ERP System Flexibility Measurement Based on Fuzzy Analytic Network Process

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***Abstract*—To meet the changes of internal and external environment, Enterprise Resources Planning (ERP) system needs to have a good flexibility. Flexibility is an indispensable request and is also a way that must be taken during the establishment process of ERP. Flexibility measurement is an important item for the implementation of ERP flexibility. According to the characteristics of ERP system, an index system for flexibility measurement of ERP system is presented with the interdependence and feedback relationships among criteria and/or indices being taken into account. Due to the vagueness and uncertainty information during the process of flexibility measurement, triangular fuzzy numbers are used to indicate the preference opinions of experts and decision makers. A flexibility measurement model of ERP system based on fuzzy analytic network process (FANP) is proposed. The local weights of criteria and indices are derived by fuzzy preference programming (FPP) method. An unweighted supermatrix based on the network structure of index system is developed, and the limit supermatrix is generated. The flexibility level of ERP system can be measured by the weights and scores of ERP. Finally, a case is given by the proposed method.**

***Index Terms*—fuzzy analytic network process, ERP, flexibility measurement, fuzzy preference programming**

I. INTRODUCTION

Although ERP implementation has been one of the most significant challenges of the last decade, it comes with a surprisingly high failure rate due to its high risk nature and low flexibility. The risks of ERP, which involve both technical and social uncertainties, must to be effectively managed and controlled. Traditional ERP practices address the implementation of ERP as a static process. Such practices focus on structure, not on ERP as something that will meet the needs of a changing organization. As a result, many relevant uncertainties that cannot be predefined are not accommodated, and cause the implementation fail in the form of project delay and cost overruns, and so on.

Different flexibility definitions and measurements have been proposed in the literatures. Flexibility is defined as "a ready capability to adapt to new, different, or changing requirements" in the Webster's Dictionary [1]. Flexibility is the ability to accommodate, withstand or handle uncertainty as well. It describes the level of capability a system can handle or absorb uncertainties or changes.

Many categories, such as machine flexibility, operation flexibility, and process flexibility, have been adopted as main strategies for improving market responsiveness in uncertain demand. In systems engineering, flexibility is the characteristic of the interface between a system and its external environment [2]. Flexibility has been widely researched in the field of manufacturing. The typical reason that manufacturing industries have adopted flexibility is to speed up the entire product cycles. Flexibility of the transportation system is one of the important performance measures. ERP flexibility is a capability to adapt the changes of enterprise's internal and external environment.

Flexibility measurement has always played a role in planning and managing complex systems. Chen and Kasikitwiwat provided a quantitative assessment of capacity flexibility for the passenger transportation network using bi-level network capacity models [3]. Fred and Sugandha proposed a general model of flexibility measurement based on Data Envelopment Analysis [4]. Giachetti et al. presented a measurement framework to analyze the structural properties of the enterprise system [5]. The framework can provide a consistent basis for specifying and using measures, which will empower system designers to better incorporate desirable structural properties to align system design with enterprise strategy. Koste et al. discussed the lack of non-industry specific measures for manufacturing flexibility, and pointed out that given the multi-dimensional complexity associated with this concept, "Churchill paradigm" was an appropriate framework [6]. Hildegard proposed a complexity measurement which addresses the functional flexibility of networks [7]. It is conjectured that the functional flexibility is reflected in a topological "diversity" of the assigned graphs, resulting from a resolution of their vertices and a rewiring of their edges under certain constraints. Cadili and Whitley explored the interpretative flexibility of ERP systems through the study of a project to implement a hosted system for the Central Accounting Department of a large multinational [8]. They questioned the extent to which technological features of the new system influence the perceived

