Fuzzy Multicriteria Decision Support for Information Systems Project Selection

Chung-Hsing Yeh, Hepu Deng, Santoso Wibowo, and Yan Xu

Abstract

This paper presents a fuzzy multicriteria group decision making approach for selecting information systems projects. The inherent subjectiveness and imprecision of the selection process is modeled by using linguistic terms characterized by triangular fuzzy numbers. To avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria analysis, a new algorithm is developed based on the degree of dominance and the degree of optimality concepts. A multicriteria decision support system is proposed to facilitate the evaluation and selection process. An information systems project selection problem is presented to demonstrate the effectiveness of the approach.

Keywords: Decision support systems, Fuzzy numbers, Information systems project selection, Multicriteria decision making.

1. Introduction

The development of information systems (IS) has been actively pursued by organizations for maintaining their competitive advantages in today's dynamic environment [1, 2]. The selection of IS projects for development needs has become an important strategic as well as operational decision issue in meeting organization's strategic goals and operational objectives. The process of evaluating and selecting IS projects is complex and challenging. It often involves (a) multiple decision makers, (b) multiple selection criteria, and (c) subjective and imprecise assessments [3-5]. To ensure that the best possible IS project is selected with proper justification, it is desirable to use a structured approach capable of comprehensively analyzing the overall performance of available IS projects in a specific decision setting.

As a structured approach, decision support systems (DSSs) have been developed to solve various decision problems. For example, Ghasemzadeh and Archer [6] develop a DSS for solving the project portfolio selection problem. Bastos et al. [7] apply an intelligent DSS to help solve a resource allocation problem. Ozbayrak and Bell [8] use a rule-based DSS for managing manufacturing parts and tools in a production line. Wen et al. [9] apply an intelligent DSS to analyze decision situations for enterprise acquisition that shows promising results. All of these studies demonstrate that the development of DSS for addressing various decision problems is of great practical benefits. However, in dealing with actual decision settings in real world applications in particular for selecting among a set of available IS projects, existing DSSs can be enhanced by (a) addressing the needs of multiple decision makers and multiple criteria, (b) modeling the subjectiveness and imprecision of the human decision making process, and (c) reducing cognitive demand on the decision makers in the process.

In this paper we present an effective fuzzy multicriteria decision making approach to the IS project selection problem. The approach facilitates and enhances the development of a DSS for assisting decision makers in evaluating and selecting IS projects. To model the subjectiveness and imprecision of the human decision making process, linguistic terms characterized by triangular fuzzy numbers are used. To avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria decision making, a new algorithm is developed by applying the degree of dominance and the degree of optimality concepts.

In subsequent sections, we first formulate the IS project selection as a fuzzy multicriteria group decision making problem. We then present the algorithm and the DSS for solving the general fuzzy multicriteria group decision making problem. An IS project selection problem is exemplified to demonstrate the applicability of the fuzzy multicriteria group decision making approach.

2. Multicriteria Group Decision Making for IS Project Selection

Multicriteria group decision making involves a group

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of decision makers evaluating a set of decision alternatives with respect to multiple, often conflicting criteria [3]. Modeled as a multicriteria group decision making problem, the evaluation and selection of IS projects usually involves the following five steps: (a) identifying the available IS projects as decision alternatives A_i (i = 1, 2, ..., m), (b) determining the evaluation criteria C_j (j = 1, 2, ..., n) and their associated sub-criteria if existent, (c) assessing the performance ratings of alternatives with respect to each criterion, and the relative importance of the criteria by a group of decision makers D_k (k = 1, 2, ..., s), (d) aggregating the alternatives' performance ratings and criteria weights for producing an overall preference value for each alternative across all criteria with the inputs from all decision makers, and (e) selecting the most preferred alternative as the most suitable IS project.

The first two steps define the multicriteria group decision making problem. The next two steps involve the procedures required for solving the problem, which are to be addressed by the new algorithm presented in the next section. The last step selects the most preferred IS project based on the outcome of the algorithm. Before presenting the algorithm in the next section, we discuss how the selection of IS projects is formulated as a fuzzy multicriteria group decision making problem, due to the subjective assessment process.

