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An Integrated Fuzzy Approach Forerp Deployment Strategy Selection Problem: A Case of Furniture Company

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--***ABSTRACT***--
The importance of the right deployment strategy is neglected while taking into account just the features and capabilities of Enterprise Resource Planning (ERP) systems. Putting the most suitable deployment strategy into the practice for maximizing the performance of the established ERP System has a crucial role. Therefore, this study focused on the analysis and implementation of ERP deployment strategies. In order to select a proper ERP deployment strategy, a combination of fuzzy extension of Analytic Hierarchy Process (AHP) and evaluation based on fuzzy MOORA (multi objective optimization by ratio analysis) is proposed. Additionally, for expressing the applicability of the offered model, it is supported by a case study. According to the results of this hybrid model Cloud-based deployment strategy was chosen as the most suitable ERP deployment strategy for a furniture company with the BNP score of 1.128175. By the opinions based on homogeneous/heterogeneous decision-makers, cloud-based is selected in all three diverse methods of fuzzy MOORA with the BNP score of 1.075024. With this hybrid method used, it has been tried to obtain clearer expression of uncertain situations. Multiple decision-making groups are better than only one group in order to prevent prejudice in decisions and minimize occasions of siding with a party in the decision-making process.
KEYWORDS: *Enterprise Resource Planning (ERP); ERP Deployment Strategy; Fuzzy MOORA; Fuzzy Extension of AHP; Group Decision Making*