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flexibility of the system. Najmabadi et al. pointed out hardware flexibility of automation systems is addressed through the introduction of three main parametric flexibility measures functional, structural, and throughput [9]. They proposed a new quantitative measurement method for these parameters in the realm of the Axiomatic Theory. Kerimoglu et al. defined organizational adoption of ERP systems through building a framework which has the core technology acceptance model variables, satisfaction and common actors of an ERP project: technology, user, organization and project management [10]. Results of their study revealed that organizational adoption can only be accomplished if the satisfaction with the ERP system is achieved by competency and flexibility of the technology along with the special efforts of project management during project implementation. Wu et al. proposed an active ERP implementation management perspective to manage ERP risks based on the Real Options theory, which addresses uncertainties over time, resolves uncertainties in changing environments that cannot be predefined [11]. By actively managing ERP implementation, managers can improve their flexibility, take appropriate action to respond to the often-changing ERP environment, and achieve a more successful ERP implementation. Özogul et al. introduced a real options-based methodology which overcomes the limitations of traditional valuation methods and enables decision-makers to value an ERP system investment incorporating multiple options [12]. The option valuation model developed in their study extends the binomial lattice framework to model a hospital information system investment opportunity with compound options. Wei and Lin proposed an intuitionistic trapezoidal fuzzy model to select an optimal ERP system according to the distance between the overall value of the alternatives and ideal solution [13]. Zheng presented a method for enterprise accounting process reengineering based on ERP system, and it would improve the efficiency of accounting process and ERP system as well [14]. Li et al. analyzed the basic condition for medium and small publishers to carry out EPR system and proposed the guidelines for remedying other shortfalls by increasing the flexibility of system [15]. They specifically analyzed five custom functions that ERP system should have which can dramatically increase the flexibility of ERP system and effectively solve many non-standard and unfixed business problems in order to better meet actual needs.

Although some scholars have researched and discussed the flexibility measurement method of ERP system, however, the interaction and feedback relationships among criteria and/or indices are not taken into account in existing research results. Furthermore, during the process of ERP flexibility measurement, there are a good deal of uncertainty and vague information. The crisp values seem to be insufficient and imprecise to indicate the right preference opinions of experts and decision-makers. Consequently, the objective of this paper is to propose a new method based on fuzzy analytic network process to make up for the deficiency of conventional ERP flexibility measurement.

II. Fuzzy Analytic Network Process

A. Triangular Fuzzy Number

In general, a triangular fuzzy number (TFN) is denoted simply as (l, m, u). The parameters l, m and u, respectively, represent the lower boundary, the most promising value, and the upper boundary that describe a fuzzy probability, as show in Figure 1. Each TFN has linear representations on its left and right side such that its membership function can be defined as,

$$u_M(x)=\begin{cases}0, & x<l;\\ \dfrac{x-l}{m-l}, & l\le x\le m;\\ \dfrac{u-x}{u-m}, & m\le x\le u;\\ 0, & x>u.\end{cases} \qquad (1)$$

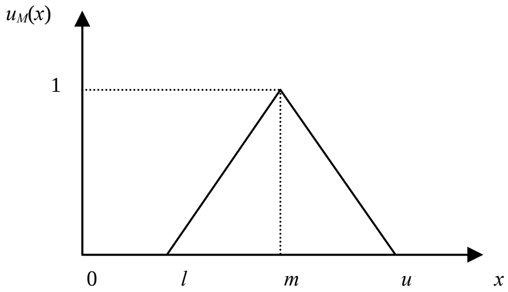

Figure 1. Triangular fuzzy number

Assume two triangular fuzzy number $A_1 = (l_1, m_1, u_1)$ and $A_2 = (l_2, m_2, u_2)$, then

$$\begin{aligned}A_1\oplus A_2 &= (l_1,m_1,u_1)\oplus(l_2,m_2,u_2)\\ &=(l_1+l_2,m_1+m_2,u_1+u_2),\end{aligned} \qquad (2)$$

$$\begin{aligned}A_1\otimes A_2 &= (l_1,m_1,u_1)\otimes(l_2,m_2,u_2)\\ &=(l_1\times l_2,m_1\times m_2,u_1\times u_2),\end{aligned} \qquad (3)$$

$$\begin{aligned}A_1 - A_2 &= (l_1,m_1,u_1)-(l_2,m_2,u_2)\\ &=(l_1-l_2,m_1-m_2,u_1-u_2),\end{aligned} \qquad (4)$$

$$\begin{aligned}A_1 \div A_2 &= (l_1,m_1,u_1)\div(l_2,m_2,u_2)\\ &=(l_1/u_2,m_1/m_2,u_1/l_2),\end{aligned} \qquad (5)$$

$$A_1^{-1}=(l_1,m_1,u_1)^{-1}=(1/u_1,1/m_1,1/l_1). \qquad (6)$$

B. Fuzzy Analytic Network Process

The Analytic Network Process (ANP), introduced by Saaty [16], is a generalization of Analytic Hierarchy Process (AHP). The basic characteristic of the AHP is to decompose the decision making process into a hierarchical structure where the relationships of elements in different levels are independent. Unfortunately, a lot of decision-making problems cannot be structured hierarchically, or there would have strong interactions and dependencies among criteria and/or indices. To meet more practical decision making properties, the ANP extends the AHP to problems with dependencies and feedback by using a supermatrix approach.

