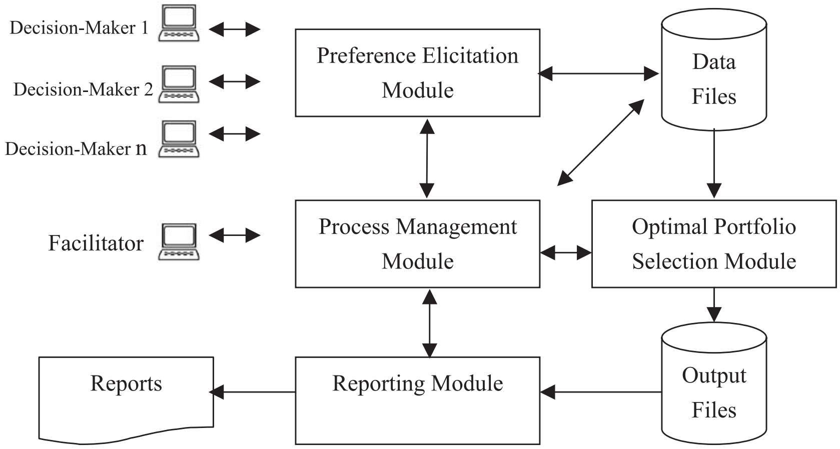

Fig. 2. System application architecture.

ule, optimal portfolio selection module and reporting module.

In order to provide users with a flexible application system, the proposed portfolio selection prototype is designed to be expandable as users wish through the interaction with an application interface. For example, in the process management module, the number of alternatives for evaluation can increase from 2 to 80, depending on a firm's demand. In addition, users can decide the type of portfolio matrix, how many criteria and the corresponding sub-criteria for evaluating the alternatives. The next flexibility advantage of our system is that users can choose the type of fuzzy integer linear programming model that satisfies their firms' needs. The process management module provides eight types of built-in fuzzy integer linear programming models (one of them is shown in the proposed example).

With the information collected by the process management module, the preference elicitation module can offer the decision-makers a set of user-friendly interfaces. Each decision-maker inputs data by interacting with the preference elicitation module using the decision-maker's screens. There are two decision-maker's screens. The first one is for collecting the individual confidence level, and defining the linguistic variables and the corresponding triangular fuzzy numbers. The other is for deriving the scores of weighing the criteria and rating the alternatives. All of the data are loaded into the data file of the preference elicitation module. After every decision-maker completes each round of preference elicitation, the facilitator, interacting via the process management module, runs the optimal portfolio selection module to obtain the results of the group decision.

The optimal portfolio selection module has three functions: (1) calculating the weighted scores of criteria for alternatives by using fuzzy weighted averages, (2) aggregating the weighted scores assessed by individual decision-maker to obtain an aggregate group result, (3) deriving the optimal portfolio through the utilization of the fuzzy integer linear programming. Regarding the first of these three functions, the results derived from the preference elicitation module, which includes weights for the criteria and scores on alternatives' criteria, are presented in fuzzy numbers. In order to obtain the weighted scores of criteria for alternatives, we use the fuzzy weighted average to deal with the arithmetic problem of fuzzy numbers times fuzzy numbers [10,25,26]. Until the implementation of first function, the data files of the preference elicitation module collect the evaluation data from individual decision-makers separately. The third function is used to select the suitable strategic plans by performing the fuzzy integer linear programming. The fuzzy integer linear programming utilizes the aggregate group data instead of separately individual data to conduct the arithmetic process. Therefore, the purpose of the second function is to apply an averaging method to aggregate the weighted scores that are from individual decision-makers to become an aggregate group result.

Through the process management module, the facilitator makes orders to the reporting module for managing the report generation and distribution process. The reporting module provides several types of results, which include scatter plot and table format. Due to the difficulties of plotting fuzzy numbers on graphs, the facilitator needs to select a method [average, optimistic, pessimistic, median] (see Appendix A) to transfer fuzzy numbers into crisp numbers before positioning SBUs and strategic plans on the graphs. However, the information that decision-makers obtained from scatter plot is displayed in crisp numbers that were transferred from fuzzy numbers. Due to the transfer process, the crisp number may present less information than fuzzy numbers do. Therefore, the purpose of scatter plot is only for rapid understanding the whole structure of the analysis results. The arithmetic process of the fuzzy integer linear programming uses the aggregated fuzzy weighted scores as input data to do the selection of an optimal project portfolio. With the fuzzy numbers representing the complete information, fuzzy integer linear programming can be used to determine precise ranking and selects strategic plans.

