Iranian Journal of Operations Research
Vol. 6, No. 1, 2015, pp. 34-52

A Fuzzy Decision Making Approach to Enterprise Resource Planning System Selection

H. Hamidi[1,*]

Here, we propose a fuzzy analytic hierarchy process (FAHP) method to evaluate the alternatives of enterprise resource planning (ERP) system. The fuzzy AHP approach allows the users get values more accurately to model the vagueness which changes according subjective ideas in the decision-making environment for ERP system selection problem. Therefore, fuzzy AHP method is used to obtain firm decisions and noticeable solutions. The criteria are determined and then compared according to their importance. The methodology also gives some suggestions about successful ERP selections. The proposed methodology can be used for other sectors with some changes. Fuzzy group decision-making can be used for this purpose. We show how effective fuzzy AHP is as a decision-making tool in system selection problem. It is seen that fuzzy AHP is a useful decision-making methodology to make more precise selection-decisions that may help the company to achieve a competitive edge in a complex environment. Fuzzy AHP approach incorporates quantitative data of the criteria, which have to be evaluated by qualitative measures. The proposed selection methodology is flexible to incorporate new or extra criteria or decisions for the evaluation process. Besides, this methodology provides the opportunity to a project team to decompose complicated selection problem into smaller parts. Thus, the project team can understand the relationships among different criteria and easily assign its own ideas to the hierarchical structure. Also, a case study is presented to demonstrate the feasibility of the framework.

Keywords: *Enterprise resource planning (ERP) system, Decision making, Analytic hierarchy process (AHP), Fuzzy logic.*

Manuscript was received on 11/08/2014, revised on 17/05/2015 and accepted for publication on 17/06/2015.

1. Introduction

Enterprise Resource Planning (ERP) systems have been considered as essential for gaining and maintaining competitive advantage in the globalized market under ever increasing competition. ERP systems integrate and support all the major processes of a company such as accounting, finance, manufacturing and human resource management, by providing a unified platform of database and business applications [1–3]. Most market-leading ERP systems are usually equipped with best practices so that, by simply implementing the systems properly, the companies can effectively improve their business processes [4–5].

With this popularity, there have been many academic studies about ERP from various perspectives [2–9]. However, despite the practical and academic interests in ERP, many companies still suffer from not being able to gain the expected benefits from it. Some companies even face the threat of bankruptcy from huge capital investment and unsuccessful selection [10–11].

Selecting an adequate ERP system for an organization is one of the crucial issues in an ERP project.

* Corresponding author
[1] Department of Industrial Engineering, K. N. Toosi University of Technology, Tehran, Iran, Email: h_hamidi@kntu.ac.ir.

Here, we show how effective fuzzy AHP is as a decision-making tool in system selection problem. Even with the complete accurate information, different decision making methods may lead to totally different results. Thus, the proposed methodology demonstrates the selection of the best ERP vendor under the cost and quality restrictions in the presence of vagueness. It is seen that fuzzy AHP is a useful decision-making methodology to make more precise selection-decisions that may help the company to achieve a competitive edge in a complex environment. Fuzzy AHP approach incorporates quantitative data of the criteria, which have to be evaluated by qualitative measures. The proposed selection methodology is flexible to incorporate new or extra criteria or decisions for the evaluation process. Besides, the methodology gives the opportunity to the project team to decompose such a complicated selection problem into smaller parts. Thus, the project team can understand the relationships among different criteria and easily assign its own ideas to the hierarchical structure. The remainder of our work is organized as follows. Section 2 presents a review of existing work on the selection of ERP systems with the fuzzy AHP method. In Section 3, an AHP framework for ERP selection and a methodology for the selection of ERP system are presented. The application of the assessment framework using a case study and the obtained results are discussed in Section 4. Conclusion and direction for future work are given in Section 5.

2. Literature Review

2.1. ERP System Selection Methods

There are a large number of research studies that investigate ERP related issues, from selection to adoption, while the scope of the review will be focused on the studies related specifically to ERP system selection problem [22–34]. Owing to the essence of IT system, selection problem is a multi-criteria decision-making (MCDM) process. Several papers adopted analytic hierarchy process (AHP) to be the analytical tool [35–36]. Lin [38] and Luo and Strong [40] studied the ERP evaluation models for universities. Selection criteria of ERP system is also a crucial issue in ERP project. When implementing an ERP project, price and time are both the most important factors. Besides, the vender's support is also a crucial issue [39]. Excepting the investment cost of ERP project, the annual maintenance cost and human resource cost are also the potential expense for organizations [41–44].There was an ERP selection model containing three categories of selection attributes including project factors, software system factors and vender factors [45]. Wei and Wang [55] developed a comprehensive methodology which considers both subjective and objective criteria while choosing the ERP software. By benefiting from the fuzzy set theory, quantitative criteria were regarded. An indicator called "fuzzy ERP suitability index" was used for determining the suitability of ERP alternatives and criteria importance weights.

Wei et al. [54] proposed an AHP based methodology for supplier selection problem. Ziaee et al. [61] presented a two stage approach. In the first stage, ERP system properties were determined by collecting information about the possible ERP sellers. In the second stage, a mathematical model was proposed for minimizing the total cost related with procurement and integration.

Wei and Wang [54] have proposed several methods for selecting a suitable ERP system [14–21]. The scoring method is one of the most popular. Although it is intuitively simple, it does not ensure resource feasibility. Teltumbde [50] suggested 10 criteria for evaluating ERP projects and constructed a framework based on the nominal group technique and the analytic hierarchy process (AHP) to make the final choice. Baki and Çakar [4] determined the ERP selection criteria and obtained the importance/weights of the criteria by a survey among firms in Turkey.

Lee and Kim [36–37] combined the analytic network process (ANP) and a 0–1 goal programming model to select an information system. However, these mathematical programming methods did not contain sufficient detailed attributes, which above all, not being easy to quantify, were restricted to some financial factors, such as costs and benefits. Furthermore, many of them involved only the consideration of internal managers, and did not offer a comprehensive process for combining evaluations of different data sources to select an ERP project objectively. In [32], an ERP system selection problem at a large airline company in Turkey was considered. First, based on the requirements and the demands of the company's executives, the ERP selection criteria were determined. Then, the alternative ERP firms and their offerings were investigated and determined. After determining the criteria and solution alternatives, a proposed hybrid methodology, consisting of fuzzy AHP incorporating the vagueness of the decision making process and TOPSIS, was applied and validated. Specifically, the importance/weights of the selection criteria were obtained via fuzzy AHP based on the triangular fuzzy preference scales. Then, these weights were used in the TOPSIS methodology to reach ranking of the alternative ERP system suppliers. It should be acknowledged that the work of [32] was subject to some limitations. Perhaps the most serious limitation of the study is its narrow focus on a single case study in aviation industry. To generalize on the findings and the viability/validity/value of the methodology, more real world cases need to be performed. Another limitation of the individual methods is the independent structure of the selection criteria. Since the comparisons are made in a piece-meal/pairwise fashion, reaching the actual optimal may not be possible. In [24], an approach was presented to select a suitable ERP system for textile industry. The proposed decision support system integrated with strategic management by using BSC may be an alternative to some methods for ERP selection. In this paper, ERP packages and vendors for textile companies were compared using fuzzy AHP. The presented methodology is flexible and can be used for other sectors with some sector specific characteristic changes. Humans are often uncertain in assigning the evaluation scores in crisp AHP. Fuzzy AHP can capture this difficulty. In this paper, fuzzy AHP cannot support all phases of ERP selection and implementation. Hence, an intelligent decision support system or expert system can be added when gathering data for selection process.