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I. INTRODUCTION

Enterprise Resource Planning (ERP) systems include integrated modules where each module is focused on a specific area of business operations such as inventory, customer service, and human resource management areas. These systems have attracted increasing attention in the last few decades so that firms decided to search practical ways to adopt strategies and competitive advantages of these technologies. Accurate usage of ERP or selecting appropriate ERP for a company has been defined as a crucial factor in reaching the benefit from an ERP installation. True business strategy enables business departments and manufacturing companies to support a well-tuned ERP type for providing real time data [1], [2], [3]. ERP systems improve business productivity greatly and serve customers better by creating values through integrating business processes and sharing current information [4]. Whether for beginner companies or expanded ones, business is as successful and effective as the management strategies that companies are adopting. Especially international firms are required to implement an ERP system in order to unite key business operations into one system for increasing efficiency and productivity of the firm. Generally, in analyzing features and capabilities of ERP systems, the importance of the appropriate deployment strategy is usually neglected. However, implementing the most suitable deployment strategy according to the companies' requirements and characteristics is essential to maximize the performance of the established ERP system. Selecting an appropriate ERP deployment strategy will enable the company to manipulate its business both at the local and global levels. Implementing ERP deployment strategies on companies has various benefits such as using a centralized system to gather local and global data in one system, effective costs management in intricate supply chains, elimination of unnecessary conversations, payment and customs obstacles, developing adaptability and enhancement, making employees' jobs simpler, increasing quality of customer service and decreasing working capital [5]; [6]. In this study, six different ERP deployment strategies are introduced that have their own specific advantages and disadvantages. For example, hybrid ERP deployment strategy is the combination of ERP in house and cloud ERP. Some companies do not want to risk their control in relation to moving to single or cloud ERP, but if they still want to use an ERP approach, they can simply choose hybrid ERP. ERP implementation is classified as one of the most expensive information technologies in the corporate world [7]; [8]. Implementation of ERP systems requires significant technical support, human resource, and financial investment, so companies can wisely prevent possible financial loss that can be happened by selecting inappropriate ERP deployment strategy. On the other hand, implementing of proper ERP deployment strategy lead to effective cost management in production, procurement, distribution, and other important areas. Therefore, selecting a suitable ERP deployment strategy for a particular company according to its own special characteristics can implicitly decrease relevant costs and lead to success in business reality. In this study, in order to evaluate applicability of six ERP deployment strategies in a furniture company, decision-making groups consist of ERP experts, academicians, and company officials managed to determine four main criteria and eleven sub-criteria based on detailed analysis. In the modern world, while diverse sophisticated technologies have been made decision-making process difficult and challenging, decision tools have become important instruments. Sometimes, Technology alone is not able to lead companies toward prosperity, and human ability of comprehension should be combined in order to make the implemented technology more effective. One of the most important decision-making tools that is introduced in the early seventies is multi-criteria decision-making theory. The combination of multi-criteria decision-making (MCDM) with fuzzy logic can be efficiently implemented for solving decision-making problems with diverse criteria [9]. When multiple criteria need to be calculated, theory of decision-making is formed a foundation for more reasonable decision-making. Enterprise Resource Planning (ERP) is the process of optimizing the performance of enterprise business processes through the utilization of integrated IT-based solutions [10]. ERP is defined as business software for at least three of the following sections of business: accounting, manufacturing, material management or distribution, and human resources (HR) management [11]. In one study, critical success factors (CSFs) for the life cycle of an ERP system are investigated. Moreover, effects of CSFs are also analyzed from the perspective of information technology governance (ITG). As a result, it is essential for an ERP system to have a performance measurement index in order to deliver value within organizations [12]. Researchers discussed ERP implementation in manufacturing and service sector organizations [4]. They focus on empirical evidence of an innovative knowledge management (KM) approach for improving knowledge competence in ERP success. Many studies conducted in the ERP area are related to success factors in implementation of ERP [13], [14]. Eleven factors are introduced as critical factors for successful implementation of ERP systems in [15]. Fourteen failure factors are identified and analyzed in another study. Moreover, three common critical failure factors are examined and discussed in [16]. ERP software selection is inspired by Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, which is a method for strategic planning [17]. These studies are limited because they only focus on quantitative criteria and they do not use advanced MCDM strategies to solve the multi-criteria optimization problems. Multimedia authorizing systems selection is considered by using AHP in [18]. The AHP method is also used to help the multi-media authorizing system selection problem [19]. An implemented fuzzy AHP approach solved the problem of service ranking and allowed the multi-objective assessment of cloud services could be done appropriately in [20]. In order to select the suitable software, AHP method is implemented as a multi-criteria decision-making technique to fit the product development procedure of a specific product [21]. In selecting suitable ERP software, a new decision support system is presented to combine both non-functional and functional analyses in [22]. A novel methodology is proposed for integrating analytic network process (ANP) and artificial neural network to determine the most suitable ERP software [23]. Fuzzy AHP and simulation by a computer-aided design SSP are presented by [24]. In the construction industry, AHP approach is presented to examine the perspective of experts about the importance of ERP software applicability [25]. A hybrid MCDM approach is introduced for solving the ERP system selection problem in the steel industry [26]. In Fuzzy AHP, fuzzy calculation and fuzzy aggregation operators are used in order to solve the hierarchical structure of problems. The calculation of fuzzy AHP is performed as per normal AHP method for weighting the criteria of decision problems in [27]. Fuzzy AHP has been successfully applied in diverse applications. Many researchers developed different variations of fuzzy AHP for analyzing fuzziness of decision-making problems [28], [29], and [30]. Project management by multi MOORA is proposed an answer to a modern transition economy with vigorous market perspectives [31]. In this research, various multi objective optimization methods are examined after their strong accomplishments in seven essential conditions. Multi MOORA and MOORA are applied in the study, and these processes supported all seven conditions. In another study, fuzzy MOORA approach is proposed for ERP system selection [32]. Moreover, some cloud technology using firms are evaluated by fuzzy AHP and MOORA methods [33]. Fuzzy AHP and fuzzy MOORA are used for selection of an ERP software system for a specific company in [34]. Furthermore, fuzzy multi MOORA method is presented for evaluation of relative farming productivity in European Union member states [35]. Integrated fuzzy AHP and fuzzy TOPSIS are proposed for ERP system selection in [36]. An integrated fuzzy AHP and fuzzy MOORA approach is proposed for the problem of industrial engineering sector selection in [37].

There are not any published studies on ERP deployment strategies selection by integrated fuzzy AHP and fuzzy MOORA with group decision-making technique. In order to prevent prejudice in making decisions and minimize possible occasions of siding with a party in the decision-making process, multiple decision-making groups are considered. Besides, fuzzy numbers are implemented to eliminate any vagueness in decision-making process. In this study, four decision-making groups are tabled to improve the analytical tool which combines fuzzy extension of AHP and fuzzy MOORA, so acquired results are more reliable. Eleven sub-criteria are clustered into four main criteria as simplicity, software architecture, cost and the characteristics of the vendor. The purpose of this study is to select the most suitable ERP deployment strategy for a furniture company. Six fundamental ERP deployment strategies are considered as single system, cloud based, operational, peer, hybrid, and multi-level. In order to combine ideas of four decision-making groups into one single idea, novel group decision-making technique is implemented. The weights of criteria and sub-criteria are calculated by fuzzy extension of AHP, and all six alternatives are ranked by fuzzy MOORA.