To model the uncertainty and subjectiveness of the human decision making process, linguistic terms are used for facilitating the subjective assessment to be made by the decision maker. These linguistic terms are represented by triangular fuzzy numbers as their approximate value between 1 and 9, denoted as (a_1, a_2, a_3), where $1 < a_1 < a_2 < a_3 < 9$. For a linguistic term represented as (a_1, a_2, a_3), a_2 is the most possible value, and a_1 and a_3 are the lower and upper bounds respectively used to reflect the fuzziness of the term. In practical applications, triangular fuzzy numbers are commonly used to characterize linguistic information [10, 11]. The popular use of triangular fuzzy numbers is mainly attributed to their simplicity in both concept and computation. Theoretically, the merits of using triangular fuzzy numbers in fuzzy modeling have been well justified [12, 13]. With the simplest form of membership function, triangular fuzzy numbers constitute an immediate solution to the optimization problem in fuzzy modeling.

Table 1 shows the linguistic terms (given as in Row 1) and their corresponding triangular fuzzy number (given as in Row 3) for individual decision makers to make qualitative assessments about the performance rating of each IS project alternative with respect to a given criterion. To assess the relative importance of the evaluation criteria, the decision makers can use the linguistic terms given in Row 2 of Table 1, which are characterized by triangular fuzzy numbers as given in Row 3 of Table 1.

Table 1. Linguistic terms for assessing performance ratings and criteria weights.

Linguistic Terms	Very Poor (VP)	Poor (P)	Fair (F)	Good (G)	Very Good (VG)
	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
Membership Function	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

3. A Fuzzy Multicriteria Group Decision Making Algorithm

Making multicriteria group decisions is always complex and challenging, due to (a) the uncertainty and imprecision of the human decision making process, (b) the cognitive demand on the decision makers in making subjective assessments, and (c) the comparison of fuzzy numbers which is complex and unreliable [3, 11, 14]. To address these issues, we develop a new algorithm for solving the fuzzy multicriteria group decision making problem. The proposed algorithm integrates three important concepts in multicriteria decision making research, including (a) the multiattribute value theory (MAVT) [15], (b) the degree of dominance [11], and (c) the degree of optimality [10].

With simplicity in both concept and computation, MAVT-based methods are intuitively appealing to the decision makers in practical applications. These methods are particularly suited to decision problems where a cardinal preference or ranking of the decision alternatives is required. In addition, these methods are the most appropriate quantitative tools for group decision support systems [16]. As such, the new algorithm developed in this paper can be readily incorporated into a DSS for solving the IS project selection problem.

The algorithm starts with assessing the performance rating of each decision alternative A_i (i = 1, 2, ..., m) with respect to each criterion C_j (j = 1, 2, ..., n). The assessment is made by each decision maker D_k (k = 1, 2, ..., s) using the linguistic terms defined in Table 1. As a result, s fuzzy decision matrices can be obtained as

$$Y^k = \begin{bmatrix} y_{11}^k & y_{12}^k & \cdots & y_{1n}^k \\ y_{21}^k & y_{22}^k & \cdots & y_{2n}^k \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1}^k & y_{m2}^k & \cdots & y_{mn}^k \end{bmatrix}, \quad k = 1, 2, ..., s. \tag{1}$$

where y_{ij}^k is the fuzzy assessment made by decision maker D_k about the performance rating of alternative A_i with respect to criterion C_j.

The relative importance of the evaluation criteria C_j can be assessed qualitatively by each decision maker D_k (k = 1, 2, ..., s) using the linguistic terms defined in Table 1. As a result, s fuzzy weight vectors are obtained as

$$w^k = (w_1^k, w_2^k, ..., w_n^k), \quad k = 1,2,..., s. \tag{2}$$

By averaging the fuzzy assessments made by individual decision makers as given in (1) and (2), the overall fuzzy decision matrix and the overall fuzzy weight vector can be obtained as

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{3}$$

$$W = (w_1, w_2, \ldots, w_n) \tag{4}$$

where $x_{ij} = \frac{\sum_{k=1}^{s} y_{ij}^k}{s}$ and $w_j = \frac{\sum_{k=1}^{s} w_j^k}{s}$, $i = 1, 2,..., m$; $j = 1, 2,..., n$. With the use of triangular fuzzy numbers, the arithmetic operations on fuzzy numbers are based on interval arithmetic [17].

The weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights (w_j) by the alternatives' fuzzy performance ratings (x_{ij}) as

$$Z = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & . & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & . & w_n x_{2n} \\ . & . & . & . \\ w_1 x_{m1} & w_1 x_{m2} & . & w_n x_{mn} \end{bmatrix} \tag{5}$$

In a typical two-phase approach for solving MAVT-based fuzzy multicriteria decision making problems [18], each alternative's overall performance (represented by a fuzzy number) is obtained by aggregating the corresponding values in the weighted fuzzy performance matrix given as in (5). To evaluate and rank all the alternatives based on their overall performance, a fuzzy number ranking method is needed for comparing their corresponding fuzzy numbers. Despite tremendous efforts being made, no best fuzzy number ranking method is available for practical decision problems of large size [10, 19]. In addition, the fuzzy number ranking process can be quite complex and may produce unreliable results, as it may (a) involve complex computational processes, (b) produce inconsistent outcomes by different fuzzy number ranking methods, and (c) generate counter-intuitive ranking outcomes for similar fuzzy numbers [10, 18, 19].