A combined methodology, based on ANP and PROMETHEE, was proposed in [41] to mitigate this problem. Each of these decision analysis techniques brings capabilities to address specific characteristics of the decision situation, including its being a highly complex multi-criteria decision situation that requires the involvement of a group of decision makers and evaluation of network structure among the decision making system factors. In this study, two prevalent multi-criteria decision making techniques, analytic network process (ANP) and preference ranking organization method for enrichment evaluations (PROMETHEEs), were used in a combination to better address the ERP selection problem. The proposed hybrid methodology successfully ranked the alternatives and identified the best ERP system based on the information obtained from a number of SMEs participated in the study. Different multi-criteria decision making techniques such as VIKOR and ELECTRE can be used and comparison of the results can be presented. Moreover, fuzzy decision making environment can also be considered in the selection models. Perhaps, the most serious limitation of this study is its narrow focus on Turkish SMEs.

In [31], the application of a hybrid multi-criteria decision making (MCDM) procedure for the evaluation of various ERP alternatives was explored. The proposed evaluation framework integrates three methodologies: analytic network process (ANP), choquet integral (CI) and measuring attractiveness by a categorical based evaluation technique (MACBETH). ANP produces the priorities of alternatives with respect to the interdependent evaluation criteria. The comparison has shown that the final ranking may change dramatically with the ignorance of the interactions and therefore erroneous decisions may be reached. In [31], Kilie intended to show how effective fuzzy AHP was as a decision-making tool in software vendor selection problem by a comparison of the traditional

AHP and fuzzy AHP approaches. Even with completely accurate information, different decision making methods may lead to totally different results. Thus, the proposed methodology demonstrates the selection of the best ERP vendor under cost and quality restrictions in the presence of vagueness.

2.2. Analytic Hierarchy Process (AHP)

In our work here, we apply the AHP approach introduced by Saaty ([46], 1980) to our selection framework. AHP is a methodology for multi-criteria analysis of choices and decision making that enables decision makers to account for the interaction of multiple factors in complex situations. The AHP process requires decision makers to develop a hierarchical structure for the factors which are explicit in the given problem and to provide judgments about the relative importance of each factor to specify a preference [46–49] for each decision alternative with respect to each factor. It provides a prioritized ranking order indicating the overall preference for the decision alternatives.

The AHP process is deemed most useful in situations where teams of experts are working on complex problems, specially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions [51]. There are unique advantages when important elements of the decision are difficult to quantify or compare, or when communication among team members is impeded by the different specializations, terminologies or perspectives. Decision situations to which the AHP was applied include [13,16]: first, ranking, that is to put a set of alternatives in order from most to least desirable; second, prioritization, that is determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them; third, resource allocation, that is to apportion resources among a set of alternatives; fourth, benchmarking, that is to compare the processes in one's own organization with those of other best-of-breed organizations; fifth, quality management, that is to deal with the multidimensional aspects of quality and quality improvement; and sixth, conflict resolution, that is to settle disputes between parties with apparently incompatible goals or positions [52–53]. Some of the real-life large-scale applications of AHP include its use in integrated manufacturing [56], in the evaluation of technology investment decisions [57], in flexible manufacturing systems [58], in layout design [59], in business management [60] and also in graduates' career decision making [13, 16].

Specifically in ERP, the AHP process has been applied as part of the solution and decision-making framework to solve various problems related to ERP selection [31–32], to measurement of ERP implementation readiness [53], to evaluation of critical success factors [24, 41, 53], to performance evaluation [17] and to risk evaluation in maintenance [32]. Recently, Sarfaraz [46] also applied a fuzzy logic-based AHP method to the customization framework of Luo and Strong [40], for evaluating ERP customization choices. This wide use of AHP in the ERP domain encouraged us to consider it for inclusion in our work. However, in contrast to Sarfaraz [46], who used an AHP variant that rests on fuzzy logic, we opted for the original AHP process as presented by Saaty (1980) because of its flexibility and the availability of mathematical axiomatic principles and techniques to obtain group preferences and priorities. More in detail, our choice was motivated by the fact that the original AHP method requires as input pieces of data that could be relatively easily available in companies. In contrast to this, fuzzy logic-based variants of the AHP method put specific requirements on the input parameters that are fed into the AHP rules, for example estimating the degree of uncertainty associated with a specific parameter.

The overall approach of AHP is to decompose the total problem into smaller sub-problems in such a way that each sub-problem can be analyzed and appropriately handled from a practical perspective in terms of data and information. For the purpose of this decomposition process, AHP uses a hierarchy that in fact deconstructs the problem into its component elements, groups the elements into homogeneous sets and arranges them hierarchically. Based on the hierarchical model, AHP provides a method to assign numerical values to subjective judgments on the relative importance of each element and then to synthesize the judgments to determine which elements have the highest priority.

The solution process consists of three stages:

(1) Determination of the relative importance of the attributes.

(2) Determination of the relative importance of each of the alternatives with respect to each attribute.

(3) Overall priority weight determination of each alternative.

In our study, the AHP approach is used to prioritize the ERP selection using the framework. It should be highlighted that all decision problems are considered as a hierarchical structure in AHP. The first level indicates the goal for the specific decision problem. In the second level, the goal is decomposed into several criteria and the lower levels can follow this principal to divide into other sub-criteria. Therefore, the general form of AHP can be depicted as shown in Fig. 1.

The four main steps of AHP can be summarized as follows [54].

Step 1: Set up the hierarchical system by decomposing the problem into a hierarchy of interrelated elements.

Step 2: Compare the comparative weight between the attributes of the decision elements to form the reciprocal matrix.

Step 3: Synthesize the individual subjective judgment and estimate the relative weight.

Step 4: Aggregate the relative weights of the elements to determine the best alternatives/strategies.

2.3. Fuzzy AHP (FAHP)

Analytic hierarchy process (AHP) developed by Saaty [46] has been one of the most widely used techniques for multi-criteria decision making problems. So, many researchers [24–32] who have studied the fuzzy AHP as an extension of Saaty's methodology, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes as compared to the traditional AHP methods. The priority values of both objective and subjective factors are obtained via pair-wise comparisons. There are mainly four levels in the AHP method. At the first level, there is the objective function. At the second level, there are the attributes. At the third level, there are the sub-attributes and finally, at the last level, there are the alternatives [25].

