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An intelligent approach to ERP software selection through fuzzy ANP

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During the implementations of enterprise resource planning (ERP) systems, most companies have experienced some problems, one of which is how to determine the best ERP software satisfying their needs and expectations. Because improperly selected ERP software may have an impact on the time required, and the costs and market share of a company, selecting the best desirable ERP software has been the most critical problem for a long time. On the other hand, selecting ERP software is a multiple-criteria decision-making (MCDM) problem, and in the literature, many methods have been introduced to evaluate this kind of problem, one of which is the analytic hierarchy process (AHP), which has been widely used in MCDM selection problems. However, in this paper, we use a fuzzy extension of an analytic network process (ANP), a more general form of AHP, which uses uncertain human preferences as input information in the decision-making process, because the AHP cannot accommodate the variety of interactions, dependencies, and feedback between higher- and lower-level elements. Instead of using the classical eigenvector prioritization method in the AHP, only employed in the prioritization stage of ANP, a fuzzy-logic method providing more accuracy on judgements is applied. The resulting fuzzy ANP enhances the potential of the conventional ANP for dealing with imprecise and uncertain human comparison judgements. In short, in this paper, an intelligent approach to ERP software selection through a fuzzy ANP is proposed by taking into consideration quantitative and qualitative elements to evaluate ERP software alternatives.

Keywords: Enterprise resource planning; Software selection; Fuzzy logic; Multiple-criteria decision-making; Analytic network process

1. Introduction

Recently, many companies have preferred to buy off-the-shelf systems to shorten the enterprise resource planning (ERP) implementation cycle due to the lack of professional expertise and experience on developing ERP systems in-house. Furthermore, any ERP software in market cannot fully meet the needs and expectations of companies, because every company runs its business with different strategies and goals. Thus, to increase the chance of success, management must choose appropriate software that most closely suits its requirements. ERP vendors

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use different hardware platforms, databases, and operation systems, and some ERP software is only compatible with some companies' databases and operation systems. Thus, companies should conduct a requirements analysis first to make sure what problems need to be solved and select ERP systems that best suit their requirements. The hardware is then selected according to the specific ERP systems' requirements. Two main aspects should be taken into consideration when selecting software/hardware: (1) compatibility of the software/hardware with the company's needs; and (2) ease of customization (Zhang *et al.* 2003).

There are several reasons why companies implement ERP systems, e.g. integration of financial information, integration of customer-order information with other information, standardization and acceleration of manufacturing processes, reduction of inventory level and order lead time, standardization of human-resource information, and so on. According to Kremzar and Wallace (2001), operating the business in a rapidly changing and highly competitive environment is the primary purpose of implementing an ERP system. Although implementing an ERP system may be costly and time-consuming, its benefits are worthwhile. With careful planning and selection of the right ERP system, a company may expect to gain significant advantages, including dramatic increases in responsiveness, productivity, on-time shipments and sales, as well as decreases in lead times, purchase costs, quality problems, and inventories.

As mentioned earlier, one of the most critical issues in implementation of an ERP system is the selection of the appropriate software to be used. Because ERP software dramatically changes the structure of a company by integrating its business functions using database technology, this provides a greater opportunity to improve the effectiveness of its business activities. Nowadays, most companies do not only implement ERP systems themselves, but also expect to have the full support of ERP software developers after installation, because ERP software is an expensive tool and requires well-defined contributions between company and a developer or its vendor/consultant firm. Therefore, the selection process for determining the most satisfying ERP software among a set of possible alternatives in the market should be achieved using one of the proven MCDM methods with a team consisting of the company, the software developer, and the vendor or consultant firm.

As one of the most commonly used methods for solving MCDM problems in the literature, the analytic hierarchy process (AHP) was first introduced by Thomas L. Saaty (1981). In AHP, a hierarchy considers the distribution of a goal among the elements being compared and judges which element has a greater influence on that goal. In reality, a holistic approach like an analytic network process (ANP) developed by Saaty is needed if all attributes and alternatives involved are connected in a network system that accepts various dependencies. Several MCDM problems cannot be hierarchically structured as being in AHP because they involve the interactions and dependencies in higher- or lower-level elements. Not only does the importance of the attributes determine the importance of the alternatives as in the AHP, but the importance of alternatives themselves also influences the importance of the attributes.

Furthermore, this application of Saaty's ANP has several shortcomings: this method is mainly used for crisp decision making problems and creates and deals with a very unbalanced scale of judgement. In addition, the ANP method does not take into account the uncertainty associated with the mapping of one's judgement to a number, and its ranking is rather imprecise. On the other hand, the subjective judgement, selection, and preference of decision-makers have a great influence on its results.

Naturally, if the conventional ANP method is used for ERP software selection, the decision-maker's requirements for evaluating a set of possible alternatives may always have ambiguity and multiplicity of meaning. In addition, it is also recognized that human assessment on qualitative attributes is always subjective and thus imprecise. Because of the vagueness and uncertainty on judgements of the decision-maker(s), the crisp pairwise comparison in the conventional ANP seems to be insufficient and imprecise to capture the correct judgements of decision-maker(s). Therefore, fuzzy logic is introduced in the pairwise comparison of the ANP to make up for this deficiency in the conventional ANP, referred to as a fuzzy ANP.

The objective of this paper is to present an intelligent approach to the ERP software-selection problem through a fuzzy ANP to help companies determine the best ERP software satisfying their needs and expectations among a set of possible alternatives on the market. Furthermore, a case study from a leading electronic device manufacturer in Turkey is presented to demonstrate this approach's applicability and validity to make it more understandable, especially for decision-maker(s) involved in the ERP software-selection process in a company.

2. Related literature

In the literature, a large number of studies addressing ERP issues have been published (Esteves and Pastor 2001), but as Stefanou (2001) argues, there is a limited amount of research concerning ERP software evaluation. For example, Sistach *et al.* (1999) proposed a method covering the entire lifecycle of an ERP acquisition process for small manufacturing companies. Brown *et al.* (2000) identified business and IT factors that influence ERP purchase decisions. Zhang *et al.* (2003) analysed critical success factors of ERP systems. Bernroider and Koch (2000) studied the critical differences between small and large organizations concerning the requirements of the ERP software and selection process. Shang and Seddon (2000) constructed a framework for classifying different business benefits of ERP software. Stefanou (2001) divided the benefits into operational and strategic in the framework and proposed ex-ante evaluation of ERP software. Verville and Halingten (2003) proposed a six-stage model for the ERP software buying process. Wei and Wang (2004) suggested a comprehensive framework for selecting ERP software. Skok and Legge (2002) used an interpretive approach to evaluate ERP systems. Sammon and Adam (2000) performed a study for a model of ERP software selection. Stefanou (2000) defined a selection process of ERP systems. Sammon and McAvinue (2004) investigated non-decision-making during an ERP software-selection process.

The AHP has been widely used for MCDM selection problems in literature (i.e. Zahedi 1986, Ayag 2002, 2005a, Scott 2002) since it was first introduced by Saaty (1981). Although the AHP is the most widely used method in solving various MCDM problems, in some cases, some problems cannot be always hierarchically structured in practice because there are possible relationships or interactions and dependencies between the higher-level elements and lower-level elements.

Therefore, a holistic model needs to be developed that can directly accommodate complicated decision-making problems without decomposing them into a simple form. The ANP may be applied to fulfil such complex requirements. The ANP approach may be considered as a second-generation AHP, which has been designed to overcome more complex problems. It replaces hierarchies with network systems that permit all possible elements and join them together in network structures. With its strength, the modelling of the interactions and dependencies among elements of the problem, the ANP may be used to generate a better in-depth analysis and to deliver a more accurate result than the AHP.