The first phase of ANP compares the measuring criteria in the overall system to form a supermatrix. This can be accomplished using pairwise comparisons. The relative importance-values of pairwise comparisons can be categorized from 1 to 9 in order to represent pairs of equal importance to extreme inequality in importance. AHP/ANP has been widely used as a decision making tool in many fields, but the AHP/ANP-based method seems to be ineffective in dealing with the fuzziness or uncertainty for the judgments during the pairwise comparison process. In real-life decision-making situation, uncertain human judgments with internal inconsistency obstructing the direct application of the ANP are frequently found. Such conditions will also occur during the process of measuring ERP flexibility. Therefore, it's more appropriate to measure ERP flexibility under fuzzy condition. To cope with this problem, Mikhailov and Singh presented fuzzy analytic network process method [17]. FANP has been used in many fields, such as commodity acquisition [18], risk evaluation [19] and knowledge management [20].

The generation of priority vectors from pairwise comparison matrices is an essential part of the FANP. A number of methods have been suggested to acquire the local weights of fuzzy matrices. For instance, Csutora and Buckley brought forward a Lambda-Max method, which is the fuzzification of *k*max method [21]. Mikhailov came up with a fuzzy preference programming (FPP) method, which can obtain crisp weights from fuzzy judgment matrices [22]. Srdjevic developed a multi-criteria approach for combining prioritization methods for AHP, such as least-squares, goal programming, eigenvector and fuzzy preference programming [23]. Wang et al. proposed a modified fuzzy logarithmic least square method to derive the local weights [24]. Yu and Cheng presented a multiple objective programming approach to acquire the local priorities for crisp or interval judgments simultaneously [25]. Huo et al. developed new parametric prioritization methods to determine priority weights in AHP [26]. Grzybowski presented new optimization techniques for deriving priority vectors via computer simulations, and the new approach provides a meaningful index that can be considered as a natural extension of the CI to all types of matrices [27], and so on.

C. Fuzzy Preference Programming Method

In this study, FPP method is adopted because the method has the following advantages over other approaches. The most important advantage is the acquirement of consistency index for fuzzy pairwise comparison matrices. It is impossible to obtain the consistency ratios without conducting an additional study in other methods. Another important aspect is that the models developed to determine the local weights can be easily solved with the help of Matlab software. The main theory of Mikhailov's approach is shown as follows [22].

Suppose a prioritization problem with n elements, where the pairwise comparison matrices are denoted by fuzzy numbers. Assume the decision-maker can provide a set $F = \{\tilde{a}_{ij}\}$ of $m \le n(n-1)/2$ fuzzy comparison judgments, $i = 1, 2, \ldots, n-1$; $j = 2, 3, \ldots, n$; $j > i$, represented as triangular fuzzy numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. The problem is to develop a priority vector $w = (w_1, w_2, \ldots, w_n)^T$, such that the priority ratios w_i/w_j are approximately within the scopes of fuzzy judgments, or

$$l_{ij} \tilde{\le} \frac{w_i}{w_j} \tilde{\le} u_{ij}, \tag{7}$$

where the symbol "$\tilde{\le}$" denotes the statement "fuzzy less or equal to".

When the inconsistent judgment occurs, the double-side inequalities (7) represent to satisfy all judgments as much as possible. Then, the priority vector w can be measured by a membership function, linear with respect to the unknown ratio w_i/w_j,

$$u_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{(w_i/w_j) - l_{ij}}{m_{ij} - l_{ij}}, & \dfrac{w_i}{w_j} \le m_{ij}, \\ \dfrac{u_{ij} - (w_i/w_j)}{u_{ij} - m_{ij}}, & \dfrac{w_i}{w_j} \ge m_{ij}. \end{cases} \tag{8}$$

The membership function (8) is linearly increasing over the interval ($-\infty$, m_{ij}) and linearly decreasing over the interval (m_{ij}, ∞). The function has a maximum value u_{ij}=1. Over the range (l_{ij}, u_{ij}), the membership function (8) coincides with the fuzzy triangular judgment (l_{ij}, m_{ij}, u_{ij}).