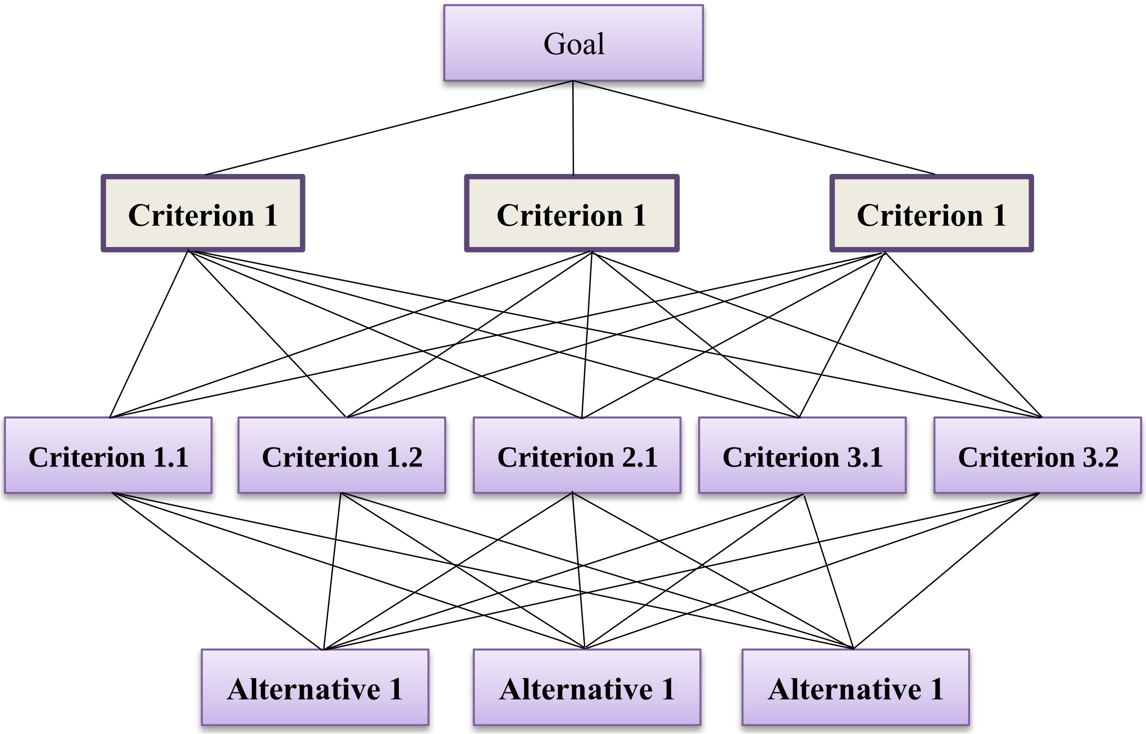

Figure 1. The hierarchical structure of AHP

Yu [60] employed goal programming to solve group decision making fuzzy AHP problems. Weck et al. [54] evaluated alternative production cycles using fuzzy AHP. Sheu [48] presented fuzzy-based approach to identify global logistics strategies. Cheng [18] proposed a new algorithm for evaluating naval tactical missile systems by fuzzy AHP based on grade values of membership function. Zhu et al. [14] discussed the extent analysis method and applications of fuzzy AHP. In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of the linguistic terms can be developed as quantitative data. A type of data set is then refined by the evaluation methods of fuzzy set theory. On the other hand, AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment. Therefore, AHP method does not take into account the uncertainty associated with the mapping [40]. The AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human's thinking style. Avoiding these risks on performance, the fuzzy AHP (F-AHP), a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems. Since crisp values are used in the AHP method, it is unable to handle the vagueness in the fuzzy decision making environment. The earliest one is presented by van Laarhoven and Pedrycz [34] comparing fuzzy ratios described by triangular membership functions. Buckley [8, 9] determined fuzzy priorities of comparison ratios having trapezoidal membership functions. Chang [13, 16] proposed a new approach utilizing triangular fuzzy numbers for pairwise comparison scale of F-AHP.

In our study, F-AHP is used to find the importances/weights of the selection criteria for ERP systems. To apply F-AHP, the procedure proposed by Buckley [8, 9] is used as follows:

Step 1: Create the hierarchies according to the problem characteristics, decompose each attribute and build up the hierarchy structure; the 0th layer represents the ultimate goal; the 1st layer represents the important decision criteria that affect the ultimate goal; the 2nd layer represents the important sub-criteria of the 1st layer, and so on. The last layer represents the alternative choices of the feasible solutions.

Step 2: Create fuzzy pairwise comparison matrix according to the layer structure built in **Step 1**, convert the important decision criteria into the semantic format used to design polling questionnaires. Two elements (criteria or alternatives) are compared by the decision makers at a time by the linguistic scale which consists of the fuzzy preference scale as shown in Table 1 and their membership functions as shown in Fig. 2.

Step 3: Group combination after creating the fuzzy pairwise comparison matrix, and calculate the geometric mean of each criterion in the matrix as suggested by Buckley [8]:

$$\tilde{m}_{ij} = (1/K) \otimes (\tilde{m}_{ij}^1 \oplus \tilde{m}_{ij}^2 \oplus \ldots \oplus \tilde{m}_{ij}^K), \quad (1)$$

where

$\tilde{m}_{ij}$ is integrate trigonometric fuzzy number,

$\tilde{m}_{ij}^K$ is the *i*th to the *j*th criteria pair comparison value by the expert *K*, and

K is total number of experts.

Step 4: Build up the fuzzy positive reciprocal matrix after **Step 3**, obtaining the final calculated fuzzy numbers for each layer form the fuzzy positive reciprocal matrix.

Table 1. Scales for pairwise comparison

	Numeric variables	**Linguistic variables**
M1	(l_1, m_1, u_1)	Equal importance
M2	(l_2, m_2, u_2)	Moderate importance
M3	(l_3, m_3, u_3)	Extreme importance

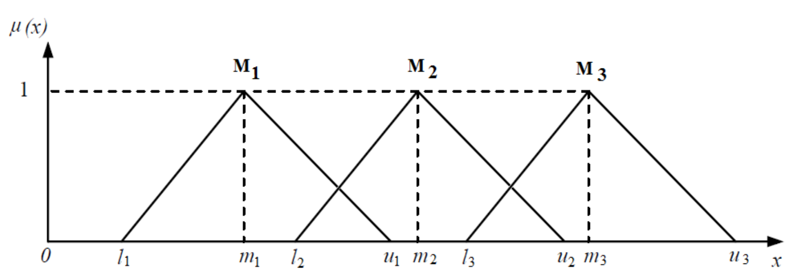

Figure 2. Membership functions for linguistic variables

Let m_{ij}^k represent a set of the *k*th decision maker's preference of one element (*i*) over another (*j*). Then, the pairwise comparison matrices are constructed.

$$M = \begin{bmatrix} m_{11}^k & \dots & m_{1(n-1)}^k & m_{1n}^k \\ m_{2n}^k & \dots & \dots & m_{2n}^k \\ m_{(n-1)1}^k & \dots & \dots & \dots \\ m_{n1}^k & \dots & m_{n(n-1)}^k & m_{nn}^k \end{bmatrix}, \quad (2)$$

where M is called the fuzzy positive reciprocal matrix.