This paper includes six different parts. First, the concept of ERP, its advantages, and importance of an appropriate ERP deployment strategy are briefly explained in the introduction section. Review of the related literature is presented in section two. The integrated fuzzy extension of AHP and fuzzy MOORA methods are proposed to select the best ERP deployment strategy for the furniture company in next section. Then, illustrative example of the furniture company is presented for the implemented hybrid fuzzy multi-criteria decision-making method, and the results are shown in section five. Eventually, the conclusion of the research and possible future work are presented in the sixth section.

II. MATERIALS AND METHODS

In this study, the proposed integrated fuzzy extension of AHP and fuzzy MOORA are considered to rank ERP deployment strategies for a furniture company in Turkey. First of all, the main criteria and sub-criteria are defined based on precise evaluation of ERP deployment strategies' characteristics and the furniture company's requirements. As a result of detailed analysis, four main criteria are determined in order to select the most appropriate deployment strategy for the furniture company as follows. First criterion is Simplicity with three sub-criteria including agility, easiness to learn and adaptability. Large organizations are complex by nature, so, simplicity will be more attractive for customers who are not interested in facing complex conditions. In all firms, experts are looking for clear data and low duplication functions since it is easy to analyze for experts and easy for employees to gather, and it is a fact that simple things are easy for people to learn and improve. Besides, it is favorable for experts of vendor's company to improve simple software rather than a complex one in possible minimum time interval that can implicitly impact service quality of the company. Second criterion is Software Architecture that includes security, innovative technology, expandability, and module framework sub criteria. According to the experts of the customers in question, one of the most important characteristics of an ERP deployment strategy should be its long lifecycle within the company. Therefore, it is necessary for an ERP deployment strategy to improve along with various changes that may happen in business through time. As sub-branches of software architecture criterion clarify, this criterion determines the ability of the implemented deployment strategy in improving service quality and the efficiency of the company. Third criterion is cost with two sub criteria as preliminary buying cost, maintenance and upgrading cost. Not to mention that low cost is an attractive criterion for every company. Eventually, characteristics of ERP system vendor is chosen as fourth criterion that consists of following two sub criteria: service quality and history of company. In this case, service quality means ability of vendor in providing service for a specific ERP deployment strategy, and history of company or deployment strategy history shows background of strategies in various applications. In general, in order to decrease the risk of strategy selection, managers are likely to buy a deployment strategy that is older and has been applied in different areas so far. Not only are firms looking for useful information systems, but they also consider service guarantee as a crucial factor.

Fuzzy scale of Chang (Table1) is used to determine priorities of criteria and sub-criteria by fuzzy extension of AHP [38]. Exclusive decisions of four decision-making groups are converted into one value through an attribute based aggregation technique. Then, fuzzy MOORA is applied to rank the ERP deployment strategies. The fuzzy scale of Chen is implemented in the fuzzy MOORA method [39].

Linguistic variables	Fuzzy scale	Response scale
Equally important	(1,1,1)	(1,1,1)
Moderately important	(2/3,1,3/2)	(2/3,1,3/2)
Important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very important	(5/2,3,7/2)	(2/7,1/3,2/5)
Much more important	(7/2,4,9/2)	(2/9,1/4,2/7)

Table1. The fuzzy scale of Chang

Linguistic variable	Fuzzy scale
Very low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium low(ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium high (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very high (VH)	(0.9,1,1)

Table2. Chen's fuzzy linguistic scale

		C1				C2				C3				C4		
	DM1	DM2	DM3	DM4	DM1	DM2	DM3	DM4	DM1	DM2	DM3	DM4	DM1	DM2	DM3	DM4
C1	E	E	E	E	1/I	1/I	E	E	1/I	1/I	1/MI	1/MI	I	1/MI	1/MI	I
C2					E	E	E	E	1/I	I	I	1/I	1/MI	1/MI	I	I
C3									E	E	E	E	I	I	MI	MI
C4													E	E	E	E