4. A case illustration

In order to evaluate the applicability of the proposed approach, we implemented it in a strategic planning project for a food corporation in Taiwan. The corporation is not only a leader in Taiwan's food industry, but also a global corporation with annual revenues that is in the billions of dollars. The following are the implementation tasks for each phase (see Fig. 3).

4.1. Phase I: pre-evaluation

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 accurately reflected the managers' strategy evaluation process, we had to first explain the purpose of this research and the concepts of the portfolio matrix, 3Cs model, fuzzy weighted average and fuzzy integer linear programming to the managers participating in this study. Furthermore, we collected the important factors from several strategic planning cases, and consulted with different departmental managers for their opinions. This step can help the managers to identify the relevant internal and external factors of positioning the SBUs, as well as the feasibility factors of the strategic plans. We then conducted a focus group that included 10 top managers and 3 experts in the field of strategic planning to decide two major things. The first set of actions is to select the following factors: (1) the internal factors to assess the business strength of the SBUs that involves a structure for evaluating the management, manufacturing, R&D and engineering and marketing; (2) the external factors to assess the industry attractiveness of the SBUs, which include the competitive, economic and government, social and market factors; (3) the feasibility factors to assess the feasibility of the strategic plans, which is relative to customer relation, businesses' capabilities and competencies. Tables 1 and 2 display the factors that evaluate the industry attractiveness/business strength of the SBU and the feasibility of the strategic plan, respectively. The second set of actions is to choose the type of the fuzzy integer linear programming model, and the relative importance of coefficients in the objective function. The fuzzy integer linear programming model that was decided by the focus group is as follows.

Three basic assumptions are stated as follows:

1. Two parameters, investment cost and expected profit, are used 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 per year.

The fuzzy integer linear programming 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