Step 5: The fuzzy weights of each criterion are obtained via the geometric mean method proposed by Buckley [8]. First, the geometric mean of fuzzy comparison value of criterion i to each criterion is computed by

$$\tilde{z}_i = (\prod_{j=1}^{n} \tilde{m}_{ij})^{1/n}, \quad i = 1, 2, ..., n. \quad (3)$$

Then, the fuzzy weight of the ith criterion represented by a triangular fuzzy number is found to be

$$\tilde{w}_i = \tilde{z}_i \otimes (\tilde{z}_1 \oplus ... \oplus \tilde{z}_n)^{-1} = (k_1 w_i, k_2 w_i, k_3 w_i) \quad (4)$$

where
$\tilde{m}_{ij}$ is relative importance between criteria i and j,
$\tilde{z}_i$ is fuzzy geometric average of criterion i,
$\tilde{w}_i$ is fuzzy weight corresponding to criterion i.

Step 6: The sequential layers are linked together to calculate the fuzzy weight values for each alternative:

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{w}_j . \tilde{r}_{ij}, \quad (5)$$

where
$\tilde{U}_i$ is fuzzy weight values of alternative i,
$\tilde{w}_j$ is fuzzy weight value for the decision key criterion, and
$\tilde{r}_{ij}$ is performance score for the selected alternative X_i to the decision key criterion X_j.

Using the fuzzy number in this Step, the best alternative is selected by ranking these fuzzy weight values.

3. Proposed Methodology

The proposed fuzzy AHP methodology has two main modeling components, namely fuzzy logic and AHP method. Since the decision making environment is usually fuzzy/uncertain in most multi-criteria decision making problems (with respect to the subjectivity of the criteria to be included in the process), instead of making unrealistic assumptions to justify a simplified crisp solution, we choose to use fuzzy logic to deal with the imprecision inherent in the decision situation. The reason behind choosing the fuzzy AHP is based on the modeling capability and suitability to the current decision situation. Selecting the most suitable ERP system is a complex and challenging decision in any industry. Fuzzy AHP technique brings forward capabilities as well as shortcomings to address specific characteristics of the decision situation, as it being a highly complex multi criteria decision situation that requires the involvement of a group of decision makers and is mostly characterized by a number of non-deterministic (i.e., fuzzy) measures. The specific reason for fuzzy AHP technique in our study can be explained as follows: within the first stage of the problem, where the structure of the problem is determined, the decisions/tasks/criteria are naturally judgmental. This is where we determine the weights of the criteria, for which a technique capable of evaluating both tangible and intangible factors is needed. At this point, a highly regarded technique "fuzzy AHP" which is capable of incorporating vagueness/ imprecision of the decision situation is employed. The main stages of the proposed methodology (as shown in Fig. 3) can briefly be summarized as follows: the first stage is to determine the criteria with respect to the requirements (needs and wants) of the company. The second stage is where the importance/weights of all the criteria are obtained via fuzzy AHP methodology. The third and the final stage is where the best ERP system is determined by fuzzy AHP methodology. Fig. 3 illustrates the conceptual framework of the proposed methodology for the ERP selection process. The model entails four principle components.

3.1. Hierarchy Establishment

The ERP selection factors have been seriously addressed and analyzed in ERP literature by many researchers [41–49]. By the literature review and numerous interviews with project teams of company, we sift out fifteen sub criteria (Fig. 4). In the current study, the effective criteria on selection of the system are extracted. According to the ERP demands and the experts' ideas, these criteria are classified, weighted and prioritized and finally a framework is provided for ERP selection with the fuzzy AHP approach. Since ERP system is being widely applied in industry, the manpower demand for ERP project implementation and ERP software operation is continuously growing in job market. After the project team is confirmed, the three-phase framework procedure goes on.

First, characteristic identification of our case is an ERP system selection problem, where the ultimate goal of 0th layer is represented. Second, from the viewpoint of project management, there are two decision criteria belonging to the 1st layer: product factors and management factors.

Level 3 contains the associated attributes that are used to measure various products, and the management. The fourth level consists of the alternative ERP systems. The distinctive performance criteria may be different in diverse ERP projects. The ERP selection critical success factors were extensively addressed and analyzed in the ERP literature by many researchers [31–32, 41, 53]. Altogether, two factors were identified as the assessment factors after a comprehensive survey on ERP selection critical success factors. These factors are classified into fifteen categories (sub-factors) as ‘‘Functionality", ‘‘Reliability", "Usability", ‘‘Efficiency", ‘‘Maintainability", ‘‘Portability", ‘‘Cost", ‘‘Implementation time", ‘‘User friendliness", ‘‘Flexibility", ‘‘Vendor reputation", ‘‘Consultancy services", ‘‘Interoperability", ‘‘Reusability", and ‘‘R&D capability". The AHP hierarchy is composed of four levels, as illustrated in Fig. 4.

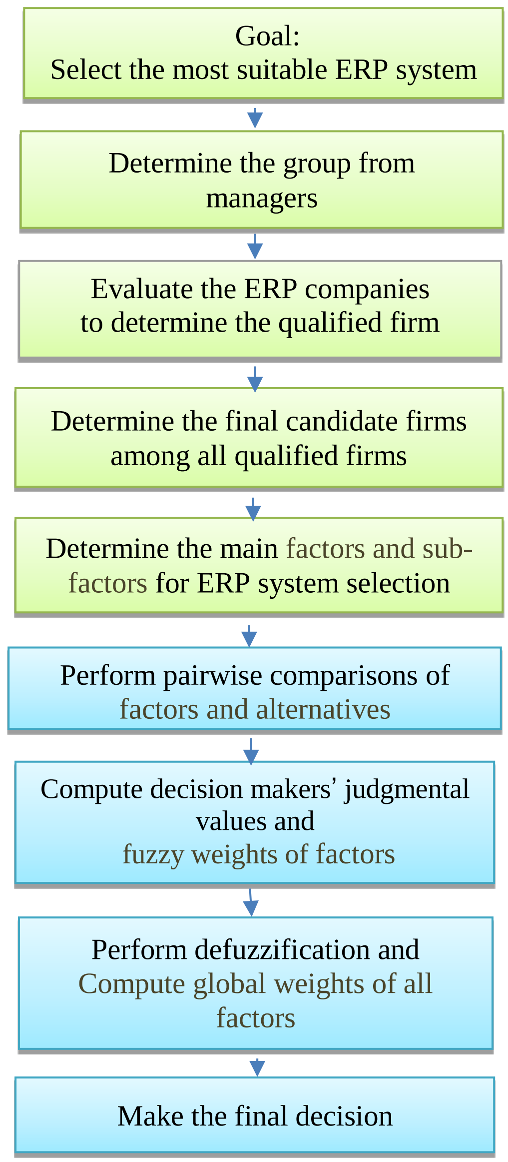

Figure 3. Proposed methodology for the selection of ERP system

We categorize ERP product characteristic as product aspect in the model. This quality identifies six key quality attributes. The detailed characterization is presented as follows:

- **Functionality:** This attribute is defined as the degree to which the software functions satisfies stated or implied needs and can be broken down into five sub-characteristics as follows: suitability, accuracy, interoperability, compliance and security [49].
- **Reliability:** The extent to which a program can be expected to perform its intended function with required precision.
- **Efficiency:** The amount of computing resources and code required by a program to perform its function.
- **Usability:** Effort required to learn, operate, prepare input, and interpret output of a program.
- **Maintainability:** Effort required to locate and fix an error in a program.

- **Flexibility:** Effort required to modify an operational program.
- **Portability:** Effort required to transfer the program from one hardware and/or software system environment to another.
- **Reusability:** Extent to which a program or parts of a program can be reused in other applications related to the packaging and scope of the functions that the program performs.
- **Interoperability:** Effort required to couple one system to another.
- **User friendliness:** Users should have access related help file from any transaction, and help files should relate in a simple wording understandable to the user. Also, user should be capable of changing standard reports and forms.

The ERP system contains five major criteria: vender factors, cost factors, time factors, R&D capability factors and consulting service factors. The detailed characterizations are presented as follows:

(1) Sub-criteria of vender factors: market share and reputation, industrial credential, service and support, and training solution. We gathered these factors based on vendor's reputation. By vendor's ability criteria, we implied vendor's technology level, implementation and service ability, consulting service, and training support. We considered vendor's financial condition, certifications and credentials.
(2) Sub-criteria of cost factors: software cost, hardware cost, annual maintenance cost, and staff training cost. This price contains licensing arrangement cost, product and technology cost and consulting cost, which involves adapting and integrating cost, supporting cost, training cost, and maintenance (upgrades) cost.
(3) Sub-criteria of time factors: time for planning and preparation, time for BPR and system tuning, time for testing and go-live.

As shown in Fig. 4, our model includes four hierarchy levels. Finally, with the weights of importance we attempt to find the best ERP vendor among all alternatives.

4. Results and Discussion

4.1. Case Study: A Numerical Example

The proposed framework was applied to ERP system selection at an electronics company in Iran. The AHP model provides priority weights for the ERP packages, based on the ERP project team's preferences on multiple characteristics. The proposed model is composed of four hierarchical stages: goal, sub-goals (factors), sub-factors and alternative ERP systems, which are related to each other by means of conjunctive arrows. This model has been applied to measure the firm's readiness to select an ERP system. First, the general manager of company organizes the project team including eight senior managers in different sections.

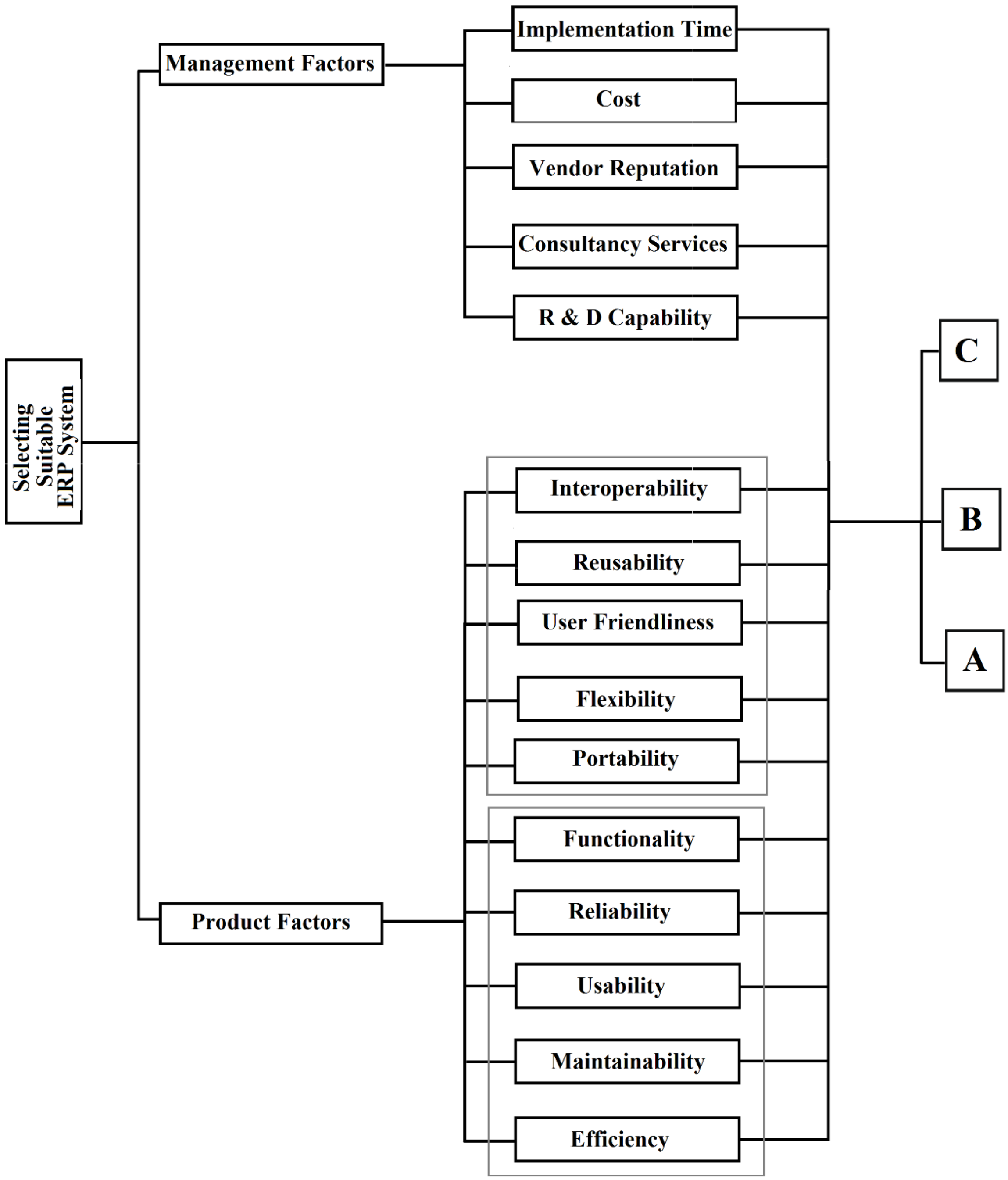

Figure 4. AHP framework for ERP selection

Three alternative firms are considered for the evaluation process. These three finalists were determined out of 8 firms that submitted full proposals to the formal RFP. Evaluation process included a thorough investigation of the firms' past performances, self-references, and independent industry studies. In order to provide objectivity among the participants and the confidentiality of the firms, the alternatives were not explicitly named in the evaluation process, instead represented by letters A, B, and C. The analytic hierarchy tree constructed for this problem is shown in Fig. 4.