CR	DM1	DM2	DM3	DM4
	0.076	0.083	0.04	0.081

Table3. Pairwise comparison matrix of main criteria by four decision makers and amounts of consistency ratios for DMs

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table4. Random consistency index

2.1. Fuzzy Set Theory

Fuzzy set theory has been used to analyze processes that are hard to describe accurately [40]. Fuzzy logic suggests a practical method to improve research reliability in specific areas when uncertainty restrict clarification of models' characteristics. In the early times of fuzzy set theory application, the primary focus of the theory is related to illustrating uncertainty in human cognitive processes. However, it is widely applied on a variety of areas such as engineering, businesses, medicine and sciences recently. Linguistic variables may be represented quantitatively by a fuzzy set and qualitatively by linguistic terms [41]. The set of elements in fuzzy set theory belongs to a space with unclear boundaries. In fuzzy set theory, objects may take on membership values in an interval of [0, 1] that represents a degree of membership [40]. The function of triangular fuzzy numbers (TFN) may be applied to shape the qualitative terms in form of fuzzy numbers [42]. If $A = (l_1, m_1, u_1)$ and $B = (l_2, m_2, u_2)$ are representing two triangular fuzzy numbers, the algebraic operations are defined as follows [43]:

$$A + B = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

$$A - B = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2)$$

$$A \times B = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$$

$$A \div B = (l_1, m_1, u_1) \div (l_2, m_2, u_2) = (l_1 \div u_2, m_1 \div m_2, u_1 \div l_2)$$

$$A^{-1} = (l_1, m_1, u_1)^{-1} = (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1})$$

$$k \times A = (kl_1, km_1, ku_1), \text{ where } k > 0$$

2.2. Fuzzy Extension of AHP

AHP is proposed as a method that consider both qualitative and quantitative information in the multi-criteria decision-making process [44]. Fuzzy AHP is presented for making decisions in an uncertain climate [38]. The M degree analysis is expressed in triangular fuzzy numbers as $M_{gi}^1, M_{gi}^2, M_{gi}^3$ $where,\ i = 1,2,\dots,n\ and\ j = 1,2,\dots,m.$

M_{gi}^i = triangular fuzzy numbers related to j target according to I criteria.

The comprehensive fuzzy degree S_i is calculated as follows:

The best scalar measure of indicator C_i is as follows:

$$d'(C_i) = min\, V(S_i \geq S_j) \quad (2)$$

$$where\ 0 \leq V(S_i \geq S_j) \leq 1, i, j = 1,2,..,n_k$$

$$V(S_i \geq S_j)\ shows\ the\ possibility\ degree\ of\ S_i \geq S_j$$

$$V(S_i \geq S_j) = \mu(d) = \begin{cases} \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)}, & l_j \leq u_j \\ o & , others \end{cases} \quad (3)$$

The indicator weight:

$$W' = (d'(C_1), d'(C_2), \dots, d'(C_n)) \quad (4)$$

The normalized indicator weight:

$$W = \left(d(C_1), d(C_2), \dots, d(C_n)\right) \quad (5)$$

The consistency ratio (CR) of the pair-wise comparison matrix should be calculated and compared with 0.1. Triangular fuzzy number $\tilde{X} = (l, m, u)$ can be simply converted to a crisp value as follows [45]:

$$p(\tilde{X}) = \frac{1}{6}(l + 4m + u) \quad (6)$$

The relative importance can be calculated by the right eigenvector w conforming to the largest eigenvector as follows [36]:

$$Aw = \lambda_{max}\, w \quad (7)$$

The weights may be obtained by normalizing any of the rows or columns of A. The consistency of pairwise comparison matrix is calculated by the relation between entries of A: $a_{ij} * a_{jk} = a_{ik}$. The consistency index (CI) is calculated as follows [46]:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (8)$$

The values of the random consistency index (RI) are acquired from Table4 [36]. The consistency ratio is calculated as the following equation, where the upper limit of CR is 0.1. If the value of CR is greater than 0.1, the assessment procedure should be revised for improving consistency.