To avoid the unreliable process of comparing fuzzy numbers for determining the overall performance of each alternative across all criteria, the new algorithm developed in this paper uses the concept of the degree of dominance between alternatives. The degree of dominance concept is originally used by Yeh and Deng [20] to compare fuzzy numbers A and B as to how much larger A is than B. The fuzzy number ranking method based on this concept compares favorably with comparable methods examined. The fuzzy set difference D_{A-B} between A and B is calculated by fuzzy subtraction as

$$D_{A-B} = A - B = \{(z, \mu_{A-B}(z)), z \in R\} \tag{6}$$

where the membership function of D_{A-B} is defined as

$$\mu_{D_{A-B}}(z) = \sup_{z=x-y} (\min(\mu_A(x), \mu_B(y)), \ x, y \in X). \tag{7}$$

To determine how much larger A is than B, a defuzzification process is required to extract a single scalar value from D_{A-B}, which can best represent D_{A-B}. Using the mean value of fuzzy numbers (i.e. the average of value intervals of all α-cuts), the degree of dominance of A over B is determined by

$$d(A-B) = \int_0^1 D_{A-B}(\alpha) d\alpha \ ;$$
$$D_{A-B}(\alpha) = \begin{cases} (d_{A-B}^{L\alpha} + d_{A-B}^{R\alpha})/2, & 0 \le \alpha \le 1, \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

where $d_{A-B}^{L\alpha}$ and $d_{A-B}^{R\alpha}$ are the lower bound and upper bound of the interval $[d_{A-B}^{L\alpha}, d_{A-B}^{R\alpha}]$ respectively, resulting from the α cut on D_{A-B} ($0 \le \alpha \le 1$). A dominates B if $d(A\text{-}B) > 0$, and A is dominated by B if $d(A\text{-}B) < 0$. The larger the value of $d(A\text{-}B)$, the higher the degree of dominance of A over B.

To apply the degree of dominance concept, a common comparison base needs to be established with respect to the weighted fuzzy performance matrix in (5). To achieve this, the concept of the fuzzy maximum and the fuzzy minimum [21, 22] is applied. Given the fuzzy vector ($w_j x_{1j}$, $w_j x_{2j}$, …, $w_j x_{mj}$) of the weighted fuzzy performance matrix for criterion C_j, a fuzzy maximum ($M_{\max}^j$) and a fuzzy minimum ($M_{\min}^j$) can be determined by (9) and (10), which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion C_j.

$$\mu_{M_{\max}^j}(x) = \begin{cases} \frac{x - x_{\min}^j}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \le x \le x_{\max}^j, \\ 0, & \end{cases} \tag{9}$$

$$\mu_{M_{\min}^j}(x) = \begin{cases} \frac{x_{\max}^j - x}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \le x \le x_{\max}^j, \\ 0, & \end{cases} \tag{10}$$

where $x_{\max}^j = \sup \bigcup_{i=1}^{n} \{x, x \in R$ and $0 < \mu_{w_j x_{ij}}(x)$

$< 1\}$; $x^j_{\min} = \inf \bigcup_{i=1}^{n} \{x, x \in R$ and $0 < \mu_{w_j x_{ij}}(x) < 1\}$, $i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$.

Zeleny [23] first introduces the concept of the ideal solution in multicriteria decision analysis as the best or desired decision outcome for a given decision setting. Hwang and Yoon [14] further extend this concept to include the negative ideal solution in order to avoid the worst decision outcome, known as the technique for order preference by similarity to ideal solution (TOPSIS). This extension is in accordance with the degree of optimality concept which is rooted in an alternative where multiple criteria characterize the notion of the best [24]. The degree of optimality suggests that the most preferred alternative should not only have the shortest distance from the positive ideal solution (i.e. the best possible alternative), but also have the longest distance from the negative ideal solution (i.e. the worst possible alternative) [13, 23]. This concept has since been widely used in developing multicriteria decision making algorithms for solving practical decision problems, due to (a) its intuitively appealing logic, (b) its simplicity and comprehensibility, and (c) its computational efficiency [25-28].