Unfavorable alternatives were eliminated by a thorough examination of system specifications and requirements derived from the main goals. After the preliminary elimination which was subjected to budget, time and system functions, three feasible ERP system alternatives were identified. The sub-factors were determined according to the vision and the strategies of the company.

After assigning the weights to each sub-factor, the evaluation team compared all ERP alternatives. Assume that thirteen sub-factors are evaluated under a fuzzy environment. For selecting the best ERP, the product factors, system factors, management factors and the vendor factors used in application, are given by fuzzy numbers. Fig. 4 shows all the main factors and sub-factors. The project team compared the sub-factors with respect to main factors in the hierarchical approach by utilizing fuzzy triangular numbers in fuzzy AHP procedure. To create pairwise comparison matrix, linguistic scale was used as given in Table 2.

Table 2. Linguistic variables describing weights of factors and sub-factors

Linguistic scale	Triangular fuzzy scale (*l, m, u*)	Inverse triangular fuzzy scale (1/*u*, 1/*m*, 1/*l*)
Just equal	(1,1,1)	(1,1,1)
Equal importance	(0.5, 1, 1.5)	(0.67,1,2)
Moderate importance	(1, 1.5, 2)	(0.5, 0.67,1)
Very strong importance	(1.5, 2, 2.5)	(0.4,0.5, 0.67)
Absolute importance	(2, 2.5, 3)	(0.33,0.4,0.5)

The pairwise comparisons for the main criteria and sub-criteria under each main criterion are determined. The pair-wise comparisons based on the triangular fuzzy numbers for the two main criteria and sub-criteria (the sub-criteria under the two main criteria) are determined as shown in tables 3–5 with the consensus of the decision makers.

Table 3. Pairwise comparisons of the main criteria

Main Criteria	Product	Management
Product	(1,1,1)	(0.5, 0.67, 1)
Management	(1, 1.5, 2)	(1,1,1)

Table 4. Pairwise comparisons of the management sub-factors

Management	Cost	Implementation time	Vendor reputation	Consultancy services	R&D capability
Cost	(1,1,1)	(1, 1.5, 2)	(2, 2.5, 3)	(1, 1.5, 2)	(0.5, 1, 1.5)
Implementation time	(0.5, 0.67, 1)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(0.5, 1, 1.5)
Vendor reputation	(0.33, 0.4, 0.5)	(0.4, 0.5, 0.67)	(1,1,1)	(0.4, 0.5, 0.67)	(0. 5,0.75,1)
Consultancy services	(0.5, 0.67, 1)	(0.5, 0.67, 1)	(1.5, 2, 2.5)	(1,1,1)	(0.5, 0.67, 1)
R&D capability	(0.67, 1, 2)	(0.67, 1, 2)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1,1,1)

Table 5. Pairwise comparisons of product sub-factors

Product	Functionality	Reliability	Usability	Efficiency	Maintainability
Functionality	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)	(0.5, 0.67, 1)	(0.5, 0.67, 1)
Reliability	(0.5, 0.67, 1)	(1,1,1)	(1, 1.5, 2)	(0.4, 0.5, 0.67)	(0.4, 0.5, 0.67)
Usability	(0.4, 0.5, 0.67)	(0.5, 0.67, 1)	(1,1,1)	(0.33, 0.4, 0.5)	(0.4, 0.5, 0.67)
Efficiency	(1, 1.5, 2)	(1.5, 2, 2.5)	(2, 2.5, 3)	(1,1,1)	(0.5, 1, 1.5)
Maintainability	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(0.67, 1, 2)	(1,1,1)
	Flexibility	**Portability**	**User friendliness**	**Interoperability**	**Reusability**
Flexibility	(1,1,1)	(0.5, 0.67, 1)	(0.4, 0.5, 0.67)	(0.33, 0.4, 0.5)	(0.4, 0.5, 0.67)
Portability	(1, 1.5, 2)	(1,1,1)	(0.4, 0.5, 0.67)	(0.4, 0.5, 0.67)	(0.4, 0.5, 0.67)
User friendliness	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(0.5, 1, 1.5)	(0.5, 0.67, 1)
Interoperability	(2, 2.5, 3)	(1.5, 2, 2.5)	(0.67, 1, 2)	(1,1,1)	(0.5, 0.67, 1)
Reusability	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1, 1.5, 2)	(1,1,1)

4.2. Analyzing and Assessment Result

The fuzzy weights of the first layer are shown in Table 6. The final fuzzy weights of the entire 15 sub-criteria are presented in Table 7.

Table 6. The fuzzy weights for the main criteria

Main criterion	Fuzzy weight
Product	(0.30, 0.21, 0.33)
Management	(0.3, 0.39, 0.61)

Table 7. The fuzzy weights for the sub-criteria

Sub-criterion	Fuzzy weight
Product	
Functionality	(0.25, 0.30, 0.39)
Reliability	(0.17, 0.20, 0.26)
Usability	(0.032, 0.061, 0.093)
Efficiency	(0.081, 0.111, 0.181)
Maintainability	(0.017, 0.032, 0.103)
Flexibility	(0.042, 0.073, 0.121)
Portability	(0.017, 0.025, 0.036)
User friendliness	(0.025, 0.041, 0.052)
Interoperability	(0.004, 0.017, 0.035)
Reusability	(0.009, 0.021, 0.060)
Management	
Cost	(0.34, 0.42, 0.62)
Implementation time	(0.18, 0.24, 0.33)
Vendor reputation	(0.08, 0.115, 0.191)
Consultancy services	(0.097, 0.156, 0.284)
R&D capability	(0.164, 0.199, 0.258)

The relative weights of all criteria for all decision makers are listed in Table 8. The decision makers were fairly consistent in ranking the sub-criteria. From Table 9, the ranking order of fuzzy appropriateness indices for the three alternatives is A, B, and C. Hence, it is obvious that the most appropriate ERP system is C. Thus, the committee can be comfortable in recommending alternative C as the most suitable ERP system for the company. From Table 9, the weight of ERP system alternative A is 0.6556, and the weights for ERP system alternatives B and C are 0.6254 and 0.6901, respectively.

Table 8. The local and global importance/weights of the sub-criteria.

