AHP AND WAFGP HYBRID MODEL FOR INFORMATION SYSTEM PROJECT SELECTION

Mohammed Bellahcene[1]
LEPPESE Laboratory, Department of Economics
University Centre of Maghnia, Algeria
bellahcene_mohammed@yahoo.fr

Fatima-Zohara Benamar
Faculty of Economics and Management Sciences
University of Tlemcen, Algeria
benamar_fatimazohra@yahoo.fr

Mohammad Mekidiche
LEPPESE Laboratory, Department of Economics
University Centre of Maghnia, Algeria
mkidiche@yahoo.fr

ABSTRACT

The aim of this study is to propose an integrated Analytic Hierarchy Process (AHP) and Weighted Additive Fuzzy Goal Programming (WAFGP) method for the selection of information system projects that can use all types of linear membership functions and offer more flexibility. The proposed methodology includes three steps. First, an expert team was formed to identify the decision criteria and build a hierarchical model for the information system project selection. Then, the AHP was used to estimate the relative weights of the criteria. Finally, a WAFGP model was formulated and used to select the projects. A hypothetical example is given to show how to use this methodology and its advantages. In comparison to other approaches, the AHP-WAFGP hybrid model gives better support for information system project selection by selecting projects that make the best use of available resources and better satisfy the decision goals. Furthermore, the sensitivity analysis reveals that the proposed model is robust, adaptable, and not sensitive to small changes. Nevertheless, the proposed methodology does not include interdependencies among criteria and alternatives.

Keywords: project selection; information system; AHP; WAFGP

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1. Introduction

Today's contemporary knowledge-intensive environment that is characterized by increased competition and rapid, unpredictable and relentless changes has led organizations to explore new possibilities for detecting and avoiding emerging threats, exploiting market shifts (Mikalef & Pateli, 2017), and improving decision making (Chiang et al., 2018) to increase their competitive advantage and performance.

Among the different solutions which can be adopted by top management to address these challenges, the selection of information systems (IS) is particularly important. Indeed, ISs support operational tasks, streamlining and progress of organizational processes, decision making, and mechanization (Burkland & Zachariassen, 2014; Almajali, Masa'deh, & Tarhini, 2016). ISs can also improve a firm's performance and increase its competitive advantage by lowering costs, achieving economies of scale, or enhancing innovation and differentiation (Weber & Pliskin, 1996; Porter & Millar, 1985). Furthermore, ISs improve communication, participation, and collaboration (Chang & Wong, 2010, Deng et al., 2008; Lu, Huang, & Heng, 2006).

Despite its potential, IS project development is not a simple task. The success of this kind of project is influenced by different organizational, technological and environmental factors (Okumus et al., 2017; Tajudeen, Jaafar, & Ainin, 2018) that include the fit of business strategy and ICT projects (Strassmann, 1990; Strassmann, 1997; Chuang & Lin, 2017), software flexibility (Wang et al., 2008) or information technology capabilities (Ray, Muhanna, & Barney, 2005, Tarafdar & Qrunfleh, 2017; OuYang, 2017). Because of these variables and others, IS projects have a high risk of failure (Pan, Pan, & Devadoss, 2008). According to several studies and reports, more than 60% of IS projects do not meet their performance objectives (Clegg et al., 1997; The Standish Group, 2010; Brownsell, Blackburn, & Hawley, 2012; Kang, O'Brien, & Mulva, 2013). Wang et al. (2008) also emphasized that "Software projects continue to be plagued by budget overruns and a failure to produce software that meets expectations. Failure to meet cost budgets may adversely impact future resource allocation and failure to meet time considerations may hamper the firm's competitive posture."

Selecting IS projects that are in accordance with corporate objectives and then allocating resources to complete these projects gives rise to critical and complicated business activities (Samvedi et al., 2018). Indeed, these kinds of decisions engage organizations in substantial long-term commitments that require large investments of resources in skills and capabilities, computer software and hardware, operational procedure adjustments, and so on (Chena & Chengb, 2009). IS project selection is a multi-criteria decision making (MCDM) process because of the large number of alternatives and the need to integrate the views of multiple decision makers (Abdel-Basset, Atef & Smarandache, 2019). There are also multiple and often conflicting quantitative and qualitative attributes that are fuzzy and imprecise such as environmental conditions, corporate objectives, benefits, project risks, users' and decision makers' preferences, and the limited availability of IS resources. Finally, interdependencies among these alternatives and criteria should be taken into account.

During the last decades, several methodologies have been developed to overcome the IS project selection difficulties. For example, Schniederjans and Wilson (1991) have

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proposed an AHP zero-one linear programming methodology for budgetary and resource constraints. After that, Lee and Kim (2001) developed an integrated Delphi-ANP-ZOGP method to consider the degree of interdependency among IS projects. Finally, to deal with the imprecise data in IS projects and uncertain judgment of decision makers, Bolat et al. (2014) developed a hybrid model for fuzzy AHP using a fuzzy multi-objective linear programming model.

In spite of this progress, some weaknesses still characterize IS project selection methodologies. For example, Preemptive/Lexicographic Goal Programming (with priority), used in many studies, is not flexible when dealing with integer problems with many goals (Kim et al., 2009). Therefore, if the experiences of experts are collected to determine decision criteria weights, then using Weighted Goal Programming can be more flexible and give more credible results. Furthermore, the fuzzy goal programming (FGP) methods used in previous studies cannot use all types of linear membership functions (MFs). To overcome these limitations, the present study proposes an easier and more flexible method for IS project selection. A hybrid method in which the Analytic Hierarchy Process (AHP) proposed by Saaty (1980) is used to formulate the problem in a hierarchical structure and estimate the relative weights of the criteria from the subjective judgments of decision-makers is combined with the Weighted Additive Fuzzy Goal Programming (WAFGP) proposed by Yaghoobi et al. (2008) to incorporate the DM's preferences and trade-off aspiration levels between objectives.

The remainder of this research paper is structured as follows: section two presents the literature review, section three describes the proposed AHP-WAFGP model, section four provides data and results of an illustrative application for verification, section five explores the sensitivity, and section six provides the conclusions.