Based on the degree of optimality concept, the positive fuzzy ideal solution consists of the fuzzy maximum with respect to each criterion across all alternatives [20, 29], as given in (9). The negative fuzzy ideal solution consists of the fuzzy minimum in regard to each criterion across all alternatives, as given in (10). The degree to which the fuzzy maximum dominates the weighted fuzzy performance (w_jx_{ij}) of alternative A_i with respect to criterion C_j can be calculated as

$$d^{+}_{ij} = d(M^j_{\max} - w_j x_{ij}) = \int D_{(M^j_{\max} - w_j x_{ij})}(\alpha)\, d\alpha \tag{11}$$

$$D_{M^j_{\max} - w_j x_{ij}}(\alpha) = \begin{cases} \dfrac{(d^{L\alpha}_{(M^j_{\max} - w_j x_{ij})} + d^{R\alpha}_{(M^j_{\max} - w_j x_{ij})}}{2}, & 0 \le \alpha \le 1. \\ 0, & \text{otherwise.} \end{cases} \tag{12}$$

Similarly, the degree of dominance of the weighted fuzzy performance (w_jx_{ij}) of alternative A_i over the fuzzy minimum with respect to criterion C_j can be calculated as

$$d^{-}_{ij} = d(w_j x_{ij} - M^j_{\min}) = \int D_{(w_j x_{ij} - M^j_{\min})}(\alpha)\, d\alpha \tag{13}$$

$$D_{(w_j x_{ij} - M^j_{\min})}(\alpha) = \begin{cases} \dfrac{d^{L\alpha}_{(w_j x_{ij} - M^j_{\min})} + d^{R\alpha}_{(w_j x_{ij} - M^j_{\min})}}{2}, & 0 \le \alpha \le 1. \\ 0, & \text{otherwise.} \end{cases} \tag{14}$$

The degree of dominance that the positive fuzzy ideal solution has on each alternative A_i and the degree of dominance that each alternative A_i has on the negative fuzzy ideal solution can be calculated respectively as

$$d^{+}_{i} = \sum_{j=1}^{n} d^{+}_{ij} \tag{15}$$

$$d^{-}_{i} = \sum_{j=1}^{n} d^{-}_{ij} \tag{16}$$

In line with the degree of optimality concept, an alternative is preferred if it is dominated by the positive fuzzy ideal solution by a smaller degree, and at the same time dominates the negative fuzzy ideal solution by a larger degree [20]. Based on this notion, an overall preference value for representing the overall performance of each alternative A_i across all criteria is obtained as

$$P_i = \frac{(d^{-}_{i})^2}{(d^{+}_{i})^2 + (d^{-}_{i})^2} \tag{17}$$

The larger the preference value P_i, the more preferred the alternative A_i.

The new algorithm presented above can be summarized as follows:

Step 1: Obtain the fuzzy decision matrix assessed by each decision maker, as expressed in (1).

Step 2: Obtain the fuzzy weighting vector assessed by each decision maker, as expressed in (2).

Step 3: Obtain the overall fuzzy decision matrix and the overall fuzzy weighting vector by (3) and (4) respectively.

Step 4: Obtain the weighted fuzzy performance matrix by multiplying the overall fuzzy decision matrix by the overall fuzzy weighting vector, as expressed in (5).

Step 5: Determine the fuzzy maximum which represents the best fuzzy performance ratings among all the alternatives as the positive fuzzy ideal solution by (9).

Step 6: Determine the fuzzy minimum which represents the worst fuzzy performance ratings among all the alternatives as the negative fuzzy ideal solution by (10).

Step 7: Calculate the degree of dominance that the positive fuzzy ideal solution has on each alternative by (11), (12) and (15).

Step 8: Calculate the degree of dominance that each alternative has on the negative fuzzy ideal solution by (13), (14) and (16).

Step 9: Obtain the overall preference value for each alternative by (17).

Step 10: Rank the alternatives in descending order of their preference value.

4. A Multicriteria Decision Support System

To help the decision makers solve the IS project selection problem in a systematic and user-friendly manner, we propose a multicriteria DSS. The DSS will allow the decision makers (a) to input values to express their assessments and (b) to examine the relationships between the evaluation criteria, and between the available alternatives and the selection outcome. Through interaction, the DSS helps the decision makers adopt a problem-oriented approach for solving the IS project selection problem effectively and efficiently.