$$CR = \frac{CI}{RI} \quad (9)$$

The additive weighted aggregation (AWA) can be used to calculate the overall weight in fuzzy extension of the AHP [47].

$$g_i = \lambda_k * g_{ik} \quad (10)$$

2.3. Fuzzy group decision-making technique

A new method is proposed for dealing with fuzzy opinion aggregation in group decision-making problems in [48]. The method is implemented for dealing with fuzzy opinion aggregation for a homogeneous/non-homogeneous group of experts. An expert group in which there is potential diversity in perspectives of its members is considered as heterogeneous (non-homogenous) group of experts. On the other hand, a homogenous group of experts consists of experts with similar perspectives. In this stage, the opinions of a homogeneous/non-homogeneous group of experts are combined to acquire a group consensus opinion [49][50]. After calculating the weights of criteria, all performance ratings are aggregated for criteria based on each alternative. The relative importance of an expert is we_k where $we_k \epsilon\, [0,1]$ and $\sum_{k=1}^{M} we_k = 1$, $K = 1, \dots, M$. The relative importance levels of experts are 1/M if they have equal importance. Pairwise comparison matrix of main criteria is given on the Table3. The steps of the aggregation method for homogeneous/non-homogeneous groups of experts are determined as follows [50]:

Step 1) Degrees of similarity of E_u expert's opinions to E_v are calculated as follows:
If $U = (u1, u2, u3)\ and\ V = (v1, v2, v3)$ be two standard triangular fuzzy numbers where $0 \leq u1 \leq u2 \leq u3 \leq 1\ and\ 0 \leq v1 \leq v2 \leq v3 \leq 1$:

$$S(U,V) = 1 - \frac{|u1 - v1| + |u2 - v2| + |u3 - v3|}{3} \quad (11)$$

$$Where\ S(U,V) \epsilon\, [0,1]$$

Step 2) After calculation of all similarity degrees between experts, the agreement matrix (AM) is obtained as follows:

$$\text{AM} = \begin{bmatrix} 1 & \cdots & S_{1M} \\ \vdots & \ddots & \vdots \\ S_{M1} & \cdots & 1 \end{bmatrix} \quad (12)$$

$$S_{uv} = \begin{cases} S(R_u, R_v), & u \neq v \\ 1, & u = v \end{cases} \quad (13)$$

Step 3) Average degree of similarity $AA(E_u)$ for each expert is calculated as follows:

$$AA(E_u) = \frac{1}{M-1} \sum_{v=1, v \neq u}^{M} S(R_u, R_v) \quad (14)$$

Step 4) Relative importance of agreement $RA(E_u)$ for experts $(u = 1, \dots, M)$ is calculated as follows:

$$RA(E_u) = \frac{AA(E_u)}{\sum_{u=1}^{M} AA(E_u)} \quad (15)$$

Step 5) The consensus degree coefficient $CC(E_u)$ for each expert is calculated as follows:

$$CC(E_u) = \beta we_u + (1 - \beta) RA(E_u) \quad (16)$$

Where β $(0 \leq \beta \leq 1)$ is relaxation factor of this method.
For a homogeneous group of experts, the value β is considered equal to zero. In this study, for a heterogeneous group of experts, this value is considered as$\beta = 0.5$.

Step 6) Aggregation of fuzzy opinions is determined as follows:

$$R_{AG} = CC(E_1) \otimes R_1 + \dots + CC(E_M) \otimes R_M \quad (17)$$

2.4. The fuzzy MOORA

The usage of multi objective optimization by ratio analysis (MOORA) was commenced based on recent research [51]. One of the most important reasons for applying the fuzzy MOORA method in this study is that the MOORA method is stronger in various factors than traditional MCDM methods; the factors are computational time, simplicity, mathematical calculations, stability, and information type [37]. This multi-criteria decision-making method (MCDM) starts with a matrix X whose elements x_{ij} express the ith alternative of the jth criterion $(i = 1,2, \dots, m \ and \ j = 1,2, \dots, n)$; additionally, the fuzzy MOORA method consists of three following parts: fuzzy ratio method, fuzzy reference point, and fuzzy multiplicative form.