In this study, we used the ANP, a more general form of the AHP due to the fact that the AHP cannot accommodate the variety of interactions, dependencies and feedback between higher- and lower-level elements. In other words, the ANP incorporates feedback and interdependent relationships among decision attributes and alternatives (Saaty 1996). This provides a more accurate approach for modelling complex decision environments.

In the literature, to the best of our knowledge, a number of studies have been conducted using the ANP. For example, Hamalainen and Seppalainen (1986) presented ANP-based framework for a nuclear-power-plant licensing problem in Finland. The ANP is also used to incorporate the product lifecycle in replacement decisions (Azhar and Leung 1993). Meade and Presley (2002) used the ANP method for R&D project selection. Agarwal and Shankar (2003) presented a framework for selecting the trust-building environment in an e-enabled supply chain. Yurdakul (2003) used the ANP method to measure the long-term performance of a manufacturing company. Meade and Sarkis (1998) used the ANP to evaluate logistics strategies for an organization seeking to be adaptive to dynamic competitive environments. Lee and Kim (2000, 2001) suggested an improved IS project selection methodology which reflects interdependencies among evaluation criteria and candidate projects using the ANP within a zero-one goal programming model. Partovi and Corredoira (2002) present a quality function deployment (QFD) model based on the ANP for prioritizing and designing rule changes for soccer games to make it more attractive to soccer enthusiasts. Karsak *et al.* (2002) conducted product planning in QFD using a combined ANP and goal programming approach. A fuzzy logic method is introduced next.

Fuzzy-set theory is a mathematical theory pioneered by Zadeh (Lootsma 1997), designed to model the vagueness or imprecision of human cognitive processes. This theory is basically a theory of classes with non-sharp boundaries. What is important to recognize is that any crisp theory can be made fuzzy by generalizing the concept of a set within that theory to the concept of a fuzzy set (Zadeh 1994). Fuzzy-set theory and fuzzy logic have been used in a great variety of applications, as reviewed by several authors (Klir and Yuan 1995, Zimmermann 1996). Within the broad scope of the applications of fuzzy-set theory, engineering design has emerged as an important activity in today's organizations that lack the tools that manage the great amount of imprecise information usually encountered.

In the literature, to the best of our knowledge, a large number of studies on fuzzy AHP and a limited number of studies on a fuzzy ANP have been carried out. For example, Huang *et al.* (2003) used a fuzzy AHP-based methodology for evaluating ERP software alternatives, while Ayag (2005b) used a fuzzy AHP-based simulation approach to evaluate concept alternatives in a new product-development environment. Buyukozkan *et al*. (2004b) proposed a fuzzy AHP approach for software-development strategy selection. Kahraman *et al*. (2004) used fuzzy AHP for a multi-attribute comparison of catering service companies in Turkey. Mikhailov and Singh (2003) used a fuzzy ANP method for the development of decision-support systems. Buyukozkan *et al*. (2004a) proposed a fuzzy optimization model for the QFD planning process using an analytic network approach.

In this study, both of the aforementioned ANP and fuzzy logic methods (referred to as a fuzzy ANP) are integrated in ERP software selection. The fuzzy ANP method allows a more accurate description of the decision-making process. We also defined an ANP-based framework that identifies critical determinants, dimensions, and attribute-enablers used in ERP software selection.

3. Proposed approach

In this paper, we propose a fuzzy ANP-based methodology using Saaty's ANP and Zadeh's fuzzy logic because, in the conventional ANP method, selection attributes are evaluated using a nine-point scaling system, where a score of 1 represents equal importance between the two elements, and a score of 9 indicates the extreme importance of one element, showing that each attribute is related with another. This scaling process is then converted to priority values to compare alternatives. In other words, the conventional ANP method does not take into account the vagueness and uncertainty on judgements of the decision-maker(s). Therefore, fuzzy logic is integrated with Saaty's ANP to overcome the inability of ANP to handle the imprecision and subjectiveness in the pairwise comparison process.

A fuzzy ANP-based methodology for the ERP software selection problem is presented step by step below and illustrated in figure 1.

3.1 *Establishment of a cross-functional team*

A cross-functional team can be established from employees working in various departments of a company. It is also strongly suggested that this team should be established by upper management and that this consists mostly of employees from ERP project-related departments (i.e. marketing, sales, manufacturing, IT). Furthermore, at least, one member who has sufficient authority to make quick decisions, when needed, should be from upper management.

3.2 *Defining the needs and expectations of a company*

The cross-functional team should analyse all business processes carried out in the company, which will be directly affected from an ERP system implementation. Most of the business processes might be modified with respect to the characteristics of ERP software selected. The team can also utilize the company's quality manual, if available, in which critical business processes are summarized based on the ISO 9000 quality-assurance system.

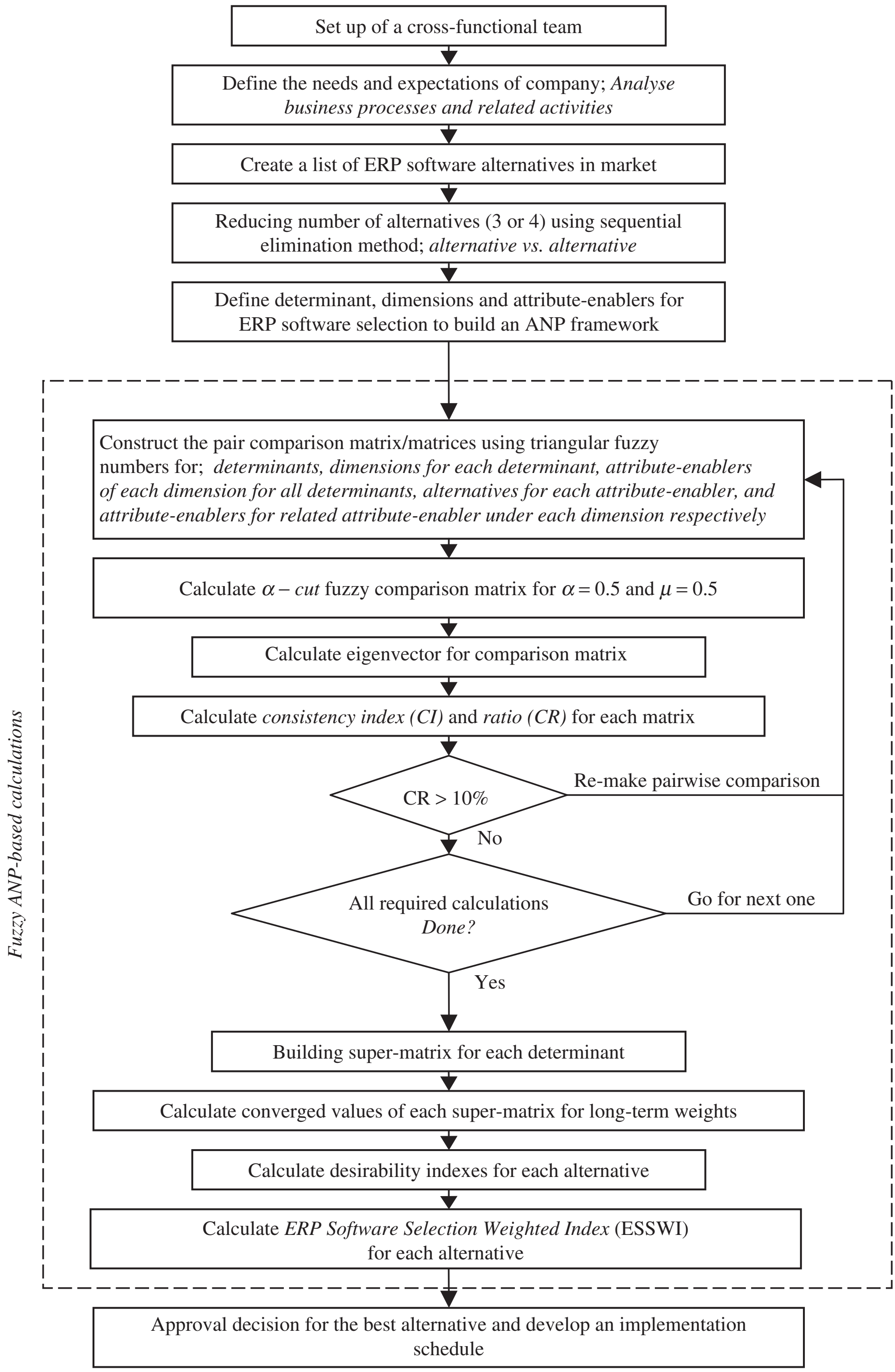

Figure 1. Fuzzy ANP-based methodology for ERP software selection.