The proposed DSS is composed of four main components, including (a) the data management subsystem, (b) the model base subsystem, (c) the knowledge management subsystem, and (d) the dialogue subsystem. The data management subsystem contains pre-defined connections to internal and external data repositories. This subsystem is responsible for providing data required by other subsystems. For example, when a decision maker requires specific information about a particular IS project, the data management subsystem will coordinate the acquisition and delivery of the summarized data in the required format. The model base subsystem includes the fuzzy multicriteria group decision making algorithm presented above. This subsystem may include other analytical tools to analyze and evaluate IS projects. The knowledge management subsystem help the decision makers identify decision alternatives and make assessments. It is inter-connected with the company's knowledge base comprising of if-then rules [4]. The dialogue subsystem provides a user friendly interface for the decision makers to communicate with the DSS.

Using the proposed DSS to select IS projects involves three phases, including (a) pre-evaluation, (b) performance assessment, and (c) decision analysis and reporting, as shown in Fig. 1. The pre-evaluation phase is used to identify the selection criteria and to determine the project alternatives, as described in Section 2. The performance assessment phase is used to define individual linguistic terms and their corresponding triangular fuzzy numbers, and to determine the criteria weights and performance ratings of project alternatives. In determining the criteria weight, the decision maker can carry out sensitive analysis on weights. In practical applications, all assessments with respect to criteria importance and alternative performance are not always fuzzy. This is because the criteria may include both quantitative and qualitative measures that satisfy the objective of the problem and the judgment of the decision maker [30]. As such, both crisp and fuzzy data are present simultaneously in a specific multicriteria selection problem [31].

The criteria weight and performance ratings of project alternatives can be assessed by a crisp value or using a linguistic term, depending on the assessment of the decision makers. To maintain the consistence of assessment data in both crisp and fuzzy forms, the decision makers' quantitative assessments are made using a crisp value in the range of 1 to 9. To make qualitative assessments, the decision makers use a set of linguistic terms. The decision makers can use the default settings given in Table 1 or define their own term set from the universe U = {excellent, very high, high to very high, high, fairly high, medium, fairly low, low, low to very low, very low, none}, which is available from the knowledge base of the DSS. The decision makers also have the option of defining the value range or the membership function of triangular fuzzy numbers to be used for representing the linguistic terms in their assessments. The DSS enables the decision makers to make both quantitative and qualitative assessments, because the fuzzy multicriteria group decision making algorithm developed in this paper for solving the IS project selection problem can handle both crisp and fuzzy assessment data.

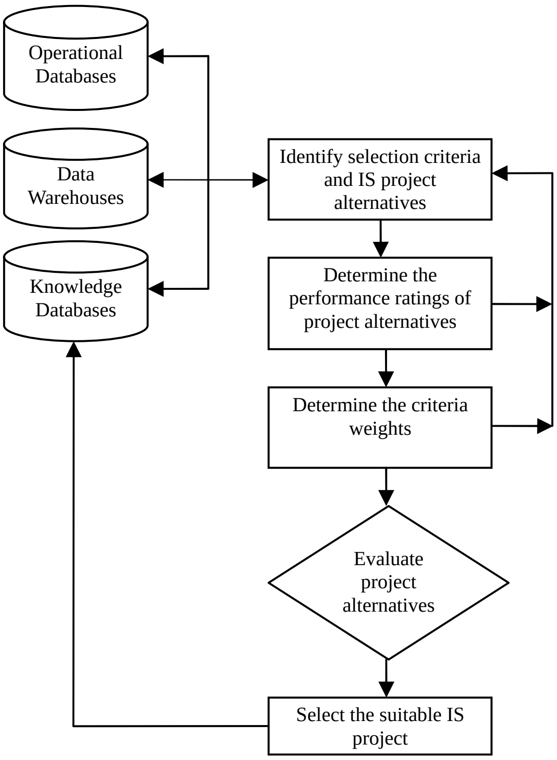

Figure 1. The DSS framework for IS project evaluation and selection.

In the decision analysis and reporting phase, the fuzzy multicriteria group decision making algorithm presented in Section 3 is applied to evaluate and select the most suitable IS project. The overall preference value of each IS project alternative, relative to other project alternatives, is obtained by aggregating the criteria weights and its performance ratings using the algorithm. Based on the overall preference value and ranking of all project alternatives, the most suitable IS project alternative can be recommended in a rational and justifiable manner.

5. An IS project selection problem

In multicriteria decision making research, the verification of the algorithms developed remains an open issue as the correct outcome of the selection problem is generally not known [32]. This is mainly due to two reasons. First, there are no objective measures of a decision maker’s values to which the results of an algorithm can be compared [33]. Second, there is no “right answer” for a given multicriteria decision making problem as the concept of an optimum does not exist in a multicriteria framework [34]. Although we cannot compare the new fuzzy multicriteria decision making algorithm developed with other algorithms based on the outcome of the selection problem, the new algorithm has a distinctive merit. It can solve the fuzzy multicriteria decision making problem effectively without applying the complex and unreliable process of fuzzy number comparison, which is usually required in other algorithms.