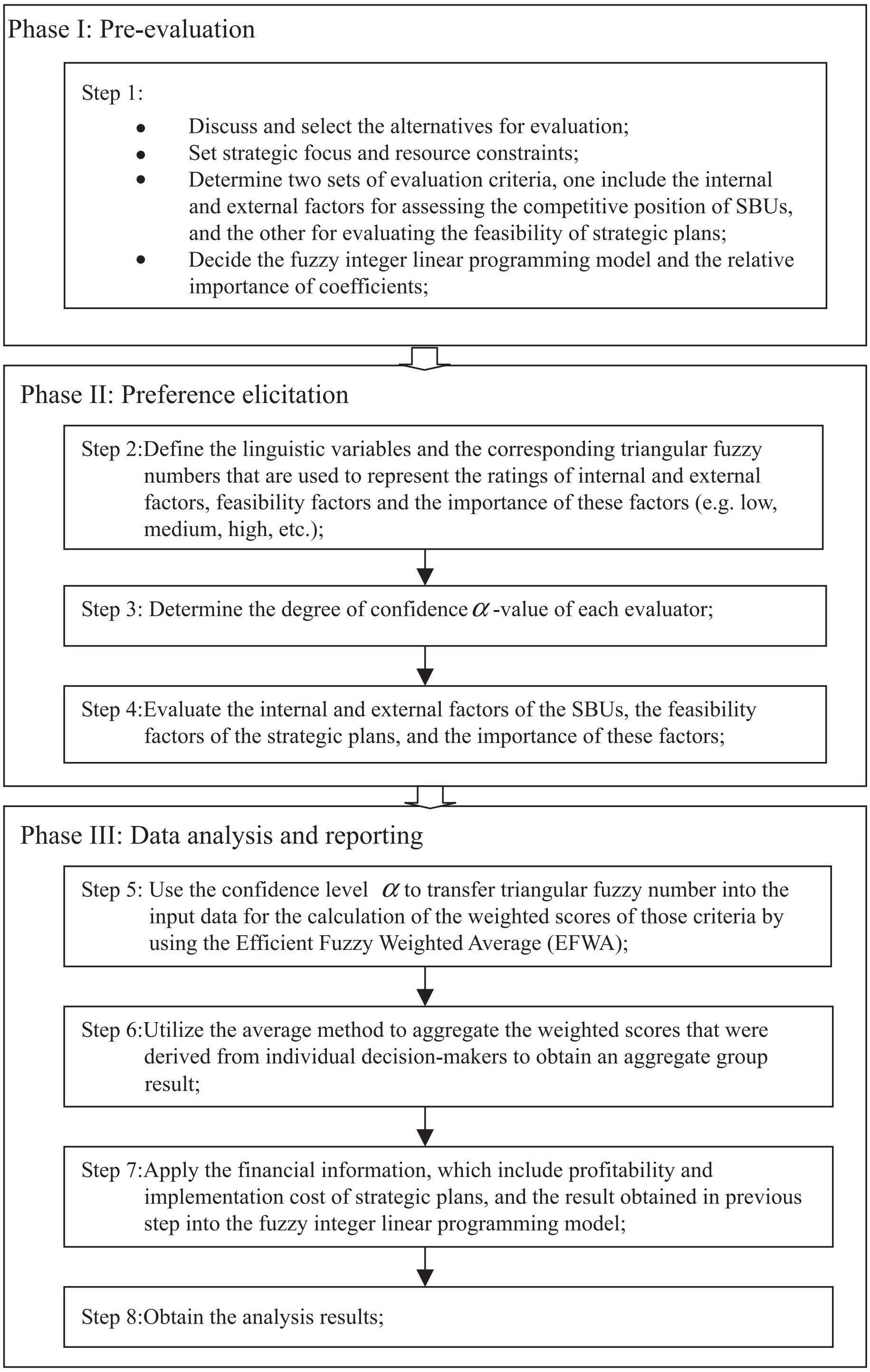

Fig. 3. Flow chart of the proposed procedure.

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

B Overall investment budget of the firm for the year
$\tilde{I}_i$ Industry attractiveness of the ith SBU
$\tilde{A}_i$ Business strength of the ith SBU
$\tilde{F}_{ij}$ Feasibility of jth strategic plan at the ith SBU

The fuzzy integer linear programming model can be stated as follows:

$$\text{Maximize} \quad \sum_i \sum_j w_{ij} r_{ij} (w_A \tilde{A}_i + w_I \tilde{I}_i + w_F \tilde{F}_{ij}) \tag{3}$$

$$\text{Subject to} \quad w_{ij} = \frac{P_{ij}}{\sum_i \sum_j (P_{ij})} \tag{4}$$

$$\sum_j r_{ij} C_{ij} \le U_i, \quad \text{for all } i \tag{5}$$

$$\sum_i \sum_j r_{ij} C_{ij} \le B \tag{6}$$

$$\sum_j r_{ij} = 1, \quad \text{for all } i \tag{7}$$

$$\sum_i \sum_j w_{ij} = 1, \quad \text{for all } i,j \tag{8}$$

$$r_{ij} = 0, 1 \quad \text{for all } i,j \tag{9}$$

The objective function, which is Eq. (3), is used to maximize the total return on investment. It includes the scores of industry attractiveness, competitive advantage, feasibility and financial potential. This implies that the higher scores the strategic plan has on industry attractiveness, competitive advantage, feasibility and financial potential, the greater returns the strategic plan will yield. The weight w_{ij} is a ratio that is equal to the potential profit of the plan divided by total potential profit of whole proposed plans. It is designed to present the level of financial potential of a specific strategic plan to maximize returns, compared to the plans proposed overall. A strategic plan with a higher financial potential will have a higher weight, which leads to a higher score in the objective function. These w_A, w_I, w_F ($w_A + w_I + w_F = 1$) denote, respectively, the importances of $\tilde{A}$, $\tilde{I}$, $\tilde{F}$ to the objective and are determined by the evaluators. Constraint Eqs. (5) and (6) limit the budget for the ith SBU and the entire firm, respectively. Meanwhile, constraint Eq. (7) guarantees that each SBU will only be assigned one strategic plan for implementation. Finally, constraint Eq. (9) specifies the integrality restriction on the values of the decision variables r_{ij}.

Then, the facilitator used the information that were obtained from the pre-evaluation phase and the profitability/implementing cost of the strategic plans that were provided by the managers of the SBUs to create the work files through the interaction with the process management module.