3.3 *Creating a list of possible alternatives*

Based on the company's needs and expectations clearly defined above, the team should prepare a list of possible ERP software alternatives on the market. At this stage, the team should also contact the software developer, vendors, and other companies to make a correct list of ERP software alternatives.

3.4 *Pre-selection process to reduce ERP alternatives*

If there are more ERP alternatives in the list than expected, a *pre-selection process* should be used to reduce the number of alternatives to an acceptable level (three or four) so that the selection process will not be too lengthy. Therefore, *sequential elimination methods* are only used to separate the strong candidates among others. These methods are applicable when one can specify values (outcomes) for all criteria and alternatives. Those values should be scalar (measurable) or at least ordinal (capable of being rank-ordered). The methods do not consider weighting, if any, of attributes. In addition these methods are simple, as anyone can learn and apply them easily. There are two kinds of sequential elimination methods such as *alternative versus standard* and *alternative versus alternative*. In the first method, if a standard value is defined incorrectly, naturally the results would not be correct. In the second method, more accurate results are obtained by comparing each alternative with others. In other words, weak alternatives are eliminated. Finally, for both methods, the second method is selected for the pre-selection process (Ayag 2002). These elements are used for evaluating a set of alternatives and are determined based on the needs and expectations of a company. These elements are critical in evaluating ERP software alternatives and should be well defined as they play an important role in finding the best alternative out of the available options.

3.5 *Determining the elements for building an ANP framework*

To identify the elements (i.e. determinants, dimensions, and attribute-enablers) required in an ANP framework and its decision environment related to ERP software selection, first we carried out literature research to determine a set of ERP selection criteria (i.e. Enzweiler 1997, Glazer 1999, Illa *et al.* 2000), and second we analysed a set of companies both currently implementing ERP systems and already implemented. Then, we observed how they defined the selection criteria for their ERP adoption as follows: the upper management of each company played an important role in formulating the project plan, integrating resources, and selecting the most suitable ERP system. In addition, the representatives of different user departments, with at least couple of years' experience in the company and expertise in their particular fields, were also chosen to participate in the project team. To encourage employee engagement and support, the project team held several promotional workshops. These meetings produced numerous valuable recommendations, to which the project team responded during the implementation to reduce resistance to the project. The project team also discussed many issues (i.e. the goals of ERP adoption, scope, organizational strengths, and weaknesses). After obtaining information

Table 1. Definition of determinants, dimensions and attribute-enablers used in building the ANP framework.

Determinants	Dimensions	Code	Definition	Code
Competitive Advantage (CA)	System cost	SC	Licence fee	LF
			Consultant expenses	CE
			Maintenance cost	MC
			Infrastructure cost	IC
Productivity (PR)	Vendor support	VS	Good reputation	GR
			Consulting performance	CP
			R&D capability	RDC
			Technical-support capability	TSC
			Training performance	TP
Profitability (PF)	Flexibility	FL	Upgrade ability	UA
			Ease of integration	EI
			Easy of in-house development	EHD
	Functionality	FU	Module completion	MOC
			Function fitness	FF
			Security level	SL
	Reliability	RE	Stability	ST
			Recovery ability	RA
	Ease of use	EU	Easy of operations	EO
			Easy of learning	EL
	Technology advance	TA	Standardization	SD
			Integration of legacy systems	ILS
			Easy to maintain	EM

for both the company and ERP systems, the project team identified the selection criteria for the ERP system selection. As a result of this, we considered three determinants, seven different dimensions, and 22 attribute-enablers, as shown in table 1.

As an example of the relationships, among the determinants, competitive advantage (CA), productivity (PR), and profitability (PF) can be given as follows: if the productivity increases, the number of units produced in a certain time (units per day), resulting in a decreasing unit cost and naturally increasing the profitability of the company. If the productivity increases, the competitive advantage of the company compared with other competitors increasing as they can sell the product at a cheaper price. These determinants are taken into consideration in the ERP selection process to find out how they are affected by the selection criteria and sub-criteria (dimensions and attribute-enablers) of an ERP system.

The seven dimensions (system cost, vendor support, flexibility, functionality, reliability, ease of use, and technological advances) also play an important role for each determinant. These dimensions also affect each other. For example, if the system cost increases, the software becomes more sophisticated and offers more options for system users, thus making the system more flexible but possibly making it more complicated to use. More vendor support is required. On the other hand, functionality and reliability increase, and more technical advances can be expected. The relationships between determinants and dimensions might be as follows: better vendor support results in better use of an ERP system and affects the determinants by increasing productivity, profitability, and the company's competitive advantage.

To explain the network relations of the attribute-enablers (good reputation consulting performance, R&D capability, technical support capability, and training performance) for the related dimension of vendor support, we can give the following example. If the R&D capability of the vendor is high, it most likely has a good training performance, technical support capability, and consulting performance, as well as a good reputation. On the other hand, if the consulting performance is satisfactory, the vendor may have a good reputation. In addition, if the R&D capability of the vendor is high, it provides better vendor support and functionality, etc. and results in better ERP system use, which leads to better productivity and profitability, and a greater competitive advantage.

3.6 *Making fuzzy ANP-based calculations*

In the following sections, a fuzzy-logic method is introduced, and then the computational steps of the fuzzy ANP are presented.

3.6.1 Fuzzy logic. The key idea of fuzzy-set theory is that an element has a degree of membership in a fuzzy set (Negoita 1985, Zimmermann 1996). A fuzzy set is defined by a membership function (all the information about a fuzzy set is described by its membership function). The membership function maps elements (crisp inputs) in the universe of discourse (an interval containing all the possible input values) to elements (degrees of membership) within a certain interval, which is usually $[0, 1]$. Then, the degree of membership specifies the extent to which a given element belongs to a set or is related to a concept. The most commonly used range for expressing the degree of membership is the unit interval $[0, 1]$. If the value assigned is 0, the element does not belong to the set (it has no membership). If the value assigned is 1, the element belongs completely to the set (it has total membership). Finally, if the value lies within the interval $[0, 1]$, the element has a certain degree of membership (it belongs partially to the fuzzy set). A fuzzy set, then, contains elements that have different degrees of membership in it.

In this study, in order to capture the vagueness, triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$, are used to represent subjective pairwise comparisons of the selection process. Triangular fuzzy numbers show the participants' judgements or preferences among the options such as equally important, weakly more important, strongly more important, very strongly more important, and extremely more important preferred (table 2). $F = \{(x, \mu_{\tilde{M}}(x)), x \in R\}$ indicates a fuzzy set, where x takes it values on the real line, $\boldsymbol{R}$: $-\infty < x < +\infty$, and $\mu_{\tilde{M}}(x)$ is a continuous mapping from R to the closed interval [0,1]. The element, x, in the set expresses the real values in the closed interval $[l, u]$ including the mean (m) of each triangular fuzzy number.

Table 2. Definition and membership function of fuzzy number (Ayag 2005b).