2.4.1. Fuzzy ratio method

Fuzzy ratio method's steps are determined as follows:
Step 1) Decision matrices are formed based on Chen fuzzy numbers (Table2) [39]:

$$\tilde{X} = \begin{bmatrix} [x_{11}^{l}, x_{11}^{m}, x_{11}^{u}] & \cdots & [x_{1n}^{l}, x_{1n}^{m}, x_{1n}^{u}] \\ \vdots & \ddots & \vdots \\ [x_{m1}^{l}, x_{m1}^{m}, x_{ml}^{u}] & \cdots & [x_{mn}^{l}, x_{mn}^{m}, x_{mn}^{u}] \end{bmatrix} \quad (18)$$

Step 2) In this part, the decision matrix is normalized since it enables us to compare alternatives with each other more accurately [52].

$$\tilde{X}_{ij}^{*} = (x_{ij}^{l*}, x_{ij}^{m*}, x_{ij}^{u*}); i = 1,2, \dots, m; j = 1,2, \dots, n \quad (19)$$

$$X_{ij}^{l*} = \frac{x_{ij}^{l}}{\sqrt{\sum_{i=1}^{m} [(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2]}} \quad (20)$$

$$X_{ij}^{m*} = \frac{x_{ij}^{m}}{\sqrt{\sum_{i=1}^{m} [(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2]}} \quad (21)$$

$$X_{ij}^{u*} = \frac{x_{ij}^{u}}{\sqrt{\sum_{i=1}^{m} [(x_{ij}^{l})^2 + (x_{ij}^{m})^2 + (x_{ij}^{u})^2]}} \quad (22)$$

Step 3) In third step, calculated weights of criteria from AHP are used to form a weighted and normalized fuzzy matrix [53].

$$\tilde{v}_{ij} = (v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}) \quad (23)$$

$$v_{ij}^{l} = w_j x_{ij}^{l*} \quad (24)$$

$$v_{ij}^{m} = w_j x_{ij}^{m*} \quad (25)$$

$$v_{ij}^{u} = w_j x_{ij}^{u*} \quad (26)$$

Step 4) The summarizing ratio $\tilde{y}_i$ is calculated for each alternative as follows [54]:

$$\tilde{y}_i = \sum_{j=1}^{g} \tilde{v}_{ij} - \sum_{j=g+1}^{n} \tilde{v}_{ij} \quad (27)$$

Where $g = 1,2,\dots,n$ shows the number of criteria to be maximized. On the other hand, $g+1,\dots,n$ shows the number of criteria to be minimized.

Step 5) In the last step, fuzzy numbers are changed to non-fuzzy numbers by best non-fuzzy performance (BNP) equation, and the values of BNP are calculated for each alternative. As a result, the alternatives with the highest values are favorable for selection.

$$BNP_i(y_i) = \frac{(y_i^u - y_i^l) + (y_i^m - y_i^l)}{3} + y_i^l \quad (28)$$

2.4.2. Fuzzy reference point

Fuzzy ratio system plays a major role in the fuzzy reference point approach. The maximal objective reference point r is obtained as well as the second step of the fuzzy ratio method. The fuzzy maximum or minimum of the jth criterion are calculated as follows:

$$\begin{cases} \tilde{x}_j^{+} = \left(\max_i x_{ij}^{l*}, \max_i x_{ij}^{m*}, \max_i x_{ij}^{u*}\right), & j \le g \\ \tilde{x}_j^{+} = \left(\min_i x_{ij}^{l*}, \min_i x_{ij}^{m*}, \min_i x_{ij}^{u*}\right), & j > g \end{cases} \quad (29)$$

All elements of the normalized matrix are calculated, and final sorting is achieved based on deviation from the reference point and the Min-Max metric of the following statement[55][56]:

$$\min_i(\max_j(\tilde{r}_j, \tilde{x}_{ij}^{*})) \quad (30)$$

2.4.3. The fuzzy multiplicative form

The overall utility of the ith alternative is obtained as follows:

$$\tilde{U}_i^{'} = \frac{\tilde{A}_i}{\tilde{B}_i} \quad (31)$$

Where $\tilde{A}_i = (A_{i1}, A_{i2}, A_{i3}) = \prod_{j=1}^{g} \tilde{x}_{ij}$, i = 1,2, …, m expresses the criteria of the ith alternative to be maximized and $g = 1,2,\dots,n$ is the number objectives to be maximized. Where $\tilde{B}_i = (B_{i1}, B_{i2}, B_{i3}) = \prod_{j=g+1}^{n} \tilde{x}_{ij}$ expresses the criteria of the ith alternative to be minimized and $n-g$ is the number of objectives to be minimized. Fuzzy numbers of overall utility $\tilde{U}_i^{'}$ should be eliminated to rank the alternatives. The alternative with higher BNP is favorable to choose [56].