FPP method is based on two main assumptions. The first one requires the existence of non-empty fuzzy feasible area P on the (n-1) dimensional simplex Q^{n-1}

$$Q^{n-1} = \{(w_1, w_2, \ldots w_n) \mid w_i > 0, \sum_{i=1}^{n} w_i = 1\}. \tag{9}$$

The membership function of the fuzzy feasible area is given by

$$u_P(w) = \min_{ij}\{u_{ij}(w) \mid i = 1,2,\ldots,n-1; j = 2,3,\ldots,n; j > i\}. \tag{10}$$

The second assumption specifies a selection rule, which determines a priority vector, having the highest degree of membership in (10). It can easily be proved that $u_p(w)$ is a convex set, so there is always a priority vector $w^* \in Q^{n-1}$ that has a maximum degree of membership,

$$\lambda^* = u_P(w^*) = \max_{w \in Q^{n-1}} \min_{ij}\{u_{ij}(w)\}. \tag{11}$$

The maximum prioritization problem (11) can be represented in the following way:

$$\begin{gathered} \text{Max } \lambda \\ \lambda \le u_{ij}(w), i = 1,2,\ldots,n-1; j = 2,3,\ldots,n; j > i, \\ \sum_{k=1}^{n} w_k = 1, w_k > 0, k = 1,2,\ldots,n. \end{gathered} \tag{12}$$

Considering the specific form of the membership functions (8), the prioritization problem (12) can be further transformed into a non-linear program

$$\begin{gathered} \text{Max } \lambda \\ (m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0, \\ (u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0, \\ \sum_{k=1}^{n} w_k = 1, w_k > 0, k = 1,2,\ldots,n. \\ i = 1,2,\ldots,n-1; j = 2,3,\ldots,n; j > i. \end{gathered} \tag{13}$$

The optimal solution to the above non-linear problem (w^*, λ^*) is a vector whose first component represents the priority vector that maximizes the degree of membership in the fuzzy feasible area, whereas its second component gives the value of the maximum achievement level λ^* of the interval judgment considering the inconsistent phenomenon, which is a consistency index. A greater value λ^* indicates greater consistency of the decision maker's judgments, and vice versa.

III. Proposed ERP Flexibility Measurement Framework

A new approach based on FANP is proposed to assist in the flexibility measurement of ERP system in this study. The measurement index system is first identified, and the measurement model is presented in the following section.

A. Index System of ERP Flexibility Measurement

To win market competition, the ERP system needs to meet the changes of external environment and internal business. On the basis of existing research results, an improved ERP flexibility measurement index system is developed. The index system is made up of five parts: architecture flexibility, function flexibility, transaction processing flexibility, responsiveness flexibility and client flexibility, as shown in Figure 2.

Architecture flexibility: the capability of ERP structure adapts system environment changes, including four sub-criteria: degree of structuring, adaptability, structure expansibility and kernel stability.

Function flexibility: the ability of ERP system meets the functionality, including four indices: module coupling degree, parametric design, matching degree and the flexibility of configuration. If the module coupling degree is higher, then the function flexibility of ERP system is lower. If the degree of parametric design, or matching degree, or the flexibility of configuration is higher, then the function flexibility of ERP system is higher.

Transaction processing flexibility: the capability of ERP handles the numbers of business and adapts the changes of business. It is an important item to measure the flexibility of ERP system, including the following three aspects: component-based business, business adaptability and business reconfiguration. The higher of business component is, the higher of business reconfiguration has and the better adaptability of ERP system gets.