Intensity of importance[a]	Fuzzy number	Definition	Membership function
1	$\tilde{1}$	Equally important/preferred	(1, 1, 2)
3	$\tilde{3}$	Moderately more important/preferred	(2, 3, 4)
5	$\tilde{5}$	Strongly more important/preferred	(4, 5, 6)
7	$\tilde{7}$	Very strongly more important/preferred	(6, 7, 8)
9	$\tilde{9}$	Extremely more important/preferred	(8, 9, 10)

[a] Fundamental scale used in pairwise comparison (Saaty 1989).

A triangular fuzzy number denoted as $\tilde{M} = [l, u]$ has the following triangular type membership function:

$$
\begin{array}{l}
0, \quad x < 1 \\
\dfrac{x-1}{m-1}, \quad l \le x \le m \\
\mu_{\tilde{M}}(x) = \dfrac{u-x}{u-m}, \quad m \le x \le u \\
0, \quad x > u.
\end{array}
$$

If x is less than the lower level of a fuzzy number (l), the function becomes 0 (zero); if x is greater than/equal to the lower level (l) and less than/equal to mean level (m), the function becomes $(x-l)/(m-l)$, and if x is greater than/equal to the mean level (m) and less than/equal to the upper level (u), the function becomes $(u-x)/(u-m)$.

Alternatively, by defining the interval of confidence level α, the triangular fuzzy number can be characterized as:

$$\forall \alpha \in [0, 1] \quad \tilde{M}_\alpha = [l^\alpha, u^\alpha] = (m-1)\alpha + l, \ -(u-m)\alpha + u.$$

Several main operations for positive fuzzy numbers are described by the interval of confidence, by Kaufmann and Gupta (1988), as given below:

$$
\begin{array}{l}
\forall m_l, m_u, n_l, n_u \in R^+, \quad \tilde{M}_\alpha = \left[m_l^\alpha, m_u^\alpha\right], \quad \tilde{N}_\alpha = \left[n_l^\alpha, n_u^\alpha\right], \quad \alpha \in [0, 1] \\
\tilde{M}_\alpha \oplus \tilde{N}_\alpha = \left[m_l^\alpha + n_l^\alpha, m_u^\alpha + n_u^\alpha\right] \quad \tilde{M}_\alpha - \tilde{N}_\alpha = \left[m_l^\alpha - n_l^\alpha, m_u^\alpha - n_u^\alpha\right] \\
\tilde{M}_\alpha \otimes \tilde{N}_\alpha = \left[m_l^\alpha n_l^\alpha, m_u^\alpha n_u^\alpha\right] \quad \tilde{M}_\alpha / \tilde{N}_\alpha = \left[m_l^\alpha / n_l^\alpha, m_u^\alpha / n_u^\alpha\right].
\end{array}
$$

The triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$, are utilized to improve the conventional nine-point scaling scheme. In order to take the imprecision of human qualitative assessments into consideration, the five triangular fuzzy numbers ($\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, $\tilde{9}$) are defined with the corresponding membership function. All attributes and alternatives are linguistically depicted in figure 2, and table 2 lists the definition and membership function of the fuzzy numbers (Ayag 2005b). The shape and position of the linguistic terms are chosen to illustrate the fuzzy extension of the method.

3.6.2 Computational steps of fuzzy ANP. A step-by-step fuzzy ANP approach to ERP software selection is now presented. In the fuzzy ANP, triangular fuzzy

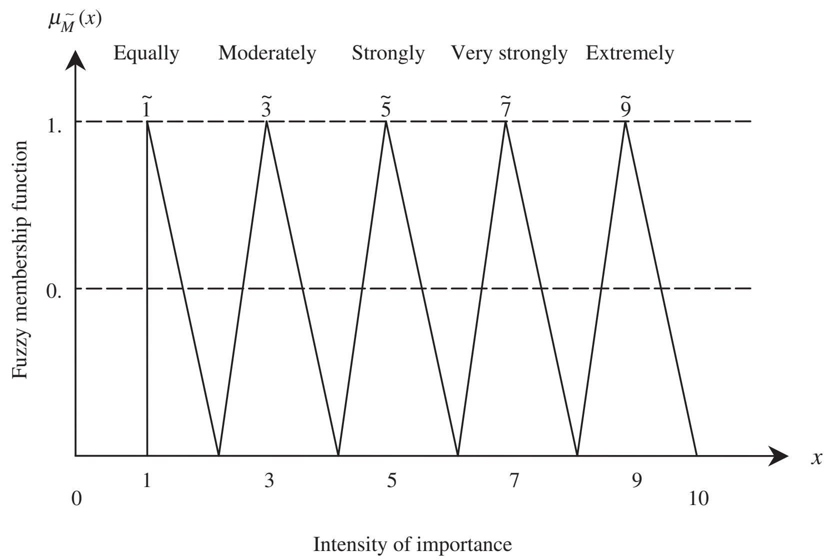

Figure 2. Fuzzy membership function for linguistic values for attributes or alternatives.

numbers are used to improve the scaling scheme in the judgement matrices, and interval arithmetic is used to solve the fuzzy eigenvector (Cheng and Mon 1994).

3.6.2.1 Step I. Model construction and problem structuring: the topmost elements in the hierarchy of determinants are decomposed into dimensions and attribute-enablers. The decision model development requires identification of dimensions and attribute-enablers at each level and the definition of their inter-relationships. The ultimate objective of hierarchy is to identify alternatives that are significant to determine the best ERP software.

In this study, we defined three evaluation determinants, CA, PR, and PF, that are aggregated in the ERP Software Selection Weighted Index (ESSWI) selection step. These determinants were determined based on the idea of how an ERP system implementation mainly affects a company or an enterprise at the top level.

To define the ANP hierarchy, we used Saaty's suggestions of using a network for categories of benefits, costs, risks, and opportunities (Saaty 1996). Instead of Saaty's categories, we used the aforementioned determinants. In order to analyse the combined influence of the determinants for ERP software selection, an ESSWI is calculated to rank ERP software alternatives. This index also takes the influences of dimensions and attribute-enablers into consideration. Figure 3 shows the ANP-based framework for the ERP software selection problem.

3.6.2.2 Step II. Pairwise comparison matrices between component/attributes levels. By using triangular fuzzy numbers ($\tilde{1}$, $\tilde{3}$, $\tilde{5}$, $\tilde{7}$, $\tilde{9}$), the decision-makers are asked to respond to a series of pairwise comparisons with respect to an upper-level 'control' criterion. These are conducted with respect to their relevance and importance towards the control criterion. In the case of interdependencies, components in the

