The Development of a Framework for Selecting a Management Information System

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The aim of this paper is to present a multiple-criteria decision-making method based on the fuzzy measure and fuzzy integral for selecting an information system project. The main point is that fuzzy integrals are able to model interaction between criteria in a flexible way for criteria aggregation in decision problems. In this paper, decision-makers' opinions are described by linguistic terms expressed in trapezoidal fuzzy numbers. After aggregating the fuzzy ratings of all decision-makers, the vertex method is applied to transform the aggregated fuzzy rating into a crisp value. And then, a new algorithm is developed to deal with the multiple-criteria decision-making problems. Finally, at the end of this paper a numerical example is given to demonstrate the procedure for the proposed method.

1 Introduction

In general, the development of any Information System (IS) project requires large investments of resources, such as human resources, computer software and hardware resources, operational procedures adjustments, and so on. Therefore, IS project selection is an important issue in any business activities (Lee and Kim, 2001; Santhanam and Kyparisis, 1995). The optimal selection of a set of IS projects from among competing candidate projects is a significant resource allocation decision that enhance operational competitive advantages of a business. However, IS project selection is difficult due to there are lots of multiple factors in the candidate IS projects, such as business goals, benefits, project risks and limited available resources aforementioned.

Traditional project selection technologies highly focused on quantitative tools, such as discounted cash flow, net present value (NPV), return on investment (ROI) and payback period (Liberatore, 1987). These approaches transformed all economic and non-economic factors into monetary values, then, applied commercial estimation software to facilitate the evaluation process of cost-benefit analysis. The selection group usually select the best set of IS projects based on the estimation results. However, these approaches ignore multiple factors that impact project selection, and do not provide a useful transformative formula to combine all relevant project selection criteria into a single decision making model.

Although, human decision making process plays a significant role in our society. It is the process of finding the best option from all of the feasible alternatives. The best solution to the problem is the choice that offers the most satisfactory trade-offs in the individual decision-maker's opinion.

Therefore, multiple criteria scoring methods (Henriksen and Traynor, 1999) and ranking methods (Buss, 1983) are widely employed to improve the performance of project selection in businesses (Cooper et al., 1999; Lee and Kim, 2001), because they are very simple and easy to understand. These methods are used to score projects with respect to each of the evaluation objectives. Each objective is assigned a weight and each project is scored with respect to the objectives. The weighted scores are summed to give a total score. Therefore, projects which provide the highest benefits at the lowest level of resource consumption would get higher scores. Finally, projects selection is conducted by scores ranking. Buss (1983) attempted to provide alternative approach to project selection with the ranking technique. He indicated that projects can be ranked on a cost-benefit basis, followed by ranking according to intangible benefits, technical importance, and degree of fit with corporate objectives. Then, priorities of projects can be summarized and composite their rankings. Henriksen and Traynor (1999) proposed an improved scoring tool for R&D project selection. The improved algorithm is based on incorporating tradeoffs among the evaluation criteria and the project value measured by merit and cost. Then, project alternatives are ranked based on the criteria of relevance, risk, reasonableness and return.

Recently, the analytic hierarchy process (AHP), proposed by Saaty (1990), is employed to guarantee that assigned weights of each objective is suitable. The design of the hierarchy involves structuring all the problem elements. Then, the elements in a level of the hierarchy are compared in pair-wise comparisons with other elements. A relative ranking of priorities of the elements is yielded and aggregated to obtain the final ranking score. AHP has been applied to solve unstructured problems ranging from simple personal decisions to complex IS project selection problems. Brenner (1994) then employed AHP for selecting and weighting suitable criteria in R&D project priority determination. Khalil (2002) applied AHP to select the most appropriate project delivery method. The proposed AHP allows decision makers to consider and determine all relevant factors influences to the final decision, then, assess the relative weights assigned to each factor. Therefore, the decision reflected the owner's needs and preferences could be made.