To demonstrate the applicability of the fuzzy multicriteria group decision making algorithm, an IS project selection problem at a high-technology manufacturing company is presented. The problem starts with the formation of a project selection committee consisting of three decision makers (D_1, D_2 and D_3) for selecting among three IS project alternatives (A_1, A_2 and A_3). A Delphi process is used to determine a set of selection criteria which meet the strategic objectives of the company. This process helps prioritize the criteria for reaching a consensus about the important criteria in selecting among a set of available IS projects. As a result of the process, five evaluation areas are identified, including organizational alignment, potential risk, financial attractiveness, vendor characteristics, and system flexibility.

Organizational alignment (C_1) reflects the perception of the decision makers on how individual IS project alternatives serve the overall long-term business strategy and organizational objectives in a competitive environment. This is measured by the contribution to the organizational objectives (C_{11}), importance to the organizational profile (C_{12}), relevance to critical success factors (C_{13}), and aid for organizational competitiveness (C_{14}).

Potential risk (C_2) is related to the potential of failure of the IS project. Issues such as the technical risk (C_{21}), the risk of cost overruns (C_{22}), and the project size risk (C_{23}) are taken into account.

Financial attractiveness (C_3) is concerned with the economical feasibility of the IS project with respect to the resource limitations of the company and its business strategy [1]. It is measured by the project cost (C_{31}), the contribution of the project to organizational profitability (C_{32}), and the project’s growth rate (C_{33}).

Vendor characteristics (C_4) are concerned with the decision maker’s confidence in vendors’ products and services. Issues such as the vendor’s ability (C_{41}), the implementation and maintenance (C_{42}), the consulting service (C_{43}), and the reputation (C_{44}) are considered.

System flexibility (C_5) is about the system capabilities in its responsiveness and adaptability to accommodate the company’s specific needs. This is measured by the upgrade capability (C_{51}), the ease of integration (C_{52}), and the ease of in-house development (C_{53}).

Table 2. Performance assessments of alternative IS projects and criteria weights.

Criteria	Project A_1			Project A_2			Project A_3			Criteria weight		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
C_{11}	VG	G	VG	VG	VG	VG	G	VG	VG	VH	VH	VH
C_{12}	G	VG	VG	VG	VG	G	G	G	VG	VH	VH	VH
C_{13}	VG	VG	VG	G	VG	VG	G	VG	VG	VH	VH	H
C_{14}	VG	G	G	VG	G	VG	VG	G	G	VH	VH	VH
C_{21}	VG	VG	G	VG	VG	G	G	G	G	VH	H	VH
C_{22}	G	VG	G	VG	VG	G	G	VG	VG	VH	H	VH
C_{23}	G	VG	VG	G	VG	VG	VG	VG	VG	VH	VH	VH
C_{31}	VG	VG	VG	G	VG	VG	G	VG	G	VH	VH	H
C_{32}	G	VG	VG	G	VG	VG	G	VG	G	VH	VH	VH
C_{33}	VG	G	VG	VG	G	VG	G	VG	VG	VH	VH	H
C_{41}	G	VG	G	G	G	G	G	G	G	H	H	VH
C_{42}	VG	VG	G	G	VG	G	G	G	G	VH	VH	VH
C_{43}	G	VG	G	G	VG	VG	VG	G	G	H	VH	VH
C_{44}	VG	G	G	G	G	VG	VG	VG	VG	H	H	VH
C_{51}	VG	G	VG	VG	G	VG	G	VG	VG	VH	H	VH
C_{52}	G	VG	G	VG	G	G	VG	G	G	VH	VH	VH
C_{53}	VG	VG	G	G	VG	G	G	VG	G	VH	VH	H

The 17 measures identified for the five evaluation areas are the evaluation criteria for the selection problem. These criteria are independent of each other, thus suitable for use in the utility-based multicriteria decision making algorithm developed above. Using the linguistic terms defined in Table 1, the performance ratings of three IS project alternatives (A_1, A_2 and A_3) with respect to the 17 criteria are assessed by the three decision makers (D_1, D_2 and D_3). Columns 2-10 of Table 2 show the assessment results, which constitute three fuzzy decision matrices as given in (1). Using the linguistics terms defined in Table 1, the importance of the 17 criteria is assessed by the three decision makers. Columns 11-13 of Table 2 show the assessment results, which constitute three fuzzy weight vectors as given in (2).