Table 2
Criteria structure related to 3Cs model

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

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)

4.2. Phase II: preference elicitation

After the information derived from the pre-evaluation phase had been loaded into the data file of the preference elicitation module, three top managers were invited to input their preferences by interacting with the preference elicitation module via decision-maker's screens. There are two main activities in this phase. The first activity is collecting the definition of the linguistic variables, the corresponding triangular fuzzy numbers, and the individual confidence level. Here, the three managers defined the linguistic variables and triangular fuzzy numbers for 'internal factors', 'external factors', 'feasibility factors' and 'weights' (shown in Table 3). Also, the three managers decided the individual confidence level for calculating the weighted scores of those criteria by using the EFWA (shown in Table 4). The second activity is to weigh the criteria and rate the alternatives. In this activity, the three managers evaluated the importance of each criterion, the internal and external factors of the SBUs, and the feasibility of the strategic plans in linguistic term.

Table 4
Individual confidence levels of three managers

	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									

M1: Manager 1; M2: Manager 2; M3: Manager 3.

4.3. Phase III: data analysis and reporting

In this phase, the facilitator performed three actions: (1) checking to make sure that all participating decision-makers had finished Phase II; (2) running the optimal portfolio selection module that encompasses two major algorithm-fuzzy weighted average and fuzzy integer linear programming; (3) defining the format of report (graph or table), which was generated at the end of Phase III. In Figs. 4 and 5, we display the results of fuzzy weighted average in scatter plot format. Fig. 4 reveals the two-dimensional analysis result for business strength/industry attractiveness of the SBUs. Adding the feasibility analysis, a three-dimensional result for strategic plans can be depicted in Fig. 5. In Table 5, we take manager 1 as an example to show the detailed table results for business strength/industry attractiveness of the SBUs and feasibility of the strategic plans in fuzzy numbers.

Table 6 displays the results of the fuzzy integer linear programming. In the proposed approach, user can determine the value of the weight vector β. The weight vector β is utilized in the last calculation step of fuzzy integer linear programming to transfer fuzzy integer linear programming into conventional parametric linear programming (see Appendix B). The weight vector β is determined by decision-makers to present their optimism level toward the internal and external environmental factors that affect the implementation of the project portfolio.

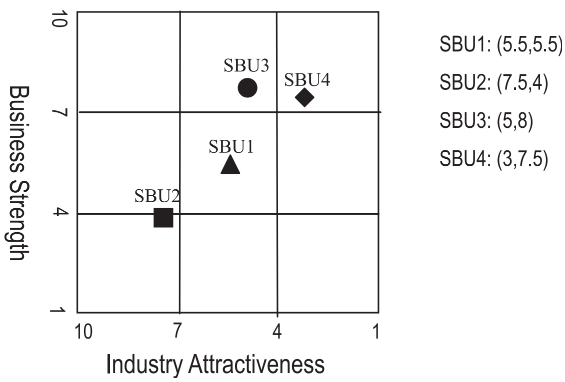

Fig. 4. Scatter plot of business strength/industry attractiveness for SBUs.

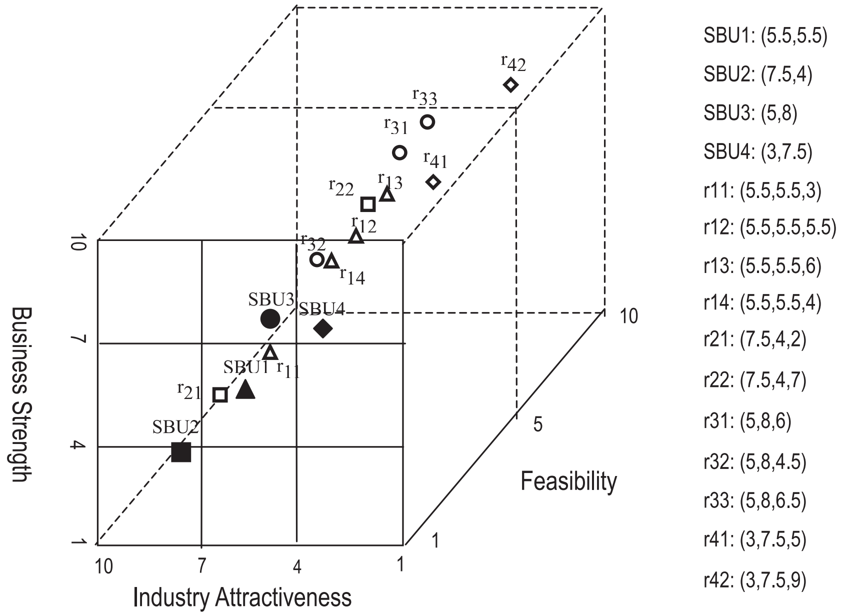

Fig. 5. Scatter plot of business strength/industry attractiveness of the SBUs and feasibility of the strategic plans ($r11$, $r12$, $r13$, $r14$ represent the strategic plans that are submitted by SBU1).