The limitation of scoring methods, ranking methods and AHP methods is compensatory bias, i.e., resource constraints have not been considered. For example, when one criterion has a low value, other criteria may offset it, then, a project with a high weighted score might be accepted even if it is poor in one of its objectives. In order to overcome optimization problems, mathematical programming models have been proposed, such as multi-objective decision making (Schniederjans and Santhanam, 1993), goal programming (Badri et al., 2001), dynamic programming (Nemhauser and Ullmann, 1969), quadratic programming (Weber et al., 1990), and nonlinear programming (Santhanam and Kyparisis, 1995). These models consider multiple objectives, moreover, some of them also consider resources constraints. Firstly, those candidate projects are characterized by multiple objective functions, which are employed to integrate the multiple objectives into a single objective function. Then, the relative value of each project is calculated from the single objective function. Secondly, optimization process of these models is implemented based on the relative value of each project, and satisfying constraints if existed. Usually, decision makers refrain from such techniques, not only due to complex implementing processes, but also the main fault of mathematical programming methods need for crisp data to get meaningful results. However, IS project selection takes place under incomplete, vague (intangible), and uncertain information environment. For instance, some factors like "importance to user" are subjective and difficult to measure. Meanwhile, the linear combination form was used as the mathematical model to approximate the human decision process. This so-called linear model is obviously inadequate, since human subjective evaluation does not always hold linearity (Chen and Tzeng, 2001). Bellman and Zadeh (1970) question the assumption in decision theory that imprecision can be equated with randomness (equal importance to any user is impractical). In addition, many selection processes environmental impacts are omitted from direct consideration since they are difficult to measure quantitatively, such as project risk, organizational objectives, and user support. Even systems that are considered technically sound may run a high risk of failure when the behavioral, political and other organizational concerns are overlooked (Ewusi-Mensah and Przasnyski, 1991). Qualitative issues are becoming more critical to the organization than ever (Ragowsky et al., 1996).

Fuzzy logic has been employed in handling inexact and vague information because of its ability to utilize natural languages in terms of linguistic variables (Ghotb and Warren, 1995). Many decision-making processes occur in an environment in which the goals, constraints and consequences of possible actions are not precisely known. Due to imprecise and subjective information that often appears in an IS project selection process aforementioned, crisp values are inadequate for solving the selection problems. A more realistic approach may be to use linguistic assessments instead of numerical values (Bellman and Zadeh, 1970; Chen, 2000; Herrera and Herrera-Viedma, 2000). A set scale of linguistic variables can be presented to the decision-makers, who can then use it to describe their opinions. Sugeno (1974) presented the theory of fuzzy measures and fuzzy integrals as means to express fuzzy systems and further proposed to use his theory in modeling human subjective evaluation process. Hence, human subjective ratings can be better approximated using fuzzy measures than using the additive ones.

In this paper, the vertex method (Chen, 2000) is applied to calculate the distance between two fuzzy numbers. The vertex method is an effective and simple approach to calculate the distance between two trapezoidal fuzzy numbers. After calculating the aggregated fuzzy rating of all decision-makers, a distance value is calculated between the aggregated fuzzy rating and the fuzzy max rating. The separation degree is calculated between the aggregated fuzzy rating and the fuzzy min rating. Then, a ranking index value is defined based on the two distance values to transform the aggregated fuzzy rating into a crisp value. And then, an IS project decision-making method is proposed based on fuzzy integral in this paper.

To further complicate such IS project selection situations, determining the best course of action may not be the responsibility of a single individual. In general, decision making by multiple decision-makers is commonplace in most IS project selections. In short, such a project selection problem is a group multiple-criteria decision-making (GMCDM) problem. In formal terms, GMCDM problems may be described by means of the following sets: (i) a set of K decision-makers called $E = \{D_1, D_2, \cdots, D_K\}$; (ii) a set of m possible alternatives called $A = \{A_1, A_2, \cdots, A_m\}$; (iii) a set of n criteria, $C = \{C_1, C_2, \cdots, C_n\}$, with which alternative performances are measured; (iv) a set of performance ratings of $A_i (i = 1,2,\ldots,m)$ with respect to criteria $C_j (j = 1,2,\ldots,n)$, called $X = \{x_{ij}, i = 1,2,\ldots m \quad j = 1,2,\ldots,n\}$.

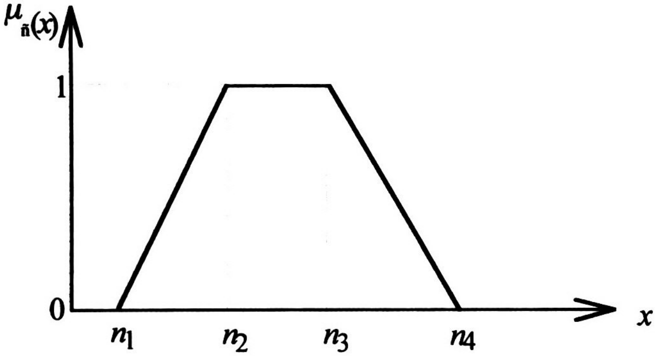
This paper is structured as follows. Section 2 introduces the basic definitions and notations of the fuzzy number, fuzzy measure and fuzzy integral. In Section 3, a systematic method based on fuzzy integral is presented to solve GMCDM problems. In Section 4, the proposed method is illustrated with an example. Finally, some conclusions are stated at the end of the paper.