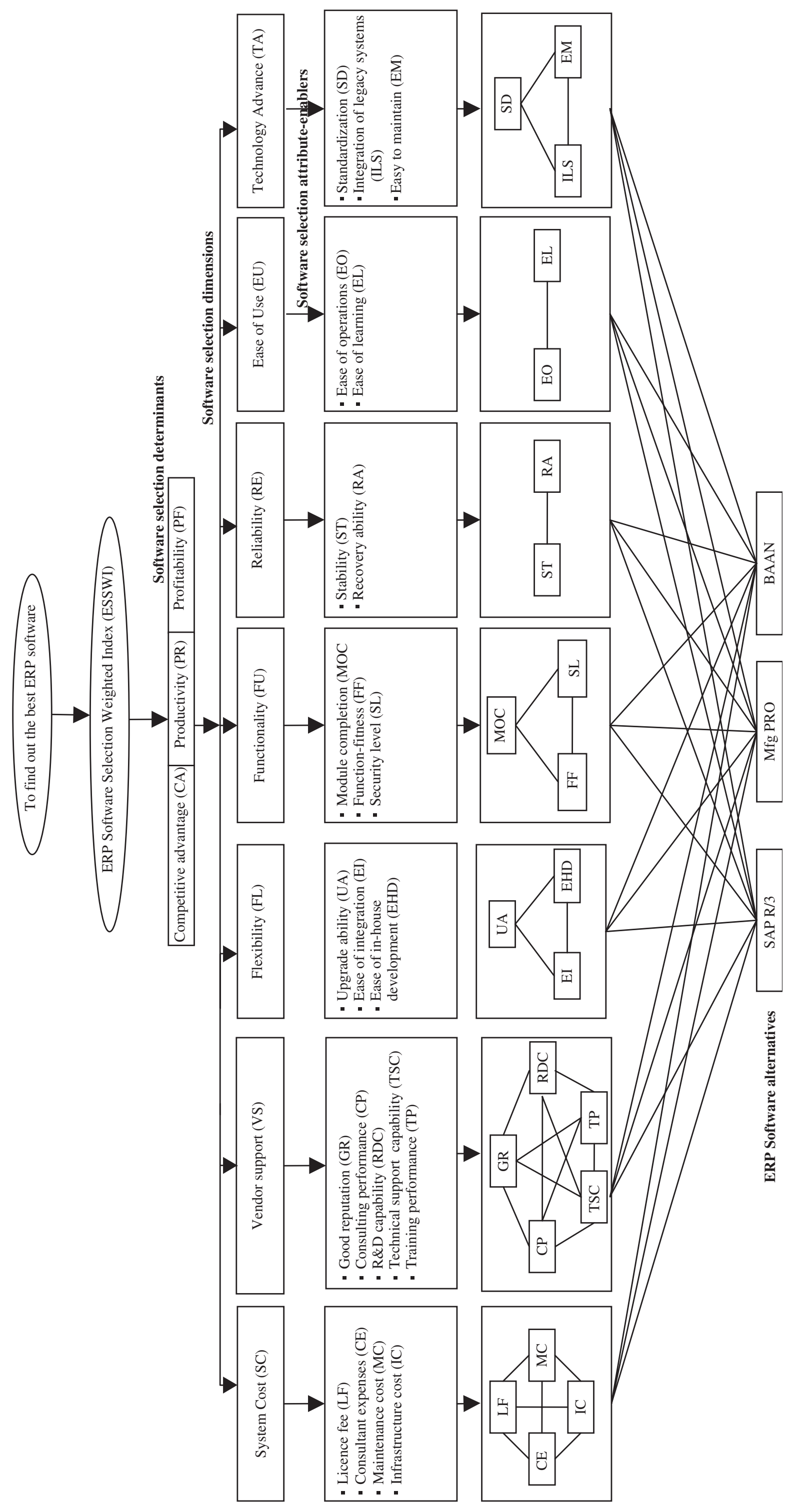

Figure 3. ANP framework for ERP software selection.

same level are viewed as controlling components for each other. Levels may also be interdependent. Through pairwise comparisons by using triangular fuzzy numbers $(\tilde{1},\ \tilde{3},\ \tilde{5},\ \tilde{7},\ \tilde{9})$, the fuzzy judgement matrix $\tilde{A}(\tilde{a}_{ij})$ is constructed as given below:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & \dots & 1 \end{bmatrix},$$

where $\tilde{a}^{\alpha}_{ij} = 1$, if i is *equal* to j, and $\tilde{a}^{\alpha}_{ij} = 1\ \tilde{a}^{\alpha}_{ij} = \tilde{1},\ \tilde{3},\ \tilde{5},\ \tilde{7},\ \tilde{9}$ or $\tilde{1}^{-1},\ \tilde{3}^{-1},\ \tilde{5}^{-1},\ \tilde{7}^{-1},\ \tilde{9}^{-1}$, if i is not equal to j.

For solving a fuzzy eigenvalue, a fuzzy eigenvalue, $\tilde{\lambda}$, is a fuzzy number solution to

$$\tilde{A}\tilde{x} = \tilde{\lambda}\tilde{x}, \tag{1}$$

where $\tilde{\lambda}_{\max}$ is the largest eigenvalue of $\tilde{A}$. Saaty (1981) provides several algorithms for approximating $\tilde{x}$, $\tilde{A}$, is the $n \times n$ fuzzy matrix containing fuzzy numbers $\tilde{a}_{ij}$, and $\tilde{x}$, is a non-zero $n \times 1$, fuzzy vector containing fuzzy number $\tilde{x}_i$. To perform fuzzy multiplications and additions by using the interval arithmetic and $\alpha -$cut, the equation $\tilde{A}\tilde{x} = \tilde{\lambda}\tilde{x}$ is:

$$\left[a^{\alpha}_{i1l}x^{\alpha}_{1l},\ a^{\alpha}_{i1u}x^{\alpha}_{1u}\right] \oplus \cdots \oplus \left[a^{\alpha}_{inl}x^{\alpha}_{nl},\ a^{\alpha}_{inu}x^{\alpha}_{nu}\right] = \left[\lambda x^{\alpha}_{il},\ \lambda x^{\alpha}_{iu}\right],$$

where

$$\tilde{A} = [\tilde{a}_{ij}], \quad \tilde{x}_i = (\tilde{x}_1, \dots, \tilde{x}_n),$$

$$\tilde{a}^{\alpha}_{ij} = [a^{\alpha}_{ijl},\ a^{\alpha}_{iju}], \quad \tilde{x}^{\alpha}_{ij} = [x^{\alpha}_{il}, x^{\alpha}_{iu}], \quad \tilde{\lambda}^{\alpha} = [\lambda^{\alpha}_{l}, \lambda^{\alpha}_{u}] \tag{2}$$

for $0 < \alpha \le 1$ and all i, j, where $i = 1, 2, \dots, n$, $j = 1, 2, \dots, n$; a^{α}_{ijl}; the lower value (l) of a triangular fuzzy number at i. line and j. column of the fuzzy judgement matrix, $\tilde{A}$ for a given α value; a^{α}_{iju}; the upper value (u) of a triangular fuzzy number at i. line and j. column of the fuzzy judgement matrix, $\tilde{A}$ for a given α value; x^{α}_{il}; the lower value (l) at i. line of the fuzzy vector for a given α value; x^{α}_{iu}; the lower value (u) at i. line of the fuzzy vector for a given α value.

$\alpha -$cut is known to incorporate the experts or decision-maker(s) confidence over his/her preference or the judgements. Degree of satisfaction for the judgement matrix $\tilde{A}$ is estimated by the index of optimism μ. The larger value of index μ indicates the higher degree of optimism. The index of optimism is a linear convex combination (Lee 1999) defined as:

$$\tilde{a}^{\alpha}_{ij} = \mu a^{\alpha}_{iju} + (1 - \mu) a^{\alpha}_{ijl}, \quad \forall \mu \in [0, 1]. \tag{3}$$

While α is fixed, the following matrix can be obtained after setting the index of optimism, μ, to estimate the degree of satisfaction. Both are defined in the range [0, 1] by decision-makers:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12}^{\alpha} & \dots & \dots & \tilde{a}_{1n}^{\alpha} \\ \tilde{a}_{12}^{\alpha} & 1 & \dots & \dots & \tilde{a}_{2n}^{\alpha} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{a}_{n1}^{\alpha} & \tilde{a}_{n2}^{\alpha} & \dots & \dots & 1 \end{bmatrix}.$$

The eigenvector is calculated by fixing the μ value and identifying the maximal eigenvalue.

After defuzzification of each pairwise matrix, the consistency ratio (CR) for each matrix is calculated. The deviations from consistency are expressed by the following equation consistency index, and the measure of inconsistency is called the consistency index (CI):

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{4}$$

The CR is used to estimate directly the consistency of pairwise comparisons. The CR is computed by dividing the CI by a value obtained from a table of Random Consistency Index (RI):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \tag{5}$$

If the CR less than 0.10, the comparisons are acceptable, otherwise it is not acceptable. RI is the average index for randomly generated weights (Saaty 1981).