2. Literature review

During the last decades, several studies have been conducted that propose a methodology to overcome the difficulties of IS project selection and help organizations, companies and IT managers with their choices.

Initially, a single criterion cost/benefit analysis was suggested by King and Schrems (1978). Despite its advantages, this method only considers tangible or monetary criteria and skips intangible effects and attributes like risk, business process improvement, or user and decision-maker satisfaction (Liang & Li, 2008).

After that, different models using ranking (Buss, 1983), scoring (Lucas & Moore, 1976; Lootsma, Mensch, & Vos, 1990) and AHP (Muralidhar, Santhnanm, & Wilson, 1990) have been proposed as alternative approaches for IS project selection. In practice, these models have been used often to solve real problems because they are uncomplicated and easy to understand so decision-makers feel comfortable with them (Lee & Kim, 2001). Scoring models and AHP models incorporate all of the crucial factors to select projects and provide a quantitative measure that can be used directly to compare alternatives and choose those with the highest scores (Keeney & Raiffa, 1978). However, even if these models seem more effective than cost/benefit analysis models, they still have three major limitations. First, ranking, scoring and AHP methods do not apply to problems that have

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resource feasibility and optimization requirements. Second, these methods ignore the interdependencies (carried costs, additional benefits, etc.) that can exist between IS projects and selection criteria. Third, IS project selection takes place in an incomplete, vague, and uncertain information environment (Chena & Chengb, 2009). Therefore, almost all of the selection objectives and constraints take on a fuzzy and imprecise character.

In order to surmount these limitations, studies have proposed more effective methods. In two of the fundamental studies in this area Santhanam et al. (1989) and Schniederjans and Wilson (1991) proposed a zero-one linear programming (ZOGP) method and an AHP-ZOGP integrated approach to consider budgetary and resource constraints.

In a second approach, several studies proposed methodologies which consider interdependencies among IS projects and integrate both qualitative and quantitative factors. For example, Santhanam and Kyparisis (1996) proposed a nonlinear ZOGP model and Lee and Kim (2001) developed a hybrid method using Delphi-ANP-GP to estimate the degree of interdependency among IS projects. Kim et al. (2009) proposed an integrated ANP-Fuzzy logic methodology, and Zandi and Tavana (2010) developed a hybrid model that combines the technique for order preference by similarity to ideal solution (TOPSIS) with multi-objective decision-making (MODM) in order to consider both quantitative and qualitative attributes as well as the interdependencies among candidate projects.

A third set of studies tried to deal with the fuzzy and imprecise character of IS project selection objectives and constraints. Chena and Chengb (2009) built a multiple-criteria decision-making method (MCDM) for selecting an information system project based on fuzzy measures and the fuzzy integral.

To consider the vague, imprecise, and subjective judgments of decision makers, users and assessors, Gerogiannis et al. (2013), presented a selection/evaluation approach that applies a hybrid group decision making method based on TOPSIS and intuitionist fuzzy sets (IFS). Bolat et al. (2014) built a systematic and comprehensive model using the fuzzy analytical hierarchical process (FAHP) and fuzzy multi-objective linear programming (FMOLP). Elahi, Shamsi, and Ghatari (2016) proposed a hybrid method integrating: fuzzy evaluation, which merged a fuzzy expert system with TOPSIS and AHP. Toloo, Nalchigar, and Sohrabi (2018) and Toloo and Mirbolouki, (2019) developed a Data Envelopment Analysis method.

Finally, taking into account the indeterminacy and the imprecise nature of linguistic assessments, Yepez (2017) developed a model based on the single valued neutrosophic number (SVN-numbers); Alava et al. (2019) proposed an integrated method of SVN-numbers with AHP; and Leyva-Vazquez, et al. (2020) proposed a hybrid approach of a Balanced Scorecard Model, neutrosophic, AHP and zero-one linear programming.

In spite of this progress, some weaknesses still exist in IS project selection methodologies. According to Kim et al. (2009), Preemptive /Lexicographic Goal Programming (with priority) that is used in almost all of the studies is not flexible when dealing with integer problems with many goals. Therefore, if the experiences of experts are collected to determine decision criteria weights, then using Weighted Goal Programming can be more flexible and give more credible results. Furthermore, the FGP methods used in previous studies cannot use all types of linear MFs to determine the fuzzy objective values. To overcome these limitations, the present study proposes an easier and more flexible method for selecting IS projects. This method is a hybrid method in which the AHP proposed by Saaty (1980) is used to formulate the problem in a hierarchical structure and estimate the relative weights of the criteria from the subjective judgments of decision-makers, combined with the WAFGP proposed by Yaghoobi et al. (2008) to incorporate the DM's preferences and trade-off aspirations between objectives to complete the project selection decision.

3. Methodology

This paper proposes an integrated methodology for IS project selection that combines the two following multi-criteria decision-making methods: AHP and WAFGP.

Introduced by Saaty (1980), the AHP is a decision-making method used in physical and social fields (Saaty & Vargas, 2012), and in almost all applications related to decision-making (Vaidya & Kumar, 2006) to address the following three fundamental problems: group decision making, conflict resolution, and pairwise comparisons and neural activity (Moreno-Jiménez & Vargas, 2018). The AHP integrates and compares qualitative and quantitative factors, and objective and subjective factors based on the subjective judgments of the decision maker (Bahurmoz, 2019). This method breaks down a complex and unstructured situation into its different components (Islam & Anis, 2015) and reorganizes them into a hierarchical structure (Saaty, 1990) to determine the priority of a set of attributes and alternatives and their relative importance in a decision-making problem (Rouyendegh & Erkan, 2011).

In this study, we used the AHP to synthesize the decision goals, criteria, and alternatives in a hierarchical model. We used judgments in a pairwise comparison matrix to estimate the relative weights (relative importance) of criteria used in IS project selection.

Proposed by Yaghoobi et al. (2008), the WAFGP is a LP model that can use all types of linear membership functions (Figure 1) to determine the degree of MFs for every variable. After finding the relative weights of attributes, we used the WAFGP to complete the decision by optimizing project selection.