2 Basic Definitions and Notations

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$, which associates with each element x in X a real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal (Zimmermann, 1991).

Definition 2.1. A positive trapezoidal fuzzy number (PTFN) $\tilde{n}$ can be defined as (n_1, n_2, n_3, n_4), shown in Fig. 1.

Figure 1 Trapezoidal fuzzy number $\tilde{n}$.



The membership function, $\mu_{\tilde{n}}(x)$, is defined as,

$$\mu_{\tilde{n}}(x)=\begin{cases} 0 & , \quad x<n_1 \\ \dfrac{x-n_1}{n_2-n_1} & , \quad n_1 \le x \le n_2 \\ 1 & , \quad n_2 \le x \le n_3 \\ \dfrac{x-n_4}{n_3-n_4} & , \quad n_3 \le x \le n_4 \\ 0 & , \quad n_4<x \end{cases} \tag{1}$$

For a trapezoidal fuzzy number $\tilde{n}=(n_1,n_2,n_3,n_4)$, if $n_2=n_3$ then $\tilde{n}$ is called a triangular fuzzy number. Let $\tilde{m}=(m_1,m_2,m_3,m_4)$ and $\tilde{n}=(n_1,n_2,n_3,n_4)$ be two trapezoidal fuzzy numbers. Then the distance between them can be calculated by using the vertex method (Chen, 2000) as

$$d_v(\tilde{m},\tilde{n})=\sqrt{\frac{1}{4}[\,m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2+(m_4-n_4)^2\,]}\,. \tag{2}$$

Definition 2.2. A linguistic variable is a variable whose values are expressed in linguistic terms. For example, "weight" is a linguistic variable whose values are very low, low, medium, high, very high, etc. These linguistic values can also be represented by fuzzy numbers.

Definition 2.3. Consider a set of evaluation criteria $X=\{C_1,C_2,\ldots,C_n\}$. If a function $g:2^X \rightarrow [0,1]$ has the following properties, g is called a fuzzy measure.

$$g(\phi)=0\,,\,g(X)=1\,. \tag{3}$$

$$A,B\in 2^X\,,A\subset B \rightarrow g(A)\le g(B)\,. \tag{4}$$

Definition 2.4. If a fuzzy measure g_λ has the following properties, then g_λ is a λ-measure. If A, $B\in 2^X$ and $A \cap B=\phi$, then

$$g_\lambda(A\cup B)=g_\lambda(A)+g_\lambda(B)+\lambda g_\lambda(A)g_\lambda(B)\,. \tag{5}$$

where $\lambda\in[-1,\infty)$.

According to the definition of g_λ, the finite set $X=\{C_1,C_2,\ldots,C_n\}$ mapping to function g_λ can be written as

$$\begin{aligned} g_\lambda(\{C_1,\ldots,C_n\}) &= \sum_{i=1}^{n} g_i+\lambda\sum_{i1=1}^{n-1}\sum_{i2=i1+1}^{n} g_{i1}g_{i2}+\ldots+\lambda^{n-1}g_1g_2,\ldots,g_n \\ &= \frac{1}{\lambda}\left|\prod_{i=1}^{n}(1+\lambda g_i)-1\right| \end{aligned} \quad . \tag{6}$$

where $\lambda\in[-1,\infty)$.

Because $g_\lambda(X)=1$, the Eq.(6) can be written as

$$\lambda+1=\prod_{i=1}^{n}(1+\lambda g_i)\,. \tag{7}$$

According to the λ value and applying Eq.(6), one can compute the fuzzy measure of each subset of X.

3 Proposed fuzzy method

A systematic approach to solve the group decision-making problem in a fuzzy environment is proposed in this section. Because linguistic assessments merely approximate the subjective judgment of decision-makers, one can consider linear trapezoidal membership functions to be adequate for capturing the vagueness of these linguistic assessments (Delgado et al., 1998; Herrera and Herrera-Viedma, 2000). It is suggested in this paper that the decision-makers use the linguistic variables shown in Tables 1 and 2 to evaluate the importance of the criteria and the ratings of alternatives with respect to each criteria.