3.6.2.3 Step III. Pairwise comparison matrices of inter-dependencies. In order to reflect the interdependencies in network, pairwise comparisons among all the attribute-enablers are calculated.

3.6.2.4 Step IV. Super-matrix formation and analysis. The super-matrix formation allows a resolution of the effects of interdependence that exists between the elements of the system. The super-matrix is a partitioned matrix, where each sub-matrix is composed of a set of relationships between two levels in the graphical model. Raising the super-matrix to the power $2k + 1$, where k is an arbitrarily large number, allows convergence of the interdependent relationships between the two levels being compared. The super-matrix is converged for obtaining a long-term stable set of weights.

3.6.2.5 Step V. Selection of the best alternative. The desirability index is calculated for each alternative that is based on the determinants by using the weights obtained from the pairwise comparisons of the alternatives, dimensions, and weights of attribute-enablers from the converged super matrix. In the equation of desirability index, D_{ia}, for alternative i and determinant a, CA is defined as:

$$D_{ia} = \sum_{j=1}^{J} \sum_{k=1}^{K_{ja}} P_{ja} A_{kja}^{D} A_{kja}^{I} S_{ikja}. \tag{6}$$

The notations used in this equation are listed in table 3.

Table 3. Notations used to calculate desirability index.

Notations	Definition
P_{ja}	Relative importance weight of dimension j on determinant a
A^{D}_{kja}	Relative importance weight for attribute-enabler k of dimension j, and Determinant a for the dependency (D) relationships between attribute-enabler's component levels
A^{I}_{kja}	Stabilized relative importance weight for attribute-enabler k of dimension j, and determinant a for the independency (I) relationships within attribute-enabler's component level
S_{ikja}	Relative impact of concept alternative i on attribute-enabler k of dimension j of concept selection network
K_{ja}	Index set of attribute-enablers for dimension j of determinant a
J	Index set for attribute j

3.6.2.6 Step VI. Calculation of ESSWI. To finalize the analysis of ERP software selection, the *ESSWI* is calculated for each alternative. The ESSWI_i for an alternative i is the product of the desirability indices, D_{ia}. After calculating the ESSWI values for each alternative, they are normalized to rank the alternatives to determine that which has the highest value.

3.7 *Approval and further actions*

The final alternative selected is presented to upper management for approval to proceed with further actions such as developing an implementation schedule, training key users, and so on.

4. Case study

A fuzzy ANP-based approach was presented above to evaluate a set of ERP software alternatives. In this section, a case study is presented to prove this approach's applicability and validity to make it more understandable, especially for decision-makers involved in the ERP-software-selection process in a company. This case study was performed in a leading company in Turkey which designs and manufacturers electronic devices such as CRT, LCD, and plasma TVs, desktop and notebook computers, and so on. It has more than 3400 different products and exports to at least 80 countries under 300 different brand names.

First of all, this company set up a cross-functional team consisting of employees from its various departments (i.e. IT, marketing and sales, production planning and control, and manufacturing) because the ERP software to be selected would affect most business functions of the company. The company's vice general manager, who is responsible for production activities, was also a member of the team to reflect management support to other team members as well as other employees. Next, the company's needs and expectations were determined by using a companywide survey done in each department and consulting middle- or upper-level managers or directors who have authorities to make all kinds of decisions at any level. Then, by evaluating the data obtained, a company map showing what kinds of expectations and needs should be met by an ERP software was obtained. Next, the cross-functional team

Table 4. Fuzzy comparison matrix for the determinants.

Determinant	CA	PR	PF
CA	1	$\tilde{5}$	$\tilde{3}$
PR	$\tilde{5}^{-1}$	1	$\tilde{1}^{-1}$
PF	$\tilde{3}^{-1}$	$\tilde{1}$	1

conducted market research and prepared a list of possible ERP software alternatives based on the company map. The list included only three of the most commonly used ERP software packages for large companies such as SAP R/3, Mfg-PRO, and BAAN. The team also performed a benchmark study for their competitors in the same sectors in Turkey as well as other countries to determine alternatives. Since there were only three alternatives, the pre-selection process was ignored, and all alternatives were taken into consideration for further work, referred to as the fuzzy ANP study.

We then carried out the fuzzy ANP study using triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$ to express the preference in the pairwise comparisons and obtained the fuzzy comparison matrix for the relative importance of the determinants shown in table 4.

The lower limit and upper limit of the fuzzy numbers with respect to α were defined as follows by applying equation (2):

$$\tilde{1}_\alpha = [1, 3 - 2\alpha],$$

$$\tilde{3}_\alpha = [1 + 2\alpha, 5 - 2\alpha], \quad \tilde{3}_\alpha^{-1} = \left[\frac{1}{5 - 2\alpha}, \frac{1}{1 + 2\alpha}\right],$$

$$\tilde{5}_\alpha = [3 + 2\alpha, 7 - 2\alpha], \quad \tilde{5}_\alpha^{-1} = \left[\frac{1}{7 - 2\alpha}, \frac{1}{3 + 2\alpha}\right],$$

$$\tilde{7}_\alpha = [5 + 2\alpha, 9 - 2\alpha], \quad \tilde{7}_\alpha^{-1} = \left[\frac{1}{9 - 2\alpha}, \frac{1}{5 + 2\alpha}\right],$$

$$\tilde{9}_\alpha = [7 + 2\alpha, 11 - 2\alpha], \quad \tilde{9}_\alpha^{-1} = \left[\frac{1}{11 - 2\alpha}, \frac{1}{7 + 2\alpha}\right].$$

Then, we substituted the values, $\alpha = 0.5$ and $\mu = 0.5$ in the above expression into the fuzzy comparison matrix and obtained the entire $\alpha -$ cuts fuzzy comparison matrix shown in table 5 (equation (3) was used to calculate the eigenvector for a pairwise comparison matrix given in table 6). One matrix was built.

Then, using equation (1), we first calculated eigenvalue of the matrix $\boldsymbol{A}$ by solving the characteristic equation of $\boldsymbol{A}$, $\det(A - \lambda I) = 0$ and determined all λ values for $A(\lambda_1, \lambda_2, \lambda_3)$. The largest eigenvalue of pairwise matrix, $\lambda_{\max}$ was calculated to be 3.099. The dimension of the matrix, n, is 3 and the random index, $RI(n)$, is 0.58 (RI is a function of the number of attributes; Saaty 1981). Finally, we calculated the CI and the CR of the matrix by using equations (4) and (5) as follows:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} = \frac{3.099 - 3}{2} = 0.05, \quad \mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = \frac{0.05}{0.58} = 0.085 < 0.10.$$

Table 5. $\alpha-$cuts fuzzy comparison matrix for the determinants ($\alpha = 0.5$).

Determinant	CA	PR	PF
CA	1	[4, 6]	[2, 4]
PR	[1/6, 1/4]	1	[1/2, 1]
PF	[1/4, 1/2]	[1, 2]	1

Table 6. Pairwise comparison matrix for the relative importance of the determinants (CR = 0.085).

Determinants	CA	PR	PF	e-Vector
CA	1.000	5.000	3.000	0.643
PR	0.208	1.000	0.750	0.141
PF	0.375	1.500	1.000	0.216
			λ_{max}	3.099
			CI	0.05
			RI	0.58
			CR	0.085 < 0.100 ok

Table 7. Fuzzy comparison matrix for the dimensions for the determinant CA.