3.1 Select an expert team and build the decision hierarchical structure

In the first step, an expert team should be selected that includes a governing board member, the IS manager, a quality manager, IS external specialists (consultants), and other managers involved with the projects. This team identifies the decision criteria and constructs a hierarchical model for IS project selection. According to AHP principles, in the first stage, the IS project selection problem is decomposed into a multilevel hierarchical structure of objective, criteria and alternatives (Sharma, Moon, & Bae, 2008) with the goal at the top, followed by objectives with a broad perspective, then criteria, through intermediate levels of criteria (on which subsequent elements depend) to the lowest level which contains the alternatives (Saaty, 2008).

3.2 Use AHP to calculate the relative weights of each criterion

In the second step, the criteria are presented to an expert team to fill out the pairwise comparison judgment matrices. Team members gave their consensual verbal judgement from the fundamental AHP scales of equally important, moderately more important, strongly more important, very strongly more important, and extremely more important. These descriptive preferences are then respectively translated into the numerical values 1, 3, 5, 7, 9 (with 2, 4, 6, and 8 as intermediate values). Then, the reciprocals of these values are used for the corresponding transposed judgments (Atkinson, Bayazit, & Karpak, 2015). Insofar as the IS selection is a strategic decision, the governing board member has the last word and gives the final judgment when significant differences persist between the expert team members.

Once the criteria comparison matrices are constructed, the largest eigenvalue and the corresponding principle eigenvector of this matrix are calculated and normalized so that its entries sum to one. The normalized eigenvector represents the relative weights of the criteria. At the end of filling out each AHP pairwise comparison matrix with judgments, the inconsistency test should be applied as the inconsistency measure is useful for identifying and correcting possible errors with the entering of the judgments. Actual inconsistencies are also identified that may have to be ironed out with the participants (Cabala, 2010).

To measure the inconsistency level of the pairwise comparison matrix, the consistency index (CI) and consistency ratio (CR) are calculated using the following formula (Saaty, 1980; 1996; Li, Wang, & Tong, 2016):

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

where λ_{max} is the largest eigenvalue of the matrix, n is the number of items being compared in the matrix, and RI is the random index (Ebrahimnejad et al., 2012; Ohta, Salomon, & Silva, 2018).

According to Saaty and Vargas (2012), a CR of 0.10 or less is acceptable to continue the AHP analysis. If this indicator is greater than 0.10, judgments should be revisited to discover and correct the causes of the inconsistency (Mu & Pereyra-Rojas, 2017).

3.3 Use the WAFGP to complete the project selection decision

At the final stage, the relative weights of the criteria (given by the AHP) are used to formulate the WAFGP model to complete the project selection decision. As an extension of the Kim and Whang (1998) model, the WAFGP formulates FGP programming unequal weights as a single linear programing problem with the concept of tolerance.

In this step, the expert team should specify the fuzzy objective value interval and subjectively choose one of the four MFs used in the FAWGP for each objective or constraint (Torabi & Hassini, 2008; Liang & Cheng, 2009; Tamiz & Yaghoobi, 2010; Díaz-Madroñero et al., 2018) (Figure 1).

3.3.1. Left membership function

The MFs, also called the "larger is better" MFs, are used to maximize the result (Chen et al., 2018). For example, in IS project selection, MFs can be used for the benefits if decision makers believe that the higher the benefits, the better the optimal solutions. The mathematical formulation of these MFs is as follows:

$$\mu_i\,(AX)_i = \begin{cases} 1 \quad if \quad (AX)_i \geq b_i \\ 1 - \frac{b_i - (AX)_i}{\Delta_{iL}} \quad if \quad b_i - \Delta_{iL} \leq (AX)_i \leq b_i \;, i = i_0 + 1, \dots, j_0 \\ 0 \quad if\ (AX)_i \leq b_i - \Delta_{iL} \end{cases} \quad (3)$$

Where:

- $(AX)_i = \sum_{j=1}^{n} a_{ij} x_j \;,\; i = 1, \dots, k.$
- $(AX)_i$ is the MFs.
- μ_i Determines the degree of MFs for the ith fuzzy goal.
- for $i = i_0 + 1, \dots, j_0$, b_i is the imprecise aspiration level for the ith fuzzy goal.
- Δ_{iL} is the lower admissible violation from the imprecise aspiration levels.

3.3.2. Right membership function

In the case where results need to be minimized, "the smaller, the better" type of MFs can also be used (Chen et al., 2018). For example, such MFs can be used for costs where the smaller the costs, the better the optimal result. These MFs are formulated as:

$$\mu_i\,(AX)_i = \begin{cases} 1 \quad if \quad (AX)_i \leq b_i \\ 1 - \frac{(AX)_i - b_i}{\Delta_{iR}} \quad if \quad b_i \leq (AX)_i \leq b_i + \Delta_{iR} \;, \quad i = 1, \dots, i_0 \\ 0 \quad if\ (AX)_i \geq b_i + \Delta_{iR} \end{cases} \quad (4)$$

Where: Δ_{iR} is the upper admissible violation from the imprecise aspiration level.

3.3.3. Triangular membership function

Also known as the nominal-the-best MFs, this MF is selected when the decision makers want to exactly reach the target value (Al-Rafaie, 2015). In this case, the positive or negative deviations of the goal from a target value should be as small as possible. The mathematical formulation for this MF is as follows:

$$\mu_i\,(AX)_i = \begin{cases} 0 \quad if \quad (AX)_i \leq b_i - \Delta_{iL} \\ 1 - \frac{b_i - (AX)_i}{\Delta_{iL}} \quad if \quad b_i - \Delta_{iL} \leq (AX)_i \leq b_i \,, i = j_0 + 1, \dots, k_0 \\ 1 - \frac{(AX)_i - b_i}{\Delta_{iR}} \quad if \quad b_i \leq (AX)_i \leq b_i + \Delta_{iR} \\ 0 \quad if \quad (AX)_i \geq b_i + \Delta_{iR} \end{cases} \quad (5)$$

3.3.4. Trapezoidal membership function

Trapezoidal MFs are selected when the decision makers prefer setting the target value within a continuous interval (Al-Rafaie, 2015). This is defined as:

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$$\mu_i\,(AX)_i = \begin{cases} 0 \quad if \qquad (AX)_i \le b_i^l - \Delta_{iL} \\ 1 - \frac{b_i^l - (AX)_i}{\Delta_{iL}}\ if \quad b_i^l - \Delta_{iL} \le (AX)_i \le b_i^l \\ 1\ \ if \quad b_i^l \le (AX)_i \le b_i^u, i = k_0 + 1, \dots, k \\ 1 - \frac{(AX)_i - b_i^u}{\Delta_{iR}}\ if\ b_i^u \le (AX)_i \le b_i^u + \Delta_{iR} \\ 0 \quad if \quad (AX)_i \ge b_i^u + \Delta_{iR} \end{cases} \tag{6}$$

Where: for $= k_0 + 1, \dots, k$, b_i^l and b_i^u denote the imprecise lower and upper bounds for the fuzzy goal, respectively.

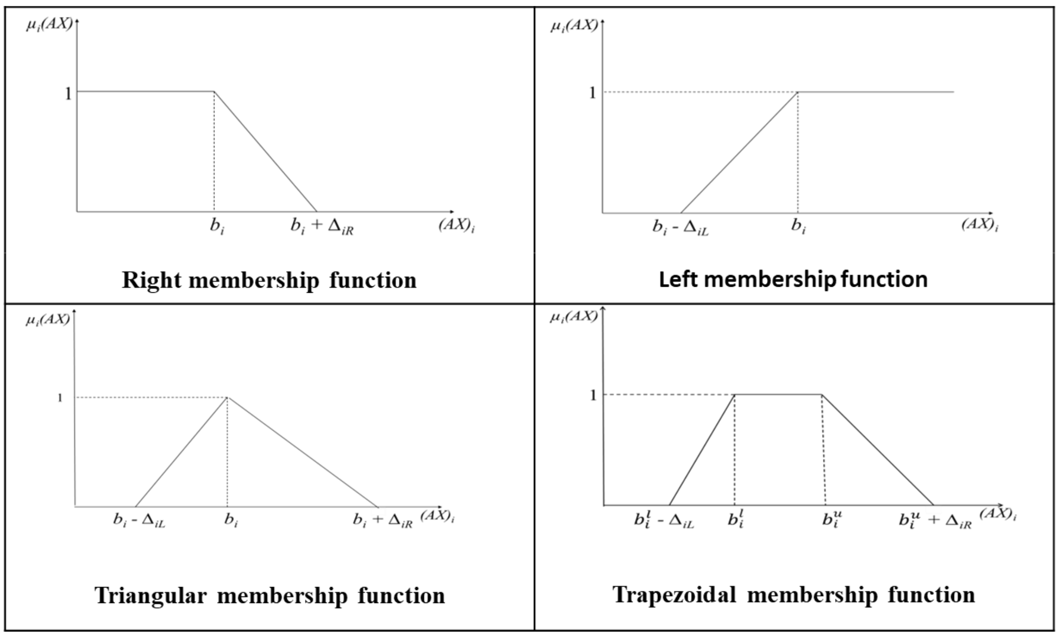

Figure 1 Linear membership function types

After selecting MFs to specify the fuzzy objective value for each objective or constraint, the data can be used in the WAFGP model to complete the project selection. The general formulation of this model is as follows:

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$$Min\, z = \sum_{i=1}^{i_0} w_i \frac{\delta_i^+}{\Delta_{iR}} + \sum_{i=i_{0}+1}^{j_0} w_i \frac{\delta_i^-}{\Delta_{iL}} + \sum_{i=j_0+1}^{K} w_i \left(\frac{\delta_i^-}{\Delta_{iL}} + \frac{\delta_i^+}{\Delta_{iR}} \right) \quad (7)$$

subject to:

$$(AX)_i - \delta_i^+ \le b_i \qquad , i = 1,2, \dots , i_0 \quad (8)$$

$$(AX)_i + \delta_i^- \ge b_i \qquad , i = i_0 + 1, \dots , j_0 \quad (9)$$

$$(AX)_i + \delta_i^- - \delta_i^+ = b_i \qquad , i = j_0 + 1, \dots , K \quad (10)$$

$$(AX)_i + \delta_i^- \ge b_i^l \qquad , i = K_0 + 1, \dots , K \quad (11)$$

$$(AX)_i - \delta_i^+ \le b_i^u \qquad , i = K_0 + 1, \dots , K \quad (12)$$

$$\mu_i + \frac{\delta_i^+}{\Delta_{iR}} = 1 \qquad , i = 1,2, \dots , i_0 \quad (13)$$

$$\mu_i + \frac{\delta_i^-}{\Delta_{iL}} = 1 \qquad , i = i_0 + 1, \dots , j_0 \quad (14)$$

$$\mu_i + \frac{\delta_i^-}{\Delta_{iL}} + \frac{\delta_i^+}{\Delta_{iR}} = 1 \qquad , i = j_0 + 1, \dots , K \quad (15)$$

$$\mu_i , \delta_i^- , \delta_i^+ \ge 0 \qquad , i = 1, \dots , K \quad (16)$$

$$x \in C_S \quad (17)$$

Where $Min\, z$ is the objective function, C_S is an optional set of hard constraints such as are found in LP; x is the decision variable; w_i denotes the weight of the fuzzy goal; δ_i^- , δ_i^+ represent the negative and positive deviations.

4. An illustrative application

To demonstrate the uses and advantages of the AHP and WAFGP hybrid model, a hypothetical example follows. Suppose that a firm has to choose five information systems projects from among ten alternatives, under the following criteria: mandated projects, benefit (B), hardware cost (C1), software cost (C2), annual cost of additional manpower (C4), other cost (C3), user preferences (S1), decision-maker preferences (S2), risk factor (R), completion time required (T1), and training time required (T2). Adapted from Badri et al. (2001), the basic data of goals achievement for each project and the maximum available resources are presented in Table 1.