Assume that a decision group has K decision makers. Let the fuzzy rating and importance weight of the k-th decision maker be $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk})$ and $\tilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4})$, $i = 1,2,\ldots,m$, $j = 1,2,\ldots,n$, respectively. Hence, the aggregated fuzzy ratings ($\tilde{x}_{ij}$) of alternatives with respect to each criterion can be calculated as

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij}). \quad (8)$$

where $a_{ij} = \min_k \{a_{ijk}\}$ $b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}$, $c_{ij} = \frac{1}{K}\sum_{k=1}^{K} c_{ijk}$, $d_{ij} = \max_k \{d_{ijk}\}$

The aggregated fuzzy weights ($\tilde{w}_j$) of each criterion can be calculated as

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}). \quad (9)$$

where $w_{j1} = \min_k \{w_{jk1}\}$ $w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2}$, $w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3}$, $w_{j4} = \max_k \{w_{jk4}\}$

Table 1 Linguistic variables for importance weight of each criterion

Extremely Low (EL)	(0, 0, 0, 0)
Very Low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1.0, 1.0)
Extremely High (EH)	(1.0, 1.0, 1.0, 1.0)

Table 2 Linguistic variables for ratings

Extremely Poor (EP)	(0, 0, 0, 0)
Very Poor (VP)	(0, 0, 1, 2)
Poor (P)	(1, 2, 2, 3)
Medium Poor (MP)	(2, 3, 4, 5)
Fair (F)	(4, 5, 5, 6)
Medium Good (MG)	(5, 6, 7, 8)
Good (G)	(7, 8, 8, 9)
Very Good (VG)	(8, 9, 10, 10)
Extremely Good (EG)	(10,10,10,10)

To avoid complexity of mathematical operations in a decision process, the linear scale transformation is used here to transform the various criteria scales into comparable scales. The set of criteria can be divided into benefit criteria (the larger the rating, the greater the preference) and cost criteria (the smaller the rating, the greater the preference). Therefore, the normalized fuzzy rating can be represented as

$$\tilde{r}_j = \left(\frac{a_j}{d_j^*}, \frac{b_j}{d_j^*}, \frac{c_j}{d_j^*}, \frac{d_j}{d_j^*}\right), \text{ if } j \in B \tag{10}$$

$$\tilde{r}_j = \left(\frac{a_j^-}{d_j}, \frac{a_j^-}{c_j}, \frac{a_j^-}{b_j}, \frac{a_j^-}{a_j}\right), \text{ if } j \in C \tag{11}$$

$$d_j^* = \max_i d_j, \text{ if } j \in B \tag{12}$$

$$a_j^- = \min_i a_j, \text{ if } j \in C. \tag{13}$$

where B and C are the sets of benefit criteria and cost criteria, respectively.

The normalization method mentioned above is to preserve the property in which the elements $\tilde{r}_j, \forall i, j$ are normalized trapezoidal fuzzy numbers. These elements $\tilde{r}_j$ can be represented as $\tilde{r}_j = (r_{j1}, r_{j2}, r_{j3}, r_{j4})$ for all *i, j*. Because $\tilde{r}_j$ and $\tilde{w}_j$ for all *i, j* are normalized trapezoidal fuzzy numbers, the fuzzy max rating ($\tilde{P}^*$) and fuzzy min rating ($\tilde{P}^-$) are defined as $\tilde{P}^* = (1,1,1,1)$ and $\tilde{P}^- = (0,0,0,0)$.

Therefore, the distance between $\tilde{r}_j$ and $\tilde{P}^*$, $\tilde{w}_j$ and $\tilde{P}^*$ can be defined as Eq.(14) and Eq.(15) respectively,

$$d_j^* = d_v(\tilde{r}_j, \tilde{P}^*). \tag{14}$$

$$wd_j^* = d_v(\tilde{w}_j, \tilde{P}^*). \tag{15}$$

where $d_v(*,*)$ is the distance between two fuzzy numbers.