Using the membership functions defined in Table 1 for the linguistic terms used in Table 2 for the fuzzy decision matrix and the fuzzy weight vector, the overall fuzzy decision matrix and the overall fuzzy weight vector of IS project alternatives can be calculated by (3) and (4) respectively. Table 3 shows the calculation results.

Table 3. The overall fuzzy decision matrix and the overall fuzzy weight vector of IS project alternatives.

Criteria	Project A_1	Project A_2	Project A_3	Criteria Weight
C_{11}	(6.33, 8.33, 9)	(7, 9, 9)	(6.33, 8.33, 9)	(7, 9, 9)
C_{12}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(7, 9, 9)
C_{13}	(7, 9, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)
C_{14}	(5.67, 7.67, 9)	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(7, 9, 9)
C_{21}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(5, 7, 9)	(6.33, 8.33, 9)
C_{22}	(5.67, 7.67, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)
C_{23}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(7, 9, 9)	(7, 9, 9)
C_{31}	(7, 9, 9)	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(6.33, 8.33, 9)
C_{32}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(7, 9, 9)
C_{33}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)
C_{41}	(5.67, 7.67, 9)	(5, 7, 9)	(5, 7, 9)	(5.67, 7.67, 9)
C_{42}	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(5, 7, 9)	(7, 9, 9)
C_{43}	(5.67, 7.67, 9)	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(6.33, 8.33, 9)
C_{44}	(5.67, 7.67, 9)	(5.67, 7.67, 9)	(7, 9, 9)	(5.67, 7.67, 9)
C_{51}	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)	(6.33, 8.33, 9)
C_{52}	(5.67, 7.67, 9)	(5.67, 7.67, 9)	(5.67, 7.67, 9)	(7, 9, 9)
C_{53}	(6.33, 8.33, 9)	(5.67, 7.67, 9)	(5.67, 7.67, 9)	(6.33, 8.33, 9)

The weighted fuzzy performance matrix can then be obtained by multiplying the fuzzy decision matrix by the fuzzy weighting vector in Table 3. Table 4 shows the weighted fuzzy performance matrix that represents the overall performance of each project alternative on each criterion.

The fuzzy maximum and fuzzy minimum with respect to each criterion across all project alternatives can then be determined by (9) and (10) respectively based on Table 4. Table 5 shows the result.

The degree of dominance (d_{ij}^{+}) of the fuzzy maximum over the weighted fuzzy performance of each project alternative, and the degree of dominance (d_{ij}^{-}) of the weighted fuzzy performance of each project alternative over the fuzzy minimum across all criteria can be calculated by (11)-(14). Table 6 shows the result.

Table 4. The weighted fuzzy performance matrix of IS project alternatives.

Criteria	Project A_1	Project A_2	Project A_3
C_{11}	(44.33, 75, 81)	(49, 81, 81)	(44.33, 75, 81)
C_{12}	(44.33, 75, 81)	(44.33, 75, 81)	(39.67, 69, 81)
C_{13}	(44.33, 75, 81)	(40.11, 69.44, 81)	(40.11, 69.44, 81)
C_{14}	(39.67, 69, 81)	(44.33, 75, 81)	(39.67, 69, 81)
C_{21}	(40.11, 69.44, 81)	(40.11, 69.44, 81)	(31.67, 58.33, 81)
C_{22}	(35.89, 63.89, 81)	(40.11, 69.44, 81)	(40.11, 69.44, 81)
C_{23}	(44.33, 75, 81)	(44.33, 75, 81)	(49, 81, 81)
C_{31}	(44.33, 75, 81)	(40.11, 69.44, 81)	(35.89, 63.89, 81)
C_{32}	(44.33, 75, 81)	(44.33, 75, 81)	(39.67, 69, 81)
C_{33}	(40.11, 69.44, 81)	(40.11, 69.44, 81)	(40.11, 69.44, 81)
C_{41}	(32.11, 58.78, 81)	(28.33, 53.67, 81)	(28.33, 53.67, 81)
C_{42}	(44.33, 75, 81)	(39.67, 69, 81)	(35.89, 63.89, 81)
C_{43}	(35.89, 63.89, 81)	(40.11, 69.44, 81)	(39.67, 69, 81)
C_{44}	(32.11, 58.78, 81)	(32.11, 58.78, 81)	(40.11, 69.44, 81)
C_{51}	(40.11, 69.44, 81)	(40.11, 69.44, 81)	(40.11, 69.44, 81)
C_{52}	(39.67, 69, 81)	(39.67, 69, 81)	(39.67, 69, 81)
C_{53}	(40.11, 69.44, 81)	(35.89, 63.89, 81)	(35.89, 63.89, 81)

Table 5. The fuzzy maximum and the fuzzy minimum.