According to the values of the weight vector β, we show two kinds of results in Table 6. For example, if decision-makers feel pessimistic to the environmental factors, they will decide the optimism level β=(1,0). Given the value of the weight vector β, the fuzzy integer linear programming will provide user with different values of the confidence level α. The confidence level α is used to present how decision-makers think of the possibility that the optimism level β will happen. For example, in the result of Table 6, if decision-makers have pessimistic attitude, they will choose the optimism level β=(1,0). Then if they think that there will be a high possibility that the optimism level β=(1,0) will happen, they will choose the confidence level $\alpha=1$, then we obtain the optimal solution: $r11=r21=r31=r41=1$, and all other r_{ij}'s$\,=0$. The result implies that the combination of all SBUs adopting their first strategic plans, the company can maximize its returns by spending an acceptable cost resulting from implementing these strategic plans. Thus the maximum profit that the company can earn is \$23 million. On the contrary, if the decision-makers have the optimism level β=(0,1) and think

Table 5
Calculation results for manager 1

	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)									

a: Business Strength, i: Industry Attractiveness, f: Feasibility.

Table 6
Result of fuzzy integer linear programming model

$r(\alpha) = (r_{11}, r_{12}, r_{13}, r_{14}, r_{21}, r_{22}, r_{31}, r_{32}, r_{33}, r_{41}, r_{42})$			
β = (1,0)			
$r(\alpha) = (0,0,0,1,1,0,0,0,1,0,1)$	$r(\alpha) = 31 - 10\alpha$	$\forall\alpha \in [0,0.375]$	$r(0) = 31$ $r(0.375) = 27.25$
$r(\alpha) = (0,0,1,0,1,0,1,0,0,0,1)$	$r(\alpha) = 30.25 - 8\alpha$	$\forall\alpha \in [0.375,0.75]$	$r(0.375) = 27.25$ $r(0.75) = 24.25$
$r(\alpha) = (1,0,0,0,1,0,1,0,0,1,0)$	$r(\alpha) = 28 - 5\alpha$	$\forall\alpha \in [0.75,1]$	$r(0.75) = 24.25$ $r(1) = 23$
β = (0,1)			
$r(\alpha) = (0,1,0,1,0,1,0,0,0,1,0)$	$r(\alpha) = 31 + 5\alpha$	$\forall\alpha \in [0,0.5]$	$r(0) = 31$ $r(0.5) = 33.5$
$r(\alpha) = (0,1,0,0,1,0,1,0,0,1,0)$	$r(\alpha) = 32 + 3\alpha$	$\forall\alpha \in [0.5,1]$	$r(0.5) = 33.5$ $r(1) = 35$

(β: optimism level; α: confidence level; r_{ij}: decision variable.)

of medium possibility that the optimism level β=(0,1) will happen, they will choose the confidence level $\alpha = 0.5$. Then the maximum profit that the company can earn is \$33.5 million. Therefore, we can see that different values in terms of the optimism level β and the confidence level α will lead to different optimal portfolio results.

5. Discussion

The firm that we cooperated with to demonstrate the proposed approach is a corporation with four strategic business units. The process that the firm previously used for strategic plan selection consists of the following five steps. (1) CEO conducts a strategic plan selection committee that includes five to six top managers. (2) The committeemen spend 2–3 weeks to review the detailed reports of all proposed strategic plans. The reports include the content and the expected profit for each of the proposed strategic plans, and the past performance of the SBU. The evaluation factors used to evaluate the strategic plan vary with committeemen. (3) The committeemen meet for a first vote to screen out half of the proposed strategic plans. (4) The committeemen meet two or three times to discuss the remaining half of the proposed strategic plans. (5) After two to three meetings, the committeemen vote again to determine the final list of the strategic plans. This process usually lasts one and half to two months. The CEO and top managers all complained that the process is not efficient and wished to have a useful approach to facilitate the process.