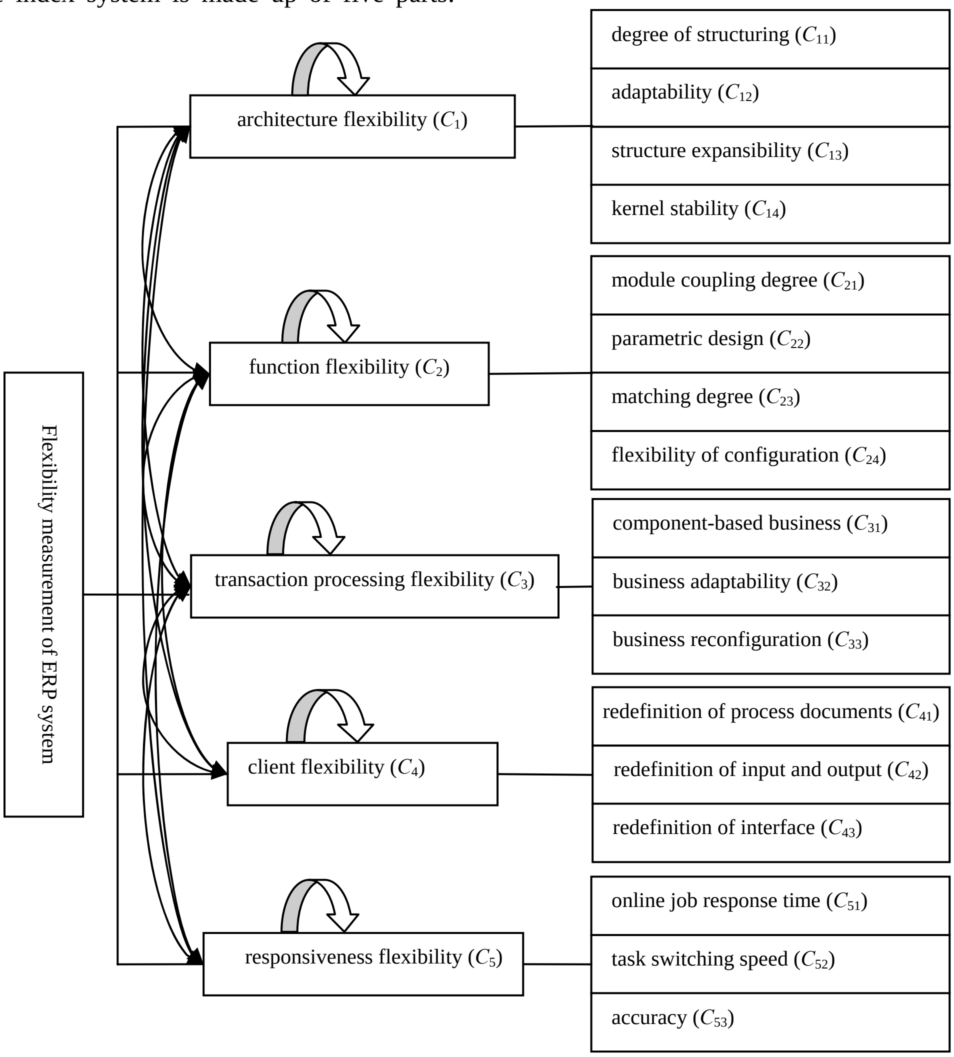

Figure 2. Index system of flexibility measurement for ERP System

Client flexibility: the ability of client adapts business changes, or the capability of ERP meets customer requirements, including three factors: redefinition of process documents, redefinition of input and output and redefinition of interface.

Responsiveness flexibility: the capability of ERP responses different environments. It is made up of three factors: online job response time, task switching speed and accuracy.

There are interaction and feedback relationships among criteria and/or indices in the above index system. For example, architecture flexibility has an effect on the flexibility of other four criteria; conversely, function flexibility, transaction processing flexibility and client flexibility will affect architecture flexibility, and so on. However, these interaction and feedback relationships are not considered in existing literatures. It is obvious that the lack of information would lead to deviation or wrong results during the flexibility measurement process of ERP system. Therefore, this paper presents an index system with dependence and feedback relationships among the criteria and/or indices. If architecture flexibility (C_1) has an effect on function flexibility (C_2), then a line with arrow from C_1 to C_2 is added. If the sub-criteria of architecture flexibility (C_1) have interaction itself, then C_1 is inner dependence, and an arc with arrow is added to C_1, as shown in Figure 2.

B. *Triangular Fuzzy Linguistic Variables*

The linguistic approach is an approximate technique, which represents qualitative aspects as linguistic values by means of linguistic variables. According to linguistic scale, linguistic preference relation is an effective tool for expressing decision makers' preferences in decision making. For an ERP flexibility measurement problem, let $E = (e_1, e_2, \ldots, e_m)$ be a set of the experts involved in the decision process, $X = (x_1, x_2, \ldots, x_n)$ be a set of considered alternatives. In the process of flexibility measurement, an expert generally needs to provide his/her preferences for each pair of indices or alternatives with respect to each criterion by the linguistic terms.

TABLE Ⅰ.