Then, the distance between $\tilde{r}_j$ and $\tilde{P}^-$, $\tilde{w}_j$ and $\tilde{P}^-$ can be defined as Eq.(16) and Eq.(17) respectively,

$$d_j^- = d_v(\tilde{r}_j, \tilde{P}^-). \tag{16}$$

$$wd_j^- = d_v(\tilde{w}_j, \tilde{P}^-). \tag{17}$$

A ranking index is defined to transform $\tilde{r}_j$ and $\tilde{w}_j$ into crisp values. The ranking indices of each $\tilde{r}_j$ and $\tilde{w}_j$ are defined as Eq.(18) and Eq.(19) respectively,

$$RI_j = \frac{d_j^-}{d_j^- + d_j^*}, \tag{18}$$

$$RW_j = \frac{wd_j^-}{wd_j^- + wd_j^*}, \tag{19}$$

where RI_{ij} is the transformation value of $\tilde{r}_j$, and RW_j is the transformation value of $\tilde{w}_j$. The final evaluation of alternative A_i can be determined by using fuzzy integral (Asai, 1995), once RI_{ij} and RW_j have been calculated. Let $RI_{i1} \geq RI_{i2} \geq \cdots \geq RI_{in}$, then the fuzzy integral evaluation of alternative A_i (see Fig. 2) is calculated as

$$\begin{aligned} FI_i = (C)\int h\,dg = RI_{in}g(H_n) + \left[RI_{in} - RI_{i(n-1)}\right]g(H_{n-1}) + \ldots + \left[RI_{i1} - RI_{i2}\right]g(H_1) \\ = RI_{in}\left[g(H_n) - g(H_{n-1})\right] + RI_{i(n-1)}[g(H_{n-1}) - g(H_{n-2})] + \ldots + RI_{i1}g(H_1) \end{aligned} \quad (20)$$

where $H_n = \{C_1, C_2, \ldots, C_n\}$, $g(H_1) = g_\lambda\{C_1\} = RW_1$.

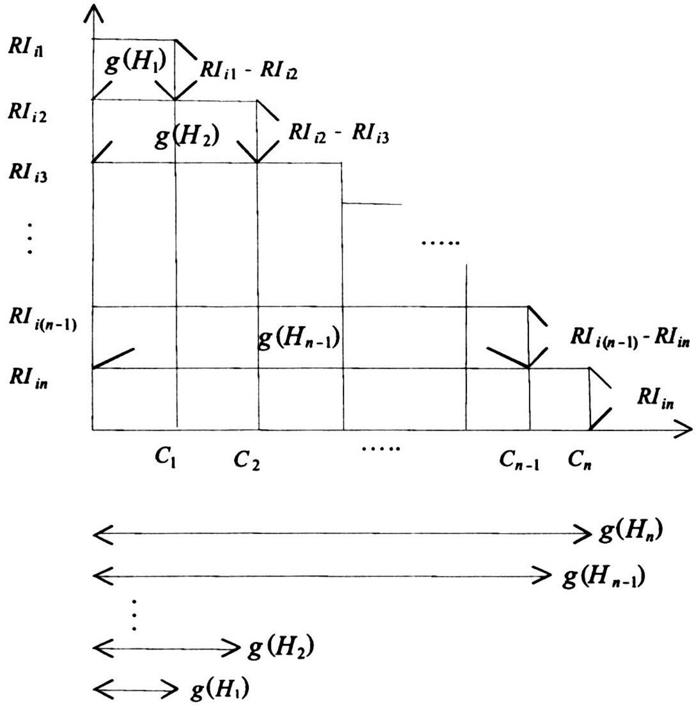
4 Numerical example

Displayed equations should be numbered consecutively in each section, with the number set flush right and enclosed in parentheses. They are to be centered on the page width. Standard English letters like x are to appear as *x* (italicized) in the text if they are used as mathematical symbols. Punctuation marks are used at the end of equations as if they appeared directly in the text.

Three benefit criteria are considered: (1) company profitability (C_1); (2) market conditions (C_2); (3) probability of technical success (C_3).

The proposed method is currently applied to solve this problem, and the computational procedure is summarized as follows:

Figure 2 The fuzzy integral computation of alternative A$_i$



Step 1. The decision-makers use the linguistic weighting variables shown in Table 1 to assess the importance of the criteria. The importance weights of the criteria by three decision-makers are shown in Table 3.

Step 2. The decision-makers use the linguistic rating variables shown in Table 2 to evaluate the rating of alternatives with respect to each criterion. The ratings of the three candidates by decision-makers under the criteria are shown in Table 4.

Step 3. The linguistic evaluations shown in Tables 3 and 4 are converted into trapezoidal fuzzy numbers and determine the aggregated fuzzy rating and fuzzy weight of each criterion, as in Table 5.