Main factors	Sub-factors	Relative weight	Ranking
Product	**Functionality**	0.190	1
	Reliability	0.181	2
	Usability	0.094	5
	Efficiency	0.102	3
	Maintainability	0.067	7
	Flexibility	0.100	4
	Portability	0.056	8
	User friendliness	0.075	6
	Interoperability	0.042	10
	Reusability	0.053	9
Management	**Cost**	0.31	1
	Implementation time	0.27	2
	Vendor reputation	0.10	5
	Consultancy services	0.15	4
	R&D capability	0.17	3

Table 9. The final weights and ranking values of the ERP system alternatives

ERP system alternatives	Fuzzy weight	Crisp weight	Ranking
A	(0.2938, 0.5846, 0.8582)	**0.6556**	2
B	(0.2764, 0.5607, 0.8265)	**0.6254**	3
C	(0.3104, 0.6146, 0.8901)	**0.6901**	1

5. Conclusion

Selecting an adequate ERP system for the organization is a crucial issue in an ERP project. In this paper, we presented an approach to select a suitable ERP system. First, based on the requirements and the demands of the company executives, the ERP selection criteria were determined. Then, the alternative ERP firms and their offerings were investigated and determined. After determining the criteria and solution alternatives, the proposed methodology, fuzzy AHP, was applied and validated. The use of fuzzy set theory improved the decision-making procedure by considering the vagueness and ambiguity prevalent in real-world systems. In order to deal with this problem appropriately, the analytic hierarchy process (AHP) method was extended into a fuzzy domain. A framework was developed to select most suitable ERP system using the fuzzy AHP. The factors and sub-factors were determined, classified, weighted and prioritized and then a framework was provided for ERP selection with the fuzzy analytic hierarchy process (FAHP) method. Then, we used fuzzy AHP to obtain pairwise comparison judgments by prioritizing criteria and assignments. A real case study was presented to demonstrate effectiveness of the method in practice. Perhaps the most serious limitation of this study is its narrow focus on a single case study. Another limitation of the individual methods is the independent structure of the selection criteria. In future, we suggest applying other decision-making methods using fuzzy concepts to capture the uncertainty in complex situations. Also, it is possible to make the decision by using fuzzy analytic network process model and compare with fuzzy AHP model, and the expert system may be used before the ERP system is selected. It may also be useful to apply the proposed hybrid methodology to other multi-criteria decision making processes.

References

[1] Abdullah, L. and Najib, L. (June 2014), A new type-2 fuzzy set of linguistic variables for the fuzzy analytic hierarchy process, *Expert Systems with Applications: An International Journal*, 41(7), 3297–3305.
[2] Alanbay, O. (2005), ERP selection using expert choice software, Presented to the 8th International Symposium on Analytic Hierarchy Process (ISAHP 2005), University of Hawaii.
[3] Asl, M.B., Khalilzadeh, A., Youshanlouei, H.R. and Mood, M.M. (2012), Identifying and ranking the effective factors on selecting enterprise resource planning (ERP) system using the combined Delphi and Shannon entropy approach, *Procedia - Social and Behavioral Sciences*, 41, 513–520.
[4] Baki, B. and Çakar, K. (2005), Determining the ERP package-selecting criteria: the case of Turkish manufacturing companies, *Business Process Management Journal*, 11(1), 75–86.
[5] Bingi, P., Sharma, M.K. and Godla, J.K. (1999), Critical issues affecting and ERP implementation, *Information Systems Management*, 16(3), 30–36.
[6] Boender, C.G.E., De Graan, J.G., and Lootsma, F.A. (1989), Multicriteria decision analysis with fuzzy pairwise comparisons, *Fuzzy Sets and Systems*, 29, 133–143.
[7] Bouyssou, D., Marchant, T., Pirlot, M., Perny, P., Tsoukias, A., and Vincke, P. (2000), Evaluation Models: A Critical Perspective, Kluwer, Boston.
[8] Buckley, J.J. (1985), Fuzzy Hierarchical Analysis, *Fuzzy Sets and Systems*, 17, 233–247.
[9] Buckley, J.J. (1985), Ranking alternatives using fuzzy members, *Fuzzy Sets and Systems*, 15, 21–31.
[10] Bueno, S.L. and Salmeron, J. (March 2008), Fuzzy modeling enterprise resource planning tool selection, *Computer Standards & Interfaces*, 30(3), 137–147.
[11] Butler, J. (1999), Risk management skills needed in a packaged software environment, *Information System Management*, 16(3), 15–20.
[12] Büyüközkan, G., Çifçi, G. and Güleryüz, S. (August 2011), Strategic analysis of healthcare service quality using fuzzy AHP methodology, *Expert Systems with Applications: An International Journal*, 38(8), 9407–9424.
[13] Chang, D.Y. (1996), Applications of the extent analysis method on fuzzy-AHP, *European Journal of Operational Research*, 95, 649–655.
[14] Zhu, K.J., Jing, Y. and Chang, D.Y. (1999), A discussion on extent analysis method and applications of fuzzy AHP, Research, Volume, Pages 450–456.
[15] Jian You , C., Lee , C. K.M. , Chen, S.L. and J. Jiao, R. (2012), A real option theoretic fuzzy evaluation model for enterprise resource planning investment, *Journal of Engineering and Technology Management*, 29(1), 47–61.
[16] Chang, D.Y. (1992), Extent Analysis and Synthetic Decision, Optimization Techniques and Applications, World Scientific, Singapore, 340–352.
[17] Chen, K. and Gorla, N. (1998), Information system project selection using fuzzy logic, *IEEE Transactions on Systems, Man, and Cybernetics, part A: Systems and Humans*, 28, 849–55.
[18] Cheng, C.H., Yang, K.L., and Hwang, C.L. (1999), Evaluating attack helicopters by AHP based on linguistic variable weight, *European Journal of Operational Research*, 116, 423–435.

[19] Cebeci, U. (July 2009), Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard, *Expert Systems with Applications: An International Journal*, 36(5), 8900–8909.

[20] Comer, A.A.P. and Castolo, J.C.G. (2012), An empirical study in selecting enterprise resource planning systems: the relation between some of the variables involve on it. Size and investment, *Procedia Technology*, 3, 292–303.

[21] Duru, O., Bulut, E. and Yoshida, S. (2012), Regime switching fuzzy AHP model for choice-varying priorities problem and expert consistency prioritization: A cubic fuzzy-priority matrix design, *Expert Systems with Applications: An International Journal*, 39(5), 4954–4964.

[22] Ertugrul Karsak, E. and Okan Özogul, C. (January 2009), An integrated decision making approach for ERP system selection, *Expert Systems with Applications: An International Journal*, 36(1), 660–667.

[23] Esteves, J. and Pastor, J. (2000), Towards the unification of critical success factors for ERP implementations, published in 10th Annual Business Information Technology (BIT) 2000 Conference, Manchester.