4.1 Form the expert team and build a hierarchy model for IS project selection

To set priorities among selection criteria and to specify the membership functions and the fuzzy values for each objective, an expert team was formed that included a governing board member, the IS manager, quality manager, financial manager, network managers, database and software manager of an Algerian energy company, and three IS specialists (the researchers).

Next, the hierarchical model was constructed with the following levels: Level 0 presents the decision goal (select five IS projects), Level 1 includes the IS project selection criteria, and Level 2 contains the ten project alternatives (Figure 2).

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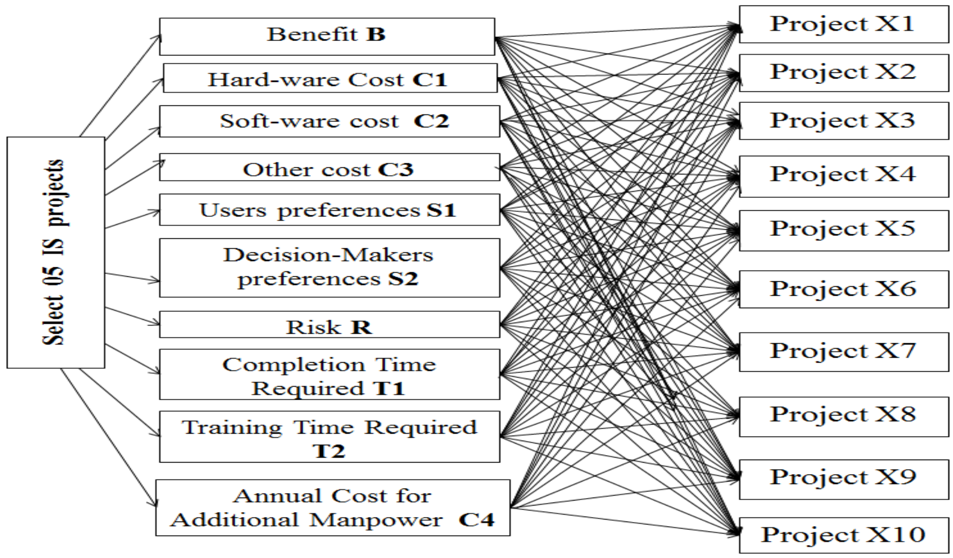

Figure 2 AHP hierarchy

4.2 Use AHP to calculate the relative weights of each criterion (attribute)

In the next step, decision attributes and alternatives were presented to the project team to reach a group consensus about each value judgement and arrive at a unique judgment matrix for prioritizing the criteria. Then, the SuperDecisions software was used to determine the normalized weights and synthesize the results. Table 2 lists the pairwise comparison judgment matrices, the relative weights of attributes and the consistency ratio. The consistency ratio was under the upper limit of 0.10 (0.06063); which means that decision makers were adequately consistent in ranking the attributes.

4.3 Formulate the WAFGP and complete the project selection decision

Once the criteria weights were calculated, the team members specified the type and the data for the membership functions to be used for each objective. As seen in Table 3, the expert team wanted to maximize the benefits, user preferences and decision-makers preferences. They assigned a left membership for these objectives and estimated their lower admissible violation from the imprecise aspiration levels respectively at 10000, 10 and 10. The experts also wanted to minimize hardware cost, software cost, other cost, risk, completion time, training time, and cost of additional manpower. They assigned a right membership for these objectives and estimated their upper admissible violation from the imprecise aspiration levels respectively at 20000, 10000, 300, 200000, 450, 500, and 100.

After that, and based on the collected information (exposed in the Tables 1, 2 and 3), the WAFGP model for IS project selection was formulated as follows:

$$Min\ Z = 0.13747\left[\frac{n_1}{10000}\right] + 0.18798\left[\frac{p_2}{20000}\right] + 0.18798\left[\frac{p_3}{10000}\right] + 0.09023\left[\frac{p_4}{300}\right] + 0.13392\left[\frac{p_5}{200000}\right] + 0.03521\left[\frac{n_6}{10}\right] + 0.03074\left[\frac{n_7}{10}\right] + 0.06653\left[\frac{p_8}{450}\right] + 0.05591\left[\frac{p_9}{500}\right] + 0.07404\left[\frac{p_{10}}{100}\right] \quad (18)$$

subject to:

$$\sum_{i=1}^{10} B_i\ x_i\ + n_1\ \geq 48000 \quad (19)$$

$$\sum_{i=1}^{10} H_i\ x_i\ - p_2\ \leq 65000 \quad (20)$$

$$\sum_{i=1}^{10} S_i\ x_i\ - p_3\ \leq 28000 \quad (21)$$

$$\sum_{i=1}^{10} O_i\ x_i\ - p_4\ \leq 360 \quad (22)$$

$$\sum_{i=1}^{10} r_i\ x_i\ - p_5\ \leq 0 \quad (23)$$

$$\sum_{i=1}^{10} PRD_i\ x_i\ + n_6\ \geq 47 \quad (24)$$

$$\sum_{i=1}^{10} PRU_i\ x_i\ + n_7\ \geq 49 \quad (25)$$

$$\sum_{i=1}^{10} t_i\ x_i\ - p_8\ \leq 0 \quad (26)$$

$$\sum_{i=1}^{10} tt_i\ x_i\ - p_9\ \leq 0 \quad (27)$$

$$\sum_{i=1}^{10} m_i\ x_i\ - p_{10}\ \leq 1100 \quad (28)$$

$$\mu_1 + \frac{1}{10000} = 1 \quad (29)$$

$$\mu_2 + \frac{1}{20000} = 1 \quad (30)$$

$$\mu_3 + \frac{1}{10000} = 1 \quad (31)$$

$$\mu_4 + \frac{1}{300} = 1 \quad (32)$$

$$\mu_5 + \frac{1}{200000} = 1 \quad (33)$$

$$\mu_6 + \frac{1}{10} = 1 \quad (34)$$

$$\mu_7 + \frac{1}{10} = 1 \quad (35)$$

$$\mu_8 + \frac{1}{450} = 1 \quad (36)$$

$$\mu_9 + \frac{1}{500} = 1 \quad (37)$$

$$\mu_{10} + \frac{1}{100} = 1 \quad (38)$$

$$x_1\ = 1 \quad (39)$$

$$\sum_{1=1}^{10} x_i\ = 5 \quad (40)$$

$$x_i\ = 0\ or\ 1; i = 1,2, \dots ,10.$$

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Table 1
Model data inputs

Project	Mandated	Benefit*	Hard-ware cost*	Soft-ware cost*	Other cost*	Decision makers preferences	Users preferences ***	Risk factor ****	Completion time**	Training time**	Annual cost for additional manpower*
1	Yes	1774	1900	3800	00	9.336	9.762	3	50	90	500
2	No	1349	11500	2254	160	9.305	9.638	3	43	18	286
3	No	40600	29500	16020	00	9.349	9.773	4	90	19	545
4	No	1200	21000	7800	18	7.727	8.008	3	60	66	29
5	No	5000	20000	750	190	9.272	9.505	2	83	84	294
6	No	3000	14000	44	20	8.661	9.517	2	67	136	100
7	No	2090	320	16000	00	9.206	9.377	3	91	69	00
8	No	1300	500	1000	30	8.604	9.286	3	97	119	00
9	No	1320	1200	3300	08	7.552	8.193	2	28	61	39
10	No	1720	00	2500	10	7.481	8.002	2	36	24	23
Max available	…….	48000	65000	28000	360	47	49	00	00	00	1100

* In 1000$. ** Required in days ***Means of scores estimated on a scale of 0-10 ****Scored on a scale of 0-10

Table 2
Pairwise comparison judgment matrices and relative weights of criteria

	C1	C2	C3	C4	B	R	T1	T2	S1	S2
C1	1	1	3	3	2	2	3	4	3	3
C2	1	1	3	3	2	2	3	4	3	3
C3	1/3	1/3	1	2	1/2	1/3	2	3	3	3
C4	1/3	1/3	½	1	1/2	1/3	3	2	3	3
B	1/2	1/2	2	2	1	2	2	3	4	4
R	1/2	1/2	3	3	1/2	1	2	3	4	4
T1	1/3	1/3	½	1/3	1/2	1/2	1	2	3	3
T2	1/4	1/4	1/3	1/2	1/3	1/3	1/2	1	4	4
S1	1/3	1/3	1/3	1/3	1/4	1/4	1/3	1/4	1	1/2
S2	1/3	1/3	1/3	1/3	1/4	1/4	1/3	1/4	2	1
w_i*	0.18798	0.18798	0.09023	0.07404	0.13747	0.13392	0.06653	0.05591	0.03074	0.03521

* Relative weights of criteria. Inconsistency: 0.06063

Table 3
Type and data of membership function for every goal

Objective	Type of membership functions	Data of membership functions	
Benefit	Left membership	(Δ_{iL}, b_i)	(10000, 48000)
Hardware cost	Right membership	(b_i, Δ_{iR})	(65000, 20000)
Software cost	Right membership	(b_i, Δ_{iR})	(28000, 10000)
Other cost	Right membership	(b_i, Δ_{iR})	(360, 300)
Risk	Right membership	(b_i, Δ_{iR})	(0, 200000)
Decision-maker's preference	Left membership	(Δ_{iL}, b_i)	(10, 47)
Users preference	Left membership	(Δ_{iL}, b_i)	(10, 49)
Completion time required	Right membership	(b_i, Δ_{iR})	(0, 450)
Training time required	Right membership	(b_i, Δ_{iR})	(0, 500)
Additional manpower required	Right membership	(b_i, Δ_{iR})	(1100, 100)

Table 4
Different methods result comparison

Method	Projects selected	Benefit*	Hardware cost*	Software cost*	Other cost*	Decision-makers preferences	Users preferences	Risk factor	Completion time**	Training time**	Annual cost for additional manpower*
AHP-WAFGP	1,3,8,9, 10	46714	33100	26620	48	42.322	45.016	14	301	313	1107
AHP	1,5,6,7, 10	13584	36220	23094	220	43.956	46.163	12	327	403	917
ZOGP	1,3,4,6, 10	48294	66400	30164	48	42.554	45.062	14	303	335	1197
AHP-ZOGP	1,7,8,9, 10	8204	3920	26600	48	42.179	44.62	13	302	363	562
Targeted values	----	48000	65000	28000	360	47	49	00	00	00	1100

* In 1000$. ** Required in days

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In Table 4, B_i is the benefit derived from implementing project i, H_i is the hardware cost associated with implementing project i, S_i is the software cost associated with implementing project i, O_i is the other costs associated with implementing project i, r_i is the likelihood of failure of project i; PRD_i is the decision-maker's preference for project i, PRU_i is the user's preference for project i, t_i is the estimated completion time for project i, tt_i is the estimated training time required for project i, m_i is the cost of additional manpower for project i, p_j and n_j are the positive and negative deviation variables for the goals j, μ_j is the degree of membership functions for the goal j, $i = 1, 2, \ldots, n$ IS projects, $j = 1,2, \ldots, m$ IS project goals, x_i is a binary variable so it takes on the value of 1 if the project i is selected, and it takes on the value 0 otherwise.

Finally, the LINGO 15.0 package was used to solve this model. The optimal solution was: $x_1 = 1, x_2 = 0, x_3 = 1, x_4 = 0, x_5 = 0, x_6 = 0, x_7 = 0, x_8 = 1, x_9 = 1, x_{10} = 1$; and the degrees of membership functions for each goal were estimated as:

$$(\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}) = (0.87, 1, 1, 1, 0.11, 0.53, 0.60, 0.84, 0.89, 0.93) \quad (42)$$

According to these results, projects 1, 3, 8, 9 and 10 should be selected as the best solutions.