Criteria	Fuzzy maximum $M^{j}_{\max}$	Fuzzy minimum $M^{j}_{\min}$
C_{11}	(44.33, 81, 81)	(44.33, 44.33, 81)
C_{12}	(39.67, 81, 81)	(39.67, 39.67, 81)
C_{13}	(40.11, 81, 81)	(40.11, 40.11, 81)
C_{14}	(39.67, 81, 81)	(39.67, 39.67, 81)
C_{21}	(31.67, 81, 81)	(31.67, 31.67, 81)
C_{22}	(35.89, 81, 81)	(35.89, 35.89, 81)
C_{23}	(44.33, 81, 81)	(44.33, 44.33, 81)
C_{31}	(35.89, 81, 81)	(35.89, 35.89, 81)
C_{32}	(39.67, 81, 81)	(39.67, 39.67, 81)
C_{33}	(40.11, 81, 81)	(40.11, 40.11, 81)
C_{41}	(28.33, 81, 81)	(28.33, 28.33, 81)
C_{42}	(35.89, 81, 81)	(35.89, 35.89, 81)
C_{43}	(35.89, 81, 81)	(35.89, 35.89, 81)
C_{44}	(32.11, 81, 81)	(32.11, 32.11, 81)
C_{51}	(40.11, 81, 81)	(40.11, 40.11, 81)
C_{52}	(39.67, 81, 81)	(39.67, 39.67, 81)
C_{53}	(35.89, 81, 81)	(35.89, 35.89, 81)

Table 6. The degree of dominance across IS project alternatives.

Criteria	d_{ij}^{+}			d_{ij}^{-}		
	Project A_1	Project A_2	Project A_3	Project A_1	Project A_2	Project A_3
C_{11}	2	1.6	2	10.2	13.8	10.2
C_{12}	0.4	0.4	4	13.3	13.3	9.8
C_{13}	0.6	3.9	3.9	13.0	9.8	9.8
C_{14}	4.0	0.4	4.0	9.8	13.3	9.8
C_{21}	1.0	1.0	7.6	15.4	15.4	8.9
C_{22}	5.7	2.4	2.4	9.3	12.6	12.6
C_{23}	2.0	2.0	1.6	10.2	10.2	13.8
C_{31}	0.8	2.4	5.7	15.9	12.6	19.4
C_{32}	0.4	0.4	4.0	13.3	13.3	9.8
C_{33}	3.9	3.9	3.9	9.8	9.8	9.8
C_{41}	6.1	9.1	9.1	11.4	8.4	8.4
C_{42}	0.8	2.7	5.7	15.9	12.3	9.3
C_{43}	5.7	2.4	2.7	9.3	12.6	12.3
C_{44}	7.4	7.4	1.2	8.9	8.9	15.1
C_{51}	3.9	3.9	3.9	9.8	9.8	9.8
C_{52}	4.0	4.0	4.0	9.8	9.8	9.8
C_{53}	2.4	5.7	5.7	12.6	9.3	9.3

The degree of dominance that the positive fuzzy ideal solution has on each alternative A_i and the degree of dominance that each alternative A_i has on the negative fuzzy ideal solution can then be determined by (15) and (16) respectively. Table 7 shows the result.

Table 7. The degree of dominance for IS project alternatives.

A_i	d_i^+	d_i^-
A_1	51.1	281.6
A_2	49.7	184.8
A_3	68.7	187.9

The overall preference value of each project alternative across all the criteria can be obtained by applying (17) to the data in Table 7. Table 8 shows the result, which suggests that A_1 is the most suitable project alternative.

Table 8. The overall preference value and ranking of IS project alternatives.

IS Project Alternative	Preference value	Ranking
A_1	0.97	1
A_2	0.93	2
A_3	0.88	3

6. Conclusion

Evaluating and selecting IS projects is a complex process, as it often involves multiple decision makers making subjective and imprecise assessments in relation to multiple IS project alternatives and multiple evaluation criteria. To address this complex issue, we have formulated the selection problem as a fuzzy multicriteria group decision making problem and developed an effective algorithm for solving the problem. The merits of the algorithm developed facilitate its incorporation into a group decision support system for solving practical IS project selection problems. With its simplicity in concept and computation, the algorithm is applicable to the general multicriteria evaluation and selection problem involving fuzzy assessments.

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