[24] GüRbüZ, T.E., Alptekin, S. and Alptekin, G.I. (December 2012), A hybrid MCDM methodology for ERP selection problem with interacting criteria, *Decision Support Systems*, 54(1), 206–214.

[25] Ishizaka, A. and Nguyen, N.H. (July 2013), Calibrated fuzzy AHP for current bank account selection, *Expert Systems with Applications: An International Journal*, 40(9), 3775–3783.

[26] Jafarnejad, A., Ansari, M., Rahmany Youshanlouei, H. and Mood, M. (July 2012), A hybrid MCDM approach for solving the ERP system selection problem with application to steel industry, *International Journal of Enterprise Information Systems*, 8(3), 54–73.

[27] Johansson, B. and Sudzina, F. (July 2011), ERP system implementation costs and selection factors of an implementation approach, *International Journal of Business Information Systems*, 8(1), 87–105.

[28] Kazancoglu, Y. and Burmaoglu, S. (July 2013), ERP software selection with MCDM: application of TODIM method, *International Journal of Business Information Systems*, 13(4), 435–452.

[29] Kazemi, A., Saeidi, S.R. and zizmohammadi, M.A. (May 2014), Selecting an ERP system using multi-criteria decision making method: a goal programming and fuzzy approach, *International Journal of Business Information Systems*, 16(1), 55–71.

[30] Khosroanjom, D., Ahmadzade, M., Niknafs, A. and Kiani Mavi, R. (September 2011), Using fuzzy AHP for evaluating the dimensions of data quality, *International Journal of Business Information Systems*, 8(3), 269–285.

[31] Kilic, H.S. (2014), Development of a hybrid methodology for ERP system selection: the case of Turkish airlines, *Decision Support Systems*, 66, 82–92.

[32] Kilic, H.S., Zaim, S. and Delen, D. (2015), Selecting "The Best" ERP system using a combination of ANP and PROMETHEE methods, *Expert Systems with Applications*, 42(5), 2343–2352.

[33] Kuo, R.J., Chi, S.C. and Kao, S.S. (2002), A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network, Computers in Industry, Volume 47 Issue 2, 199-214.

[34] Laarhoven, P.J.M. and Pedrycz, W. (1983), A fuzzy extension of saaty's priority theory, *Fuzzy Sets and Systems*, 11, 229–241.

[35] Lall, V. and Teyarachakul, S. (2006), Enterprise resource planning (ERP) system selection: a data envelopment analysis (DEA) approach, *Journal of Computer Information Systems*, 47(1), 123–127.

[36] Langenwalter, G.A. (2000), Enterprise Resources Planning and Beyond Integrating Your Entire Organization, CRC Press LLC, Florida.
[37] Lee, J.W. and Kim, S.H. (2001), An integrated approach for interdependent information system project selection, *International Journal of Project Management*, 19, 111–118.
[38] Lee, S., Kim, W., Kim, Y.M. and Joo Oh, K. (2012), Using AHP to determine intangible priority factors for technology transfer adoption, *Expert Systems with Applications: An International Journal*, 39(7), 6388–6395.
[39] Lin, C.H. (2002), An ERP application study on college property management system, Master's Thesis, Nanhua University, Chiayi, Taiwan, R.O.C.
[40] Lootsma, F. (1997), Fuzzy Logic for Planning and Decision-Making, Kluwer, Dordrecht.
[41] Luo, W. and Strong, D.M. (2004), A framework for evaluating ERP implementation choices, IEEE Transactions on Engineering Management 51(3):322 - 333.
[42] Onut, S. and Efendigil, T. (November 2010), A theorical model design for ERP software selection process under the constraints of cost and quality: A fuzzy approach, *Journal of Intelligent & Fuzzy Systems: Applications in Engineering and Technology*, 21(6), 365–378.
[43] Parthasarathy, S. (2012), Research directions for enterprise resource planning (ERP) projects, *International Journal of Business Information Systems*, 9(2), 202–221.
[44] Ptak, C.A. (2000), ERP Tools, Techniques, and Applications for Integrating the Supply Chain, St. Lucie Press.
[45] Ribeiro, R.A. (1996), Fuzzy multiple criterion decision making: a review and new preference elicitation techniques, *Fuzzy Sets and Systems*, 78, 155–181.
[46] Saaty, T.L. (1980), The Analytic Hierarchy Process, McGraw-Hill, New York.
[47] Sarfaraz, A., Jenab, K. and D'Souza, A.C. (2012), Evaluating ERP implementation choices on the basis of customisation using fuzzy AHP, *International Journal of Production Research*, 50(23), 7057–7067.
[48] Sheu, J.B. (2004), A hybrid fuzzy-based approach for identifying global logistics strategies, *Transportation Research*, 40, 39–61.
[49] Simon, H.A. (1977), The New Science of Management Decision: Prentice-Hall PTR.
[50] Tavana, M., Khalili-Damghani, K. and Abtahi, A.R. (February 2013), A hybrid fuzzy group decision support framework for advanced-technology prioritization at NASA, *Expert Systems with Applications: An International Journal*, 40(2), 480–491.
[51] Teltumbde, A. (2000), A framework of evaluating ERP projects, *International Journal of Production Research*, 38, 4507–4520.
[52] Tsai, W.H. and Lee, P.L. (January 2012), A comprehensive study of the relationship between enterprise resource planning selection criteria and enterprise resource planning system success, *Information and Management*, 49(1), 36–46.
[53] Tzeng, G.H. and Huang, J.J. (2011), Multiple Attribute Decision Making Method and Applications, CRC Press, Taylor & Francis Group.
[54] Weck, M., Klocke, F., Schell, H. and Rüenauver, E. (1997), Production cycles using the extended fuzzy AHP method, *European Journal of Operational Research*, 100(2), 351–366.
[55] Wei, C.C., Chien, C.F. and Wang, M.J. (2005), An AHP-based approach to ERP system selection, *International Journal of Production Economics*, 96, 47–62.
[56] May, J., Dhillon, G. and Caldeira, M. (2013), Defining value-based objectives for ERP systems planning, *Decision Support Systems*, 55(1), 98–109.
[57] Wei, C.C. and Wang, M.J. (2004), A comprehensive framework for selecting an ERP system, *International Journal of Project Management*, 22, 161–169.
[58] Wilson, F., Desmond, J. and Roberts, H. (1994), Success and failure of MRPII implementation, *British Journal of Management*, 5, 221–240.
[59] Yazgan, H.R., Boran, S. and Goztepe, K. (July 2009), An ERP software selection process with using artificial neural network based on analytic network process approach, *Expert Systems with Applications: An International Journal*, 36(5), 9214–9222.

[60] Yu, C.S. (2002), A GP-AHP method for solving group decision-making fuzzy AHP problems, *Computers and Operations Research*, 29, 1969–2001.

[61] Ziaee, M., Fathian, M. and Sadjadi, S.J. (2006), A modular approach to ERP system selection: a case study, *Information Management & Computer Security*, 14(5), 485–495.