In order to illustrate the quality of support provided by an AHP-AWFGP integrated model for IS project selection, we compared its outputs with those that we obtained separately using AHP, ZOGP and combined AHP-ZOGP approaches (AHP data and ZOGP programs are presented in Appendix 1 and Appendix 2). As shown in Table 4, the benefits provided by the combined AHP-AWFGP solution are better than those with the AHP and AHP-ZOGP methods, and with less unused resources. In comparison with the ZOGP results, even if its benefits are 3.38% superior to those generated by the AHP-WAFGP solution, we have shown that these results require fewer financial resources, training, and completion time. While the AHP-WAFGP solution respects the budget constraints and requires a budget of $60,857,000, the ZOGP solution exceeds the hardware cost, software cost, and annual cost of additional manpower limitations, and requires $97,809,000 ($33,490,000 additional budgeting when compared to the target values). In the end, we can say that the integrated AHP-WAFGP model gives better support for IS project selection decisions by choosing those projects that better satisfy the different decision goals and makes better use of the available resources.

5. Sensitivity analysis

To determine the adaptability and robustness of the proposed model, a sensitivity analysis was performed.

On one hand, since the IS implementation is usually plagued by budget and time overruns, the three scenarios were built to accommodate this. The first and second scenarios suppose an initial progressive decline and then a gradual rise in hardware and software budgets. The third presumes a progressive reduction of quantity of tolerance (Δ_{iR}) for completion and training time.

On the other hand, two expert team members wanted to give more importance to the benefits and the users and decision-makers preferences, so the last scenario investigates the effect of varying these relative weights on the final decision.

5.1 Scenario 1: decreasing hardware and software budgets

The first scenario suggests successive reductions of 10%, 12.5% then 15% of hardware and software available budgets. As seen in Table 5, running our model with a 10% reduction yielded the same selected projects of the initial scenario. In the one exception, a reduction of 12.5% or 15% results in the selection of project 6 instead of project 9. Therefore, the selected portfolio for these last two includes projects 1, 3, 6, 8 and 10. Compared to the initial scenario, the second scenario better satisfies users and decision-makers and has a greater benefit ($48,394,000). However, this solution has higher costs for hardware ($45,900,000), software ($23,364,000) and additional manpower ($11,680,000). Moreover, this solution needs more training time (388 days) and requires a longer completion time (344 days). It should be noted that except for the annual cost for additional manpower, all of the costs respect the initial estimated budgets in this solution.

5.2 Scenario 2: increasing hardware and software budgets

The second scenario supposes a successive increase of 10%, 12.5% then 15% of the hardware and software available budgets. As seen in Table 5, all three yield the same selected projects as the initial scenario.

5.3 Scenario 3: decreasing the quantity of tolerance for completion and training time

The third scenario supposes successive decreases of 10%, 12.5% then 15% of the quantity of tolerance (Δ_{iR}) for completion and training time. As shown in Table 5, these three yielded the same selected projects of the initial scenario.

5.4 Scenario 4: changing criteria weights

More importance was given to the benefits, users preferences, and decision-makers preferences in this scenario and the inputs of the pairwise comparison judgment matrices of the criteria varied with a recalculated output. Three versions were calculated using a one point increase for each in the pairwise comparison weights of benefit, user preferences and decision-maker (DM) preferences. Table 6 shows the resulting relative weights for the criteria. All three versions resulted in the selection of the same project portfolio as the initial scenario (Table 5).

Therefore, we can conclude that the AHP-WAFGP hybrid model proposed here for IS selection is adaptable, robust, and not sensitive to small changes in criteria weights, hardware and software cost, and quantity of tolerance for completion and training time.

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Table 5
Results comparison for different scenarios

IS Project		X01	X02	X03	X04	X05	X06	X07	X08	X09	X10
Initial Scenario		✓		✓					✓	✓	✓
Scenario 1: Cost increase	Run1: -10%	✓		✓					✓	✓	✓
	Run2: -12.5%	✓		✓			✓		✓		✓
	Run3: -15%	✓		✓			✓		✓		✓
Scenario 2: Cost decrease	Run1: +10%	✓		✓					✓	✓	✓
	Run2: +12.5%	✓		✓					✓	✓	✓
	Run3: +15%	✓		✓					✓	✓	✓
Scenario 3: Δ_{iR} Reduction	Run1: -10%	✓		✓					✓	✓	✓
	Run2: -12.5%	✓		✓					✓	✓	✓
	Run3: -15%	✓		✓					✓	✓	✓
Scenario 4: Changing weights	Run1	✓		✓					✓	✓	✓
	Run2	✓		✓					✓	✓	✓
	Run3	✓		✓					✓	✓	✓

Table 6
Criteria relative weights estimated for Scenario 4

Criteria	Initial Scenario	Run 1 Benefit +1	Run 2 Users preference +1	Run 3 DM preference +1
Benefit	0.13747	0.18888	0.13598	0.13624
Hardware cost	0.18798	0.17213	0.18463	0.1844
Software cost	0.18798	0.17213	0.18463	0.1844
Other cost	0.09023	0.08602	0.08859	0.08834
Risk	0.13392	0.12777	0.13236	0.13256
Decision makers preference	0.03521	0.03375	0.03284	0.05039
Users preference	0.03074	0.02946	0.04401	0.05604
Completion time	0.06653	0.06305	0.06511	0.06511
Training time	0.05591	0.05361	0.05946	0.05604
Cost of additional manpower	0.07404	0.07321	0.07239	0.07242
CR		0.05992	0.06555	0.06281

6. Conclusions

As a strategic decision, IS project selection is very important for companies because this kind of choice is usually a risky and costly long-term commitment. Furthermore, as it is an MCDM problem, any IS selection method that is used must accommodate different alternatives, and multiple and often conflicting fuzzy and imprecise attributes.

To deal with these constraints, different models have been developed. However, even if the latest methods reported in the literature consider the diversity and fuzzy nature of the attributes, Preemptive/Lexicographic Goal Programming that is often used is not flexible when dealing with an integer problem that has many goals.

The aim of this study was to present a simpler, easier, and more flexible methodology for IS project selection that can use all types of linear membership functions to specify the fuzzy objective values. The proposed approach combines the AHP and the WAFGP.

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First, the AHP was used to estimate the decision criteria weights, and then these weights were used to formulate a WAFGP model and complete the project selection decision.