TRIANGULAR FUZZY LINGUISTIC SCALES FOR RELATIVE IMPORTANCE OF PAIRWISE COMPARISON

Linguistic scales for relative importance	Triangular fuzzy numbers	Triangular fuzzy reciprocal numbers
Equally important(EI)	(1, 1, 1)	(1, 1, 1)
Intermediate1(IM_1)	(1, 2, 3)	(1/3, 1/2, 1)
Moderately important(MI)	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate2(IM_2)	(3, 4, 5)	(1/5, 1/4, 1/3)
Important(I)	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate3(IM_3)	(5, 6, 7)	(1/7, 1/6, 1/5)
Very important(VI)	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate4(IM_4)	(7, 8, 9)	(1/9, 1/8, 1/7)
Absolutely important(AI)	(9, 9, 9)	(1/9, 1/9, 1/9)

There are some kinds of linguistic scales. The triangular fuzzy linguistic scale is effective one which is often used to express the subjective preference of experts. Variables describing the experts' preferences can be divided into numerous linguistic criteria, such as equally important, moderately important, important, very important and absolutely important. A 9-point scale of triangular fuzzy numbers and their reciprocals is presented for the relative importance of pairwise comparison, as shown in Table Ⅰ.

C. *FANP-based Approach for Flexibility Measurement of ERP System*

The approach of FANP-based that combines the FPP and the ANP has the following steps:

Step 1. Construct a network structure according to the decision goal and list the dependences among all components of the network structure and define the impact between each. A three-level measurement index system is presented: the first level is the comprehensive flexibility measurement of ERP system; the second level is criteria, including five parts: architecture flexibility, function flexibility, transaction processing flexibility, client flexibility and responsiveness flexibility; the third level is sub-criteria, including 17 indices, as shown in Figure 2.

Step 2. Build pairwise comparison matrices of the components by a decision committee using the triangular fuzzy linguistic scales given in Table Ⅰ. The experts or decision makers are asked to respond to a series of pairwise comparison with respect to the criteria/indices in Figure 2. For instance, two indices adaptability (C_{12}) and structure expansibility (C_{13}) are compared using the question "How important is adaptability (C_{12}) when it is compared with structure expansibility (C_{13}) at the dimension of degree of structuring (C_{11}) under the criterion architecture flexibility (C_1)?" and the answer is "intermediate important (IM_1)", so this linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (1, 2, 3). All the triangular fuzzy comparison matrices are produced in the same manner.

Step 3. Perform the FPP method on each comparison matrix individually to derive each set of local priorities. According to equation (13), local weights and consistency indices of the triangular fuzzy matrices are calculated with the help of a Matlab program.

Step 4. Establish an unweighted supermatrix with the derived local priorities from Step 3. The supermatrix is a partitioned matrix, where each sub-matrix is made up of a set of relationships among criteria and indices.

Step 5. Generate a weighted supermatrix with column stochastic property. The reason is that each column of the unweighted supermatrix consists of several eigenvectors, and hence the entire column of the matrix may sum to an integer greater than one.

Step 6. Derive a limit supermatrix with a sufficiently large power number to converge into a stable supermatrix. Then we can choose any column from the limit supermatrix as the global weights of the indices.

$$\overline{W} = \lim_{t \to \infty} W^t. \quad (14)$$

Step 7. Measure the flexibility of ERP system. The comprehensive flexibility level V of ERP system is calculated by the following equation:

$$V = \sum_{i=1}^{n} (w_i * V_i), \quad (15)$$

where $i = 1, 2, \ldots, n$; w_i is the global weight of index, and V_i is the score of ERP system which is given by the decision committee based on the measurement index system. The flexibility level of ERP system is given in Table Ⅱ.

TABLE Ⅱ.
THE FLEXIBILITY LEVEL OF ERP SYSTEM

flexibility level of ERP	bad	poor	general	good	Excellent
score	<0.40	0.40~0.55	0.55~0.70	0.70~0.85	>0.85

IV. CASE STUDY

In order to have a better development and win market competition, a medium-sized technology company would like to adopt a new ERP system through pre-test. To understand whether the ERP system adapts the surroundings of enterprise's internal requirement and external environment, the decision makers of the company want to have a flexibility measurement of the system. Therefore, a cross-functional decision committee consisting of various departments works to measure the flexibility of the new ERP system. The flexibility measurement process based on FANP is as follows.

Step 1. According to the decision goal and the interaction relationships among criteria and/or indices, a three-level measurement index system is presented, as shown in Figure 2.

Step 2. Build pairwise comparison matrices of the components by the decision committee using the triangular fuzzy linguistic scales given in Table Ⅰ, and the scores of the ERP system are determined as well.