CA							
Dimensions	SC	VS	FL	FU	RE	EU	TA
SC	1	$\tilde{1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{5}$	$\tilde{5}$	$\tilde{7}$
VS	$\tilde{1}^{-1}$	1	$\tilde{1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{1}$	$\tilde{3}$
FL	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	1	$\tilde{1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{3}$
FU	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	1	$\tilde{1}$	$\tilde{5}$	$\tilde{5}$
RE	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	1	$\tilde{1}$	$\tilde{1}$
EU	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	1	$\tilde{1}$
TA	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{1}^{-1}$	1

We also followed the same method to build fuzzy pairwise comparison matrices of the dimensions for each determinant and performed all fuzzy calculations. A total of three matrices were constructed. In tables 7–9, the fuzzy pairwise comparison matrix of the dimensions for the determinant CA is presented.

Then, to reflect the interdependencies in the network, we constructed fuzzy pairwise comparison matrices for the attribute-enablers under each dimension for all three determinants and performed all fuzzy calculations. A total of 21 matrices were built. In tables 10–12, the fuzzy pairwise comparison matrices for attribute-enablers under flexibility (FL) for CA using triangular fuzzy numbers are presented.

We also built fuzzy pairwise comparison matrices that can reflect the interdependencies in the network and the fuzzy pairwise comparisons are

Table 8. $\alpha-$cuts fuzzy comparison matrix for the determinant CA ($\alpha=0.5$).

CA							
Dimensions	SC	VS	FL	FU	RE	EU	TA
SC	1	[1, 2]	[2, 4]	[1, 2]	[4, 6]	[4, 6]	[6, 8]
VS	[1/2, 1]	1	[1, 2]	[2, 4]	[1, 2]	[1, 2]	[2, 4]
FL	[1/4, 1/2]	[1/2, 1]	1	[1, 2]	[2, 4]	[2, 4]	[2, 4]
FU	[1/2, 1]	[1/4, 1/2]	[1/2, 1]	1	[1, 2]	[4, 6]	[4, 6]
RE	[1/6, 1/4]	[1/2, 1]	[1/4, 1/2]	[1/2, 1]	1	[1, 2]	[1, 2]
EU	[1/6, 1/4]	[1/2, 1]	[1/4, 1/2]	[1/6, 1/4]	[1/2, 1]	1	[1, 2]
TA	[1/8, 1/6]	[1/4, 1/2]	[1/4, 1/2]	[1/6, 1/4]	[1/2, 1]	[1/2, 1]	1

Table 9. Pairwise comparison matrix for the relative importance of the dimensions for the determinant CA (CR = 0.099).

CA								
Dimensions	SC	VS	FL	FU	RE	EU	TA	e-Vector
SC	1.000	1.500	3.000	1.500	5.000	5.000	7.000	0.303
VS	0.750	1.000	1.500	3.000	1.500	1.500	3.000	0.186
FL	0.375	0.750	1.000	1.500	3.000	3.000	3.000	0.156
FU	0.750	0.375	0.750	1.000	1.500	5.000	5.000	0.162
RE	0.208	0.750	0.375	0.750	1.000	1.500	1.500	0.081
EU	0.208	0.750	0.375	0.208	0.750	1.000	1.500	0.065
TA	0.146	0.375	0.375	0.208	0.750	0.750	1.000	0.047
							λ_{max}	7.786
							CI	0.131
							RI	1.32
							CR	0.099 < 0.100 ok

Table 10. Fuzzy comparison matrix of attribute-enablers under CA and FL.

CA			
FL	UA	EI	EHD
UA	1	$\tilde{7}$	$\tilde{9}$
EI	$\tilde{7}^{-1}$	1	$\tilde{1}$
EHD	$\tilde{9}^{-1}$	$\tilde{1}^{-1}$	1

conducted among all the attribute-enablers. A total of 66 matrices were built to obtain three super-matrices for all determinants. Fuzzy pairwise comparison matrices of the attribute-enablers for upgrade ability (UA) under flexibility (F) and CA are presented in tables 13–15.

Table 11. $\alpha-$cuts fuzzy comparison matrix of attribute-enablers under CA and FL ($\alpha = 0.5$).

CA			
FL	UA	EI	EHD
UA	1	[6, 8]	[8, 10]
EI	[1/8, 1/6]	1	[1, 2]
EHD	[1/10, 1/8]	[1/2, 1]	1

Table 12. Pairwise comparison matrix for the relative importance of the attribute-enablers of the dimension, FL for the determinant, CA (CR = 0.047).

CA				
FL	UA	EI	EHD	e-Vector
UA	1.000	7.000	9.000	0.792
EI	0.146	1.000	1.500	0.120
EHD	0.113	0.750	1.000	0.087
			λ_{max}	3.055
			CI	0.027
			RI	0.58
			CR	$0.047 < 0.100$ ok

Table 13. Fuzzy comparison matrix for attribute-enablers for UA under CA and FL.

UA	EI	EHD
EI	1	$\tilde{1}$
EHD	$\tilde{1}^{-1}$	1

Table 14. $\alpha-$cuts fuzzy comparison matrix for attribute-enablers for UA under CA and FL ($\alpha = 0.5$).

UA	EI	EHD
EI	1	[1, 2]
EHD	[1/2, 1]	1

Table 15. Pairwise comparison matrix for the relative importance of the attribute-enablers for UA under CA and FL.

UA	EI	EHD	e-Vector
EI	1	1.500	0.586
EHD	0.750	1	0.414

The final standard fuzzy pairwise comparison evaluations are required for the relative impacts of each ERP software alternative. The number of fuzzy pairwise comparison matrices is dependent on the number of attribute-enablers included in the ANP framework of ERP software selection. Then, we built 66 fuzzy pairwise comparison matrices for the alternatives (SAP R/3, Mfg-PRO, and BAAN) for each attribute-enabler for all determinants and performed all fuzzy calculations. Pairwise comparison matrices of the alternatives under CA, F, and UA are presented in tables 16–18.

The super-matrix, M, shows the detailing results of the relative importance measures for each of the attribute-enablers for the determinant CA of ERP software

Table 16. Fuzzy comparison matrix for the alternatives under CA, FL, and UA.

CA			
UA	SAP R/3	Mfg-PRO	BAAN
SAP R/3	1	$\tilde{1}$	$\tilde{7}$
Mfg-PRO	$\tilde{1}^{-1}$	1	$\tilde{5}$
BAAN	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	1

Table 17. $\alpha-$cuts fuzzy comparison matrix for criteria ($\alpha=0.5$) for alternatives under CA, FL, and UA.

CA			
UA	SAP R/3	Mfg-PRO	BAAN
SAP R/3	1	[1, 2]	[6, 8]
Mfg-PRO	[1/2, 1]	1	[4, 6]
BAAN	[1/8, 1/6]	[1/6, 1/4]	1

Table 18. Pairwise comparison matrix for the relative importance of ERP software alternatives under CA, FL, and UA (CR = 0.053).

CA				
UA	SAP R/3	Mfg-PRO	BAAN	e-Vector
SAP R/3	1.000	1.500	7.000	0.540
Mfg-PRO	0.750	1.000	5.000	0.383
BAAN	0.146	0.208	1.000	0.077
			λ_{max}	3.061
			CI	0.031
			RI	0.58
			CR	0.053 < 0.100 ok

selection clusters. Since there are 22 fuzzy pairwise comparison matrices, one for each of the interdependent attribute-enablers in the CA hierarchy, there will be 22 non-zero columns in this super-matrix. Each of the non-zero values in the column in M is the relative importance weight associated with the interdependently pairwise comparison matrices. In this model, there are three super-matrices, one for each of the determinants (CA, PR, and PF) of the best ERP software selection hierarchy network, which need to be evaluated. Then, M is converged to obtain a long-term stable set of weights. For this, the power of the super-matrix is raised to an arbitrarily large number. In our case study, convergence was reached at the 65th power. Table 19 shows the values after convergence.