2.5. Illustrative example of proposed methodology

In this study, a real-life problem is considered for selecting ERP deployment strategies for a furniture company. In order to analyze the appropriate alternatives, this study proposes a new integrated fuzzy method in the third section. The deployment strategy selection procedure consists of important parts such as determination of alternatives and criteria, gathering information from four decision making groups, converting opinions of the four groups into on single decision perspective, calculating weights of criteria and sub criteria, and ranking alternatives. The expert team includes four decision-making groups that consists of academicians, company officials and ERP experts. In this study, decision-makers introduced four main criteria and eleven sub criteria in order to select the best possible ERP deployment strategy for the furniture company. Main criteria include simplicity, software architecture, cost, and characteristics of vendor. Simplicity criterion includes agility, easiness to learn, and adaptability sub criteria. Software architecture criterion includes security, innovative technology, expandability, and module framework sub criteria. Cost criterion consists of preliminary buying cost and maintenance and upgrading costs sub criteria. Characteristics of vendor criterion includes service quality and history of company sub criteria. According to detailed analysis of experts, ERP deployment strategies are determined as single-system, cloud-based, operational, peer, hybrid, and multi-level alternatives. In order to calculate weights of the criteria and sub-criteria, fuzzy extension of AHP along with novel fuzzy group decision-making technique are applied, and ERP deployment strategies are ranked by fuzzy MOORA. In decision hierarchy for ERP deployment strategy selection, four main criteria in second row and eleven sub-criteria in third row are considered (Fig. 1).