This model was demonstrated with a hypothetical example. The results show that the integrated AHP-WAFGP approach seems to be easier and simpler than the previous methods (AHP, ZOGP, and combined AHP-ZOGP) and gives better support for IS project selection decisions by choosing those projects that better satisfy the different decision goals and also makes better use of the available resources. A sensitivity analysis demonstrated that the proposed model is robust, adaptable, and not sensitive to small changes in the model parameters.

Despite its advantages, the integrated AHP-WAFGP approach neglects the uncertain nature of the decision makers' judgments and the interdependencies that can exist among criteria and IS project alternatives. Authors can use fuzzy ANP or fuzzy non-linear mathematical programming to overcome these limits. Furthermore, we have supposed, in the second step of the model that the expert team members should arrive at a consensual judgment. In practice, this consensual judgement was not easily reached. Future studies can therefore be improved by using an appropriate method to solicit and aggregate expert judgments. Finally, even as it takes into account the fuzzy nature of objectives (goals), the proposed model neglects the fuzzy nature of the relative weight of criteria and the constraints. Future research could integrate fuzzy AHP with a fuzzy parameters model having fuzzy constraints.

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APPENDIX 1
AHP data

Table 6
Pairwise comparison matrix of alternatives with respect of benefit (B)

	X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**
X1	1	3	1/5	5	1/4	1/3	1/2	5	5	2
X2	1/3	1	1/7	4	1/7	1/7	1/5	3	2	½
X3	5	7	1	7	3	4	4	7	7	5
X4	1/5	1/4	1/9	1	1/7	1/7	1/5	½	1/3	1/5
X5	4	7	1/3	7	1	2	2	7	7	5
X6	3	7	¼	7	1/2	1	2	7	7	5
X7	2	5	¼	5	1/2	1/2	1	5	5	3
X8	1/5	1/3	1/7	2	1/7	1/7	1/5	1	1/2	¼
X9	1/5	1/2	1/7	3	1/7	1/7	1/5	2	1	1/3
X10	1/2	2	1/5	5	1/5	1/5	1/3	4	3	1

Table 7
Relative weights of alternatives with respect to each criterion

	C1	C2	C3	C4	B	R	T1	T2	S1	S2
X1	0.07972	0.03907	0.19273	0.02005	0.07652	0.07420	0.10935	0.15206	0.20401	0.21740
X2	0.05784	0.10943	0.02352	0.03854	0.03578	0.07420	0.15463	0.01773	0.15165	0.14337
X3	0.01697	0.01669	0.19273	0.01467	0.30572	0.04200	0.03129	0.02175	0.28487	0.28473
X4	0.02149	0.02913	0.07114	0.11331	0.01728	0.07027	0.07789	0.05683	0.02094	0.01614
X5	0.02993	0.21664	0.01564	0.02789	0.19441	0.14424	0.04129	0.10817	0.08620	0.11111
X6	0.04190	0.28148	0.04829	0.05546	0.16121	0.15821	0.05599	0.27837	0.11092	0.05669
X7	0.21161	0.01993	0.19273	0.24624	0.10844	0.07420	0.02234	0.08043	0.05624	0.07943
X8	0.15102	0.15536	0.03418	0.24624	0.02075	0.07420	0.01574	0.21295	0.04070	0.04038
X9	0.10960	0.05768	0.11452	0.07846	0.02643	0.14424	0.28033	0.04148	0.02856	0.02882
X10	0.27992	0.07459	0.11452	0.15916	0.05346	0.14424	0.21112	0.03021	0.01590	0.02194
CR	0.04675	0.05400	0.01553	0.04100	0.06387	0.00452	0.05809	0.04280	0.04200	0.03755

Table 8
Alternatives final weights and rankings

Alternatives	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**
Final Weights	0.0914	0.0723	0.0945	0.0457	0.1112	0.1373	0.1145	0.1073	0.0934	0.1324
Ranking	8	9	6	10	4	1	3	5	7	2

APPENDIX II
Pre-emptive ZOGP mathematic formulation

$Min\ z =$
$P_1\ (n_1), P_2\ (p_2), P_3\ (p_3), P_4\ (p_4), P_5\ (p_5), P_6\ (n_6), P_7\ (n_7), P_8\ (p_8), P_9\ (p_9), P_{10}\ (n_{10})$; (43)

Subject to:

$$\sum_{i=1}^{10} B_i x_i + n_1 - p_1 = 48000; \quad (44)$$

$$\sum_{i=1}^{10} H_i x_i + n_2 - p_2 = 65000; \quad (45)$$

$$\sum_{i=1}^{10} S_i x_i + n_3 - p_3 = 28000; \quad (46)$$

$$\sum_{i=1}^{10} O_i x_i + n_4 - p_4 = 360; \quad (47)$$

$$\sum_{i=1}^{10} r_i B_i x_i + n_5 - p_5 = 00; \quad (48)$$

$$\sum_{i=1}^{10} PRD_i x_i + n_6 - p_6 = 47; \quad (49)$$

$$\sum_{i=1}^{10} PRU_i x_i + n_7 - p_7 = 49; \quad (50)$$

$$\sum_{i=1}^{10} t_i x_i + n_8 - p_8 = 00; \quad (51)$$

$$\sum_{i=1}^{10} tt_i x_i + n_9 - p_9 = 00; \quad (52)$$

$$\sum_{i=1}^{10} m_i x_i + n_{10} - p_{10} = 1100; \quad (53)$$

$$\sum_{i=1}^{10} x_i = 5; \quad (54)$$

$$x_1 = 1; \quad (55)$$

$$x_i = 0 \text{ or } 1; \quad i = 1,2,..,10; \quad (56)$$

For ZOGP-AHP, the same mathematic formulation was used with the following objective function:

$$MinZ = P_2(p_2), P_3(p_3), P_1(n_1), P_5(p_5), P_4(p_4), P_{10}(n_{10}), P_8(p_8), P_9(p_9), P_6(n_6), P_7(n_7), P_{11}(0.0914n_{11} + 0.0723n_{12} + 0.0945n_{13} + 0.0457n_{14} + 0.1112n_{15} + 0.1373n_{16} + 0.1145n_{17} + 0.1073n_{18} + 0.0934n_{19} + 0.1324n_{20}); \quad (56)$$