Step 4. The normalized fuzzy ratings of all criteria are shown as in Table 6.

Step 5. The transformation values of all normalized fuzzy ratings are constructed as in Table 7.

Table 3 Importance weight of criteria from three decision-makers

		Decision-makers		
		D_1	D_2	D_3
Criteria	C_1	H	H	H
	C_2	VH	VH	VH
	C_3	VH	VH	H

Table 4 Ratings of the three candidates by decision-makers under various criteria

Criteria	Alternatives	Decision-makers		
		D_1	D_2	D_3
C_1	A_1	MG	MG	MG
	A_2	G	G	G
	A_3	VG	G	G
C_2	A_1	MG	MG	VG
	A_2	G	G	G
	A_3	MG	G	G
C_3	A_1	MG	MG	MG
	A_2	VG	VG	G
	A_3	VG	VG	VG

Table 5 Aggregated fuzzy ratings and fuzzy weights of three alternatives

	C_1	C_2	C_3
A_1	(5,6,7,8)	(5,7,8,10)	(5,6,7,8)
A_2	(7,8,8,9)	(7,8,8,9)	(7,8.7,9.3,10)
A_3	(7,8.3,8.7,10)	(5,7.3,7.7,9)	(8,9,10,10)
Weight	(0.7,0.8,0.8,0.9)	(0.8,0.9,1,1)	(0.7,0.87,0.93,1)

Step 6. The transformation values of fuzzy weights of three criteria are computed as

$$RW_1 = 0.79.\ RW_2 = 0.89, \text{ and } RW_3 = 0.81 .$$

Step 7. The λ value of fuzzy measures can be computed as

$$1 + \lambda = (1 + 0.79\lambda)(1 + 0.89\lambda)(1 + 0.81\lambda) .$$

Then, $\lambda = -\ 0.999$.

Step 8. Because $RI_{12} \geq RI_{11} = \geq RI_{13}$, the fuzzy measures of alternative A_1 according to the λ value can be computed as

$$g_\lambda(C_2) = RW_2 = 0.89 ,$$

$$g_\lambda(C_2,C_1) = 0.89 + 0.79 - (0.999)(0.89)(0.79) = 0.98 ,$$

$$g_\lambda(C_2,C_1,C_3) = 1.0 .$$

Step 9. The fuzzy integral value of alternative A_1 can be computed as

$$FI_1 = 0.64 \times 1.0 + (0.64 - 0.64) \times 0.98 + (0.71 - 0.64) \times 0.89 = 0.70 .$$

Step 10. Repeating the same process of steps 8 and 9, the fuzzy integral values of alternatives A_2 and A_3 can be computed as $FI_2 = 0.86$ and $FI_3 = 0.87$.

According to the fuzzy integral values, the ranking order of the three alternatives is $A_3 > A_2 > A_1$.

5 Conclusions

In general, the criteria are not independent for dealing with the multiple-criteria decision-making problems. Moreover, the use of linguistic variables in decision problems is highly beneficial in a decision-making process when performance values cannot be expressed by means of numerical values. In other words, very often, in assessing of alternatives with respect to criteria and importance weights, it is appropriate to use linguistic

Table 6 Normalized fuzzy ratings of three criteria

	C_1	C_2	C_3
A_1	(0.5,0.6,0.7,0.8)	(0.5,0.7,0.8,1)	(0.5,0.6,0.7,0.8)
A_2	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.87,0.93,1)
A_3	(0.7,0.83,0.87,1)	(0.5,0.73,0.77,0.9)	(0.8,0.9,1,1)

Table 7 Transformation values of three criteria

	C_1	C_2	C_3
A_1	0.64	0.71	0.64
A_2	0.79	0.79	0.87
A_3	0.83	0.70	0.89

variables instead of numerical values. This paper has proposed a linguistic MCDM method based on fuzzy measures and integrals for IS project selection. The key point is that the non-additively of fuzzy measures enables the modeling of interaction between criteria. The proposed method has applied to solve a selection of IS (R&D) project selection problem for high-technology company. A result presented the proposed linguistic MCDM method is practical and useful.

Significantly, the proposed method provides more flexible and objective information in dealing with multi-criteria decision-making problems in a fuzzy environment. However, improving the approach for solving multi-criteria decision-making problems more efficiently and developing a decision support system in a fuzzy environment can be considered as a topic for future research.

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