From interviews with the CEO and top managers, we found that there are three concepts that they expected the new strategic plan selection approach to be able to achieve. The three concepts are accuracy, objectivity and justice, and efficiency, which are consistent with prior research [6,13,22]. The CEO and top managers thought that the new approach should be accurate to evaluate the potential of the strategic plans; and that it should be an objective and fair decision-making method; and that it should be efficient in doing the evaluation. The proposed approach has the following advantages: (1) The evaluation factors used to evaluate the strategic plan, including portfolio matrix model and financial data are determined by the focus group. Through interacting with the system, each evaluator is able to evaluate the strategic plans using the same evaluation factors. Therefore, the system provides a complete and accurate evaluation structure to evaluate the potential of the strategic plans. (2) The system employs a fuzzy approach to consider the fuzziness problem resulted form the uncertainty of linguistic terms, as well as the diversity of confidence level and optimism level. Furthermore, a fuzzy integer linear programming is incorporated to help managers select the strategic plans. Hence, the proposed approach, which is based on a mathematical method with sound theoretical basis, provides an objective and just decision-making method. (3) The approach is designed according to the concept of group decision support system as an expandable and easy-to-use strategic portfolio selection tool. It provides a computer-aided evaluation environment to reduce meeting time and offer the evaluators the freedom of doing the evaluations in their own offices at any time.

Through using the proposed approach, the CEO and the top managers had three meetings, one for the training program of using the proposed approach, and another for the focus group. Then, they had two weeks to do the evaluation. After they had completed the evaluation, they met again for knowing the final evaluation result and shared the experience of using the proposed approach. Hence, the total project portfolio selection process lasted 2–3 weeks, which is one month less than the original process. In addition, the CEO and top managers stated that they were comfortable with the design and using the proposed approach, and that felt confident with the evaluation results. Hence, the CEO and top managers were pleased and thought that the proposed approach is able to satisfy, or even exceed their expectation.

6. Conclusion

In this study, the proposed DSS of FPSS is a flexible and expandable system that: (a) simultaneously considers all the different criteria in determining the most suitable project portfolio, (b) takes advantage of the best characteristics of the existing methods by decomposing the process into a flexible and logical series of activities and applying the most appropriate technique(s) at each stage, (c) involves the full participation of the decision-makers in deciding the number of decision-makers, alternative projects, evaluation criteria and sub-criteria, the type of fuzzy integer linear programming model, the confidence level, and the optimism level, and (d) provides that users can investigate the impact of changes in certain parameters on the solution and quickly receive feedback on the consequences of such changes. In addition to its flexibility and expandability, the other characteristics of a sound DSS are its user-friendliness. The implementation of the proposed DSS of FPSS for a strategic planning project undertaken by a major food company in Taiwan confirmed the above considerations. The top managers of the company were pleased and agreed with our recommendations since the DSS of FPSS can reduce the decision-making time, and is a practical tool for dealing with the uncertainty problem of linguistic terms, the diversity of decision-makers' confidence levels, and the effect of the optimism level. 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 the strategic plans, the approach can also work with other evaluation measures.

Appendix A. Basic definitions of the fuzzy set theory

Dubois and Prade [11] defined a fuzzy number and described its meaning and features. A fuzzy number $\tilde{A}$ is a fuzzy set which membership function is $\mu_{\tilde{A}}(x){:}R \rightarrow [0.1]$. A triangular fuzzy number $\tilde{A}$=(l, m, u) can conform to the characteristics that are depicted in Fig. 6. In management implication, 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 $\tilde{A}$ is expressed as:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{(x-1)}{m-l}, & 1 \leq x < m, \\ \dfrac{(x-u)}{m-u}, & m \leq x \leq u, \\ 0, & \text{others}, \end{cases} \tag{A1}$$

The α-cut set of a fuzzy number $\tilde{A}_\alpha = \{x | \mu_{\tilde{A}}(x) \geq \alpha\}$ $\alpha \in \{0,1\}$, is expressed as (l^α, m^α, u^α). The confidence interval of $\tilde{A}_\alpha$ at α-level can also be stated $\tilde{A}_\alpha[a_1^\alpha, a_2^\alpha]$.