To select the best alternative, we used equation (6) and carried out all calculations as given in table 20. Table 20 shows the calculations for the desirability indices (D_i cost) for ERP software alternatives based on the CA control hierarchy by using the weights obtained from the fuzzy pairwise comparisons of ERP software alternatives, dimensions, and attribute-enablers from the converged super-matrix. The weights were used to calculate a score for the determinant of ERP software selection desirability for each alternative being considered. For example, the desirability indexes of the alternatives (SAP R/3, Mfg-PRO, and BAAN) under the first determinant CA, where the index, a, is equal to 1, were calculated using equation (6), as illustrated in table 20.

To determine the best solution, the ESSWI was calculated for each ERP software alternative (SAP R/3, Mfg-PRO and BAAN). The final results are given in table 21. The table indicates that the best alternative is SAP R/3.

For SAP R/3 to be approved by the company's top management, a more detailed implementation schedule was first prepared in cooperation with SAP A.G. (Turkish branch) using Microsoft Project, and then further activities were carried out step by step until it went live. The company also customized SAP R/3 system and added extra modules according to their needs, and now SAP R/3 is working well and is continuously being developed to make it more useful for a team in the company.

5. Conclusions

In this paper, a fuzzy ANP-based methodology for ERP software selection problem has been proposed by taking into consideration quantitative and qualitative elements to evaluate ERP software alternatives.

The conventional ANP methodology uses a nine-point scale and is quite new and vastly improved over the AHP method, as it allows for feedback between hierarchical levels. Because of the vagueness and uncertainty on judgements of the decision-maker(s), the nine-point scale pairwise comparison in the conventional ANP could be insufficient and imprecise for reflecting the right judgements of decision makers. For this reason, fuzzy logic was integrated with the conventional ANP to overcome this problem.

As compared with the fuzzy AHP, the analysis using the fuzzy ANP is relatively cumbersome, because a great deal of fuzzy pairwise-comparison matrices using triangular fuzzy numbers should be built for a typical study. In our study, we built a total of 157 fuzzy pairwise comparison matrices. Acquiring the relationships among determinants, dimensions and attribute-enablers took a very long time and

Table 19. Super-matrix for CA after convergence (M^{65}).

CA	LF	CE	MC	IC	GR	CP	RDC	TSC	TP	UA	EI	EHD	MOC	FF	SL	ST	RA	EO	EL	SD	ILS	EM
LF	0.392	0.392	0.392	0.392																		
CE	0.303	0.303	0.303	0.303																		
MC	0.200	0.200	0.200	0.201																		
IC	0.112	0.112	0.112	0.112																		
GR					0.353	0.354	0.354	0.354	0.354													
CP					0.272	0.272	0.272	0.272	0.272													
RDC					0.176	0.176	0.176	0.176	0.176													
TSC					0.127	0.127	0.127	0.127	0.127													
TP					0.067	0.067	0.067	0.067	0.067													
UA										0.439	0.439	0.439										
EI										0.301	0.301	0.301										
EHD										0.260	0.260	0.260										
MOC													0.465	0.464	0.465							
FF													0.433	0.433	0.433							
SL													0.102	0.102	0.102							
ST																1.000	1.000					
RA																0.000	0.000					
EO																		1.000	1.000			
EL																		0.000	0.000			
SD																				0.465	0.465	0.465
ILS																				0.311	0.311	0.311
EM																				0.224	0.224	0.224

Table 20. ERP software selection desirability indexes for CA ($a = 1$).

Dimension	Attribute enabler	P_{j1}	A^{D}_{kj1}	A^{I}_{kj1}	S_{1kj1}	S_{2kj1}	S_{3kj1}	ERP alternative: SAP R/3	Mfg-PRO	BAAN
1	1	0.303	0.483	0.392	0.529	0.355	0.116	0.0303	0.0204	0.0067
	2	0.303	0.328	0.303	0.487	0.433	0.079	0.0147	0.0130	0.0024
	3	0.303	0.129	0.200	0.643	0.216	0.141	0.0050	0.0017	0.0011
	4	0.303	0.060	0.112	0.116	0.355	0.529	0.0002	0.0007	0.0011
2	5	0.186	0.398	0.353	0.660	0.249	0.091	0.0172	0.0065	0.0024
	6	0.186	0.233	0.272	0.739	0.153	0.108	0.0087	0.0018	0.0013
	7	0.186	0.242	0.176	0.745	0.182	0.074	0.0059	0.0014	0.0006
	8	0.186	0.072	0.127	0.662	0.274	0.064	0.0011	0.0005	0.0001
	9	0.186	0.056	0.067	0.116	0.355	0.529	0.0001	0.0002	0.0004
3	10	0.156	0.792	0.439	0.540	0.383	0.077	0.0293	0.0208	0.0042
	11	0.156	0.120	0.301	0.487	0.433	0.079	0.0027	0.0024	0.0004
	12	0.156	0.087	0.260	0.529	0.355	0.116	0.0019	0.0013	0.0004
4	13	0.162	0.564	0.465	0.662	0.274	0.064	0.0281	0.0116	0.0027
	14	0.162	0.368	0.433	0.660	0.249	0.091	0.0170	0.0064	0.0023
	15	0.162	0.068	0.102	0.116	0.355	0.529	0.0001	0.0004	0.0006
5	16	0.081	0.739	1.000	0.643	0.216	0.141	0.0385	0.0129	0.0084
	17	0.081	0.261	0.000	0.487	0.433	0.079	0.0000	0.0000	0.0000
6	18	0.065	0.831	1.000	0.529	0.355	0.116	0.0286	0.0192	0.0063
	19	0.065	0.169	0.000	0.660	0.249	0.091	0.0000	0.0000	0.0000
7	20	0.047	0.643	0.465	0.739	0.153	0.108	0.0104	0.0022	0.0015
	21	0.047	0.216	0.311	0.643	0.216	0.141	0.0020	0.0007	0.0004
	22	0.047	0.141	0.224	0.662	0.274	0.064	0.0010	0.0004	0.0001
Total desirability indices (D_{i1}) of CA for ERP software alternatives								0.243	0.125	0.043

Table 21. ESSWI for ERP alternatives.

Alternatives	Determinants: Competitive Advantage (CA) 0.643	Productivity (PR) 0.141	Profitability (PF) 0.216	Calculated weights for alternatives: ESSWI	Normalization
SAP R/3	0.243	0.164	0.173	0.217	0.587
Mfg-PRO	0.125	0.055	0.095	0.109	0.294
BAAN	0.043	0.051	0.043	0.044	0.119
Total				0.370	1.000

exhaustive efforts. Software support, then, needs to carry out all calculations. In our study, we used Microsoft Excel because we had a limited number of attribute-enablers, dimensions, and determinants. As the number of these components increases, the method becomes more complex to solve even using Excel. On the other hand, advantage of the fuzzy ANP is to capture interdependencies that can occur in the decision hierarchies. This means that the fuzzy ANP provides a more reliable solution than the fuzzy AHP.

The full support of middle- and upper-level management will help us to use their experiences about the business processes of the company and thus eliminate the biases in the weights for ERP software alternatives. This approach can be used by experts or decision-makers, members of a cross-functional team of a company which plans to implement an ERP system. In defining determinants, dimensions, and attribute-enablers, the team should ask for help from internal and external sources. To carry out the computational steps of the fuzzy ANP, the team might need a software tool based on the number of elements in the selection hierarchy. For motivation of the team and its members, and the success of an ERP implementation project, the support of upper management should certainly be provided.

For future study, a knowledge-based (KB) or expert system (ES) can be integrated to help decision-makers make fuzzy pairwise calculations more concisely and interpret the results in each step of the fuzzy ANP. In addition to the ERP software selection problem, the fuzzy ANP, especially with a KB or ES, can successfully support a large variety of decisions (i.e. marketing, medical, political, social, forecasting, prediction, and so on).

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