For instance, the decision committee needs to establish four matrices for measuring architecture flexibility as the indices of it have inner interaction and feedback relationships. Table Ⅲ is the pairwise comparison matrix for adaptability (C_{12}), structure expansibility (C_{13}) and environmental kernel stability (C_{14}) at the dimension of degree of structuring (C_{11}) under the criterion of architecture flexibility (C_1). Experts' opinions are first indicated by fuzzy linguistic scales. Then they will be converted into the corresponding triangular fuzzy numbers according to Table Ⅰ, as shown in Table Ⅲ. All the triangular fuzzy comparison matrices are produced in the same way.

TABLE Ⅲ.
COMPARISON MATRIX AT THE DIMENSION OF DEGREED OF STRUCTURING UNDER THE CRITERION OF ARCHITECTURE FLEXIBILITY

C_{11}	C_{12}	C_{13}	C_{14}	w
C_{12}	（1，1，1）	（1，2，3）	（1/3，1/2，1）	0.2857
C_{13}		（1，1，1）	（1/6，1/4，1/2）	0.1429
C_{14}			（1，1，1）	0.5714
		λ=1		1

Step 3. Perform the FPP method on each comparison matrix individually to derive the local weights. For example, according to formulation (13), the local weights of Table Ⅲ can be acquired by solving the following non-linear programming.

TABLE Ⅳ.
THE UNWEIGHTED SUPERMATRIX

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}
C_{11}	0	0.4615	0.2857	0.5428	0.4	0.4	0.1394	0.3911	0.1394	0.3	0.4	0	0	0	0.3	0.3	0.2
C_{12}	0.2857	0	0.5714	0.1658	0.1	0.1	0.4662	0.3298	0.255	0.2	0.2	0	0	0	0.2	0.2	0.4
C_{13}	0.1429	0.2308	0	0.2914	0.2	0.3	0.1394	0.1804	0.1394	0.1	0.3	0	0	0	0.1	0.1	0.1
C_{14}	0.5714	0.3077	0.1429	0	0.3	0.2	0.255	0.0987	0.4662	0.4	0.1	0	0	0	0.4	0.4	0.3
C_{21}	0.4662	0.1	0.3514	0.4662	0	0.4663	0.1429	0.4286	0.3514	0.4	0.3911	0.3514	0.4444	0.4662	0.2	0.2	0.2
C_{22}	0.255	0.2	0.3514	0.255	0.4663	0	0.2857	0.4286	0.3514	0.2	0.3298	0.3514	0.2222	0.255	0.1	0.1	0.1
C_{23}	0.1394	0.3	0.1921	0.1394	0.1721	0.1721	0	0.1428	0.1921	0.1	0.1804	0.1921	0.2222	0.1394	0.3	0.3	0.3
C_{24}	0.1394	0.4	0.1051	0.1394	0.3616	0.3616	0.5714	0	0.1051	0.3	0.0987	0.1051	0.1112	0.1394	0.4	0.4	0.4
C_{31}	0.4784	0.2	0.4663	0.4663	0.4784	0.4784	0.2	0.1721	0	0.4	0.5	0.4	0.3333	0.5417	0.4	0.4	0.3
C_{32}	0.1263	0.6	0.1721	0.1721	0.1263	0.1263	0.4	0.3616	0.3	0	0.5	0.2	0.3333	0.2963	0.3	0.3	0.3
C_{33}	0.3953	0.2	0.3616	0.3616	0.3953	0.3953	0.4	0.4663	0.7	0.6	0	0.4	0.3334	0.162	0.3	0.3	0.3
C_{41}	0.4663	0.4	0.4663	0.4663	0.1721	0.4663	0.3333	0.4	0.4663	0.4663	0.3333	0	0.4	0.4	0	0	0
C_{42}	0.1721	0.4	0.3616	0.3616	0.3616	0.1721	0.3333	0.4	0.3616	0.3616	0.3333	0.7	0	0.6	0	0	0
C_{43}	0.3616	0.2	0.1721	0.1721	0.4663	0.3616	0.3334	0.2	0.1721	0.1721	0.3334	0.3	0.6	0	0	0	0
C_{51}	0	0	0	0	0.4663	0.3616	0.2621	0.2621	0.5417	0.2963	0.3334	0	0	0	0	0.4	0.5
C_{52}	0	0	0	0	0.3616	0.1721	0.4331	0.3048	0.2963	0.162	0.3333	0	0	0	0.3	0	0.5
C_{53}	0	0	0	0	0.1721	0.4663	0.3048	0.4331	0.162	0.5417	0.3333	0	0	0	0.7	0.6	0