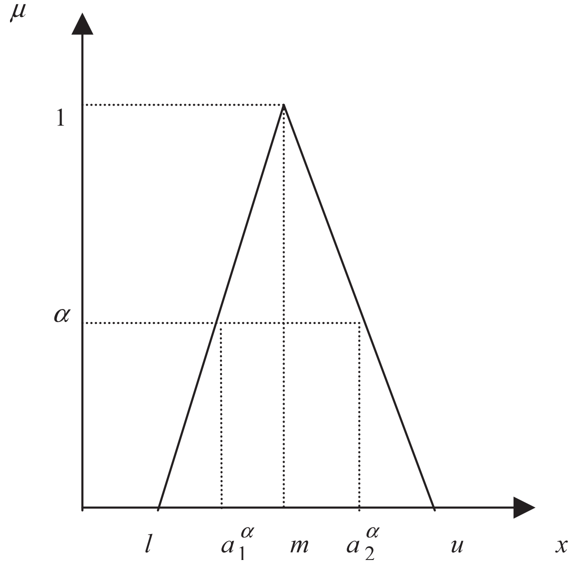

Fig. 6. Triangular fuzzy number.

a_1^α and a_2^α mean the upper and lower boundaries of confidence interval.

Appendix B. Fuzzy integer linear programming problems with imprecise coefficients

Here we study FILP problems with imprecise coefficients in the objective function, that is, with coefficients defined by fuzzy numbers [17,18]. The problem can be written as

$$\begin{aligned}\max\ z &= \sum_{j\in N}\tilde{c}_j x_j\\ s.t.\quad &\sum_{j\in N} a_{ij}x_j \le b_i,\quad i\in M,\\ &x_j\ge 0,\quad j\in N,\\ &x_j\in N,\quad j\in N,\end{aligned}\tag{A2}$$

where a_{ij}, $b_i\in$R are real coefficients, and the costs in the objective are fuzzy numbers, that is, $\tilde{c}_j\in F$(R), F(R) being the set of real fuzzy numbers, $i\in M$, $j\in N$.

First, the fuzzy solution for Eq. (A2) can be obtained from the solution of the following Multi-objective Integer Programming problem:

$$\begin{aligned}&\max\ (c^1x, c^2x, \ldots, c^nx)\\ &s.t.\quad Ax\le b,\\ &\qquad x\ge 0,\quad c^k\in E(1-\alpha),\\ &\qquad \alpha\in[0,1],\quad k=1,2,\ldots,n\end{aligned}\tag{A3}$$

where $E(1-\alpha)\subset\Gamma(1-\alpha)$ is the subset constituted by vectors whose jth component is equal to either the upper or the lower bound of c_j, $\phi_j(1-\alpha)$ or $\varphi_j(1-\alpha)$, $j\in N$.

On the other hand, according to some results by Lee and Park [25], on the use of interval arithmetic for solving LP problems with interval objective functions, the fuzzy solution for Eq. (A2) can be found from the parametric solution of the following biobjective parametric problem, $P(\alpha)$:

$$\begin{aligned}&\max\ z'(\alpha) = (z^1(x,\alpha), z^c(x,\alpha))\\ &s.t.\ Ax\le b,\\ &\qquad x_j\in N,\quad j\in N,\\ &\qquad \alpha\in[0,1],\end{aligned}\tag{A4}$$

where $z^1(x,\ \alpha)$ and $z^c(x,\ \alpha)$ in the case of triangular fuzzy numbers are defined by

$$z^1(x,\alpha) = \sum_{j=1}^{n}[c_j - \alpha(c_j - r_j)]x_j,$$

$$\text{and } z^c(x,\alpha) = \frac{1}{2}\sum_{j=1}^{n}[2c_j + \alpha(R_j + r_j - 2c_j)]x_j.$$

which is a fuzzy set giving the fuzzy solution to the former problem, in which $S(1-\alpha)$ is defined as the set of solutions of the auxiliary problem considered according to the two approaches Eq. (A3) or Eq. (A4), for every $\alpha\in[0,1]$.

Concretely, a decision-maker may be able to assign weights $\beta_k\in[0,1]$ to each of the objectives taking part in Eq. (A3) or Eq. (A4), such that

$\Sigma_k \beta_k = 1$. Then conventional parametric LP problems are obtained.

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