$$\text{Max } \lambda$$
$$\lambda w_2 - w_1 + w_2 \le 0;$$
$$\lambda w_2 + w_1 - 3w_2 \le 0;$$
$$(1/6)\lambda w_3 - w_1 + (1/3)w_3 \le 0;$$
$$(1/2)\lambda w_3 + w_1 - w_3 \le 0;$$
$$(1/12)\lambda w_3 - w_2 + (1/6)w_3 \le 0;$$
$$(1/4)\lambda w_3 + w_2 - (1/2)w_3 \le 0;$$
$$w_1 + w_2 + w_3 = 1;$$
$$w_1, w_2, w_3 \ge 0.$$

It can be solved by a Matlab program, and the optimal solutions are w_1=0.2857, w_2=0.1429, w_3=0.5714, as shown in Table Ⅲ. Consistency index λ is 1, which means that the experts' opinions have a good consistency, and the local weights are acceptable. All the local weights of triangular fuzzy comparison matrices are calculated in the same manner.

Step 4. According to the local weights derived from step 3, an unweighted supermatrix is generated, as shown in Table Ⅳ.

Step 5. The weighted supermatrix is derived by randomizing the unweighted supermatrix.

Step 6. According to formulation (14), the limit supermatrix is obtained by multiplying the weighted supermatrix by itself until the supermatrix's row values converge to the same value for each column of the matrix. We can select any column from the limit supermatrix as the global weights of the indices, as shown in Table Ⅴ. The final comprehensive weights of the indices are:

W^*=(0.0803, 0.0579, 0.047, 0.067, 0.1067, 0.0888, 0.055, 0.0714, 0.0716, 0.0525, 0.074, 0.0604, 0.066, 0.0525, 0.0176, 0.0144, 0.0168).

Step 7. According to formulation (15), the flexibility level of the ERP system can be calculated, as shown in Table Ⅵ. The flexibility score of the ERP system is 0.7253, and it indicates that the flexibility level of the ERP system is good according to Table Ⅱ.

V. Conclusions

Taking into account the interaction and feedback relationships among criteria and/or indices, an index system for measuring the flexibility of ERP system is proposed. Taking into consideration the uncertainty and the inaccuracy information, a flexibility measurement model for ERP system based on fuzzy analytic network process is developed. The local weights of indices are determined by fuzzy preference programming method. An unweighted supermatrix is generated based on the network structure of index system. The convergent limit supermatrix is acquired by multiplying the weighted supermatrix, which is the randomizing of the unweighted supermatrix. Accordingly, the comprehensive weights of indices and final flexibility score of the ERP system can be calculated. A numerical example is given by the proposed method, and the result is shown that it can deal well with this kind of problem.

TABLE Ⅴ.
THE LIMIT SUPERMATRIX

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}
C_{11}	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803	0.0803
C_{12}	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579	0.0579
C_{13}	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
C_{14}	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
C_{21}	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067	0.1067
C_{22}	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888	0.0888
C_{23}	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
C_{24}	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714	0.0714
C_{31}	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716	0.0716
C_{32}	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525
C_{33}	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
C_{41}	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604	0.0604
C_{42}	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
C_{43}	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525
C_{51}	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176
C_{52}	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144
C_{53}	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168	0.0168

TABLE VI.
SCORE OF INDICES AND FLEXIBILITY LEVEL OF ERP SYSTEM

indices	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{51}	C_{52}	C_{53}	sum
weights	0.08	0.058	0.047	0.067	0.107	0.089	0.055	0.071	0.072	0.053	0.074	0.06	0.066	0.053	0.018	0.014	0.017	0.9999
scores	1	0.5	1	0.75	0.75	1	1	0.5	0.75	1	0.75	0.25	0.5	0.25	0.5	0.75	1	-
weighted scores	0.08	0.029	0.047	0.05	0.08	0.089	0.055	0.036	0.054	0.053	0.056	0.015	0.033	0.013	0.009	0.011	0.017	0.7253

Compared with the existing research results, the proposed method is fully considering the interaction and feedback relationship among dimensions and/or attributes. The using of triangular fuzzy numbers helps to make more accurate and reasonable decisions under uncertain and fuzzy conditions.

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