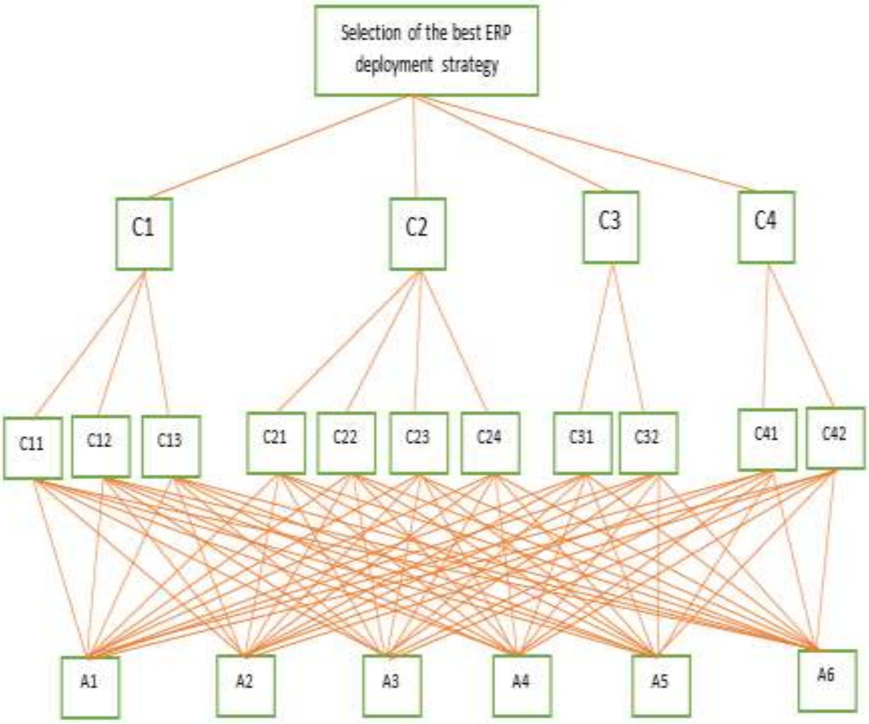

Figure 1- Decision hierarchy for ERP deployment strategy selection

III. RESULTS

Fig. 1 shows a decision hierarchy for the selection of an ERP deployment strategy for the furniture company. The importance of criteria and sub-criteria is determined in the first step of this hybrid model. Fuzzy extension of AHP is implemented in order to determine the importance among criteria and sub-criteria. To do this, Table 3is obtained by preferences of decision-making groups and by using equations (1-10). The blank parts of Tables refer to equivalent scales in falling on its symmetry. For example, according to equations (1-10), total weights of the criteria for Table 4 are acquired in Table 5, and total weights of the sub criteria are similarly calculated. In the last step of weights calculation, according to equation 10, by multiplying over all weights of sub criteria with overall weights of criteria that is presented in Table 5, aggregated weights are calculated and presented in Table 6. The obtained aggregated weights are used in following steps.

In the next step, fuzzy group decision-making technique is applied to unify precedence of four decision-making groups into one. In order to do so, an evaluation is created between ERP deployment strategies and criteria based on decision-makers with the help of the data obtained from four decision-making groups. All values of fuzzy group decision-making techniques for Agility sub criterion (C11) and for all six alternatives are calculated by Equations (11-17).Similarly for six alternatives, aggregations of fuzzy opinions for other 10 sub criteria are obtained, and results for both homogeneous and heterogeneous decision-makers are obtained. These are our fuzzy decision matrices for homogeneous and heterogeneous decision-makers, which are used in the fuzzy MOORA method for ranking the ERP deployment strategies (alternatives). In the fuzzy ratio method, fuzzy decision matrices are formed. Then, normalized decision matrices are acquired by Equations (19-22). After that, weighted normalized matrices are calculated by Equations (23-26). Then, the summarizing ratio is calculated for each alternative by equation 27. Finally, the values of Best Non-fuzzy Performances (BNP) are obtained by Equation 28. Results of the fuzzy ratio method (Summarizing Ratio & BNP) are shown in Table 7 (homogeneous) and Table 8 (heterogeneous). Furthermore, based on equation 29 and matrix 30, calculation for the fuzzy reference point method is done for both homogeneous and heterogeneous decision-making groups and presented in Tables (9,10). Finally, in the last technique of the fuzzy MOORA method, according to equation 31, overall utility of alternatives is also calculated for homogeneous and heterogeneous decision-making groups and is shown in Tables (11,12). As tables (7-12) show, According to both homogeneous and heterogeneous decision-makers, the second alternative (cloud-based) is selected in all three diverse methods of fuzzy MOORA. As a result, Cloud-based deployment strategy is chosen as the most suitable ERP deployment strategy for the furniture company.

	C1	**C2**	**C3**	**C4**	**Weights of DMs**
DM1	0.19	0.19	0.57	0.05	0.175
DM2	0.06	0.37	0.44	0.13	0.325
DM3	0.21	0.4	0.18	0.21	0.325
DM4	0.31	0.26	0.31	0.12	0.175
Overall Weight	0.18	0.33	0.35	0.14	

Table5. Total weights of major criteria for all decision makers

Main criteria	**weights**	**Sub criteria**	**weights**	**Overall weights**
C1	0.18	C11	0.33	0.0594
		C12	0.44	0.0792
		C13	0.23	0.0414
C2	0.33	C21	0.22	0.0726
		C22	0.27	0.0891
		C23	0.21	0.0693
C3	0.35	C24	0.3	0.099
		C31	0.825	0.28875
		C32	0.175	0.06125
C4	0.14	C41	0.425	0.0595
		C42	0.575	0.0805

Table6. The overall weights of all sub criteria

6 steps of fuzzy group decision-making technique are used to obtain aggregated fuzzy decision matrix for alternatives.

	y_i	**BNP**	**Rank**
A1(Single-system)	(0.068,0.096,0.109)	0.09102	3
A2(Cloud-based)	(0.103,0.12,0.124)	0.115729	1
A3(Operational)	(0.024,0.041,0.064)	0.042927	4
A4(Peer)	(-0.002,0.006,0.03)	0.011349	6
A5(Hybrid)	(0.069,0.098,0.113)	0.09362	2
A6(Multi-level)	(0.024,0.035,0.055)	0.038275	5

Table7. The fuzzy ratio method results (Homogeneous)

	y_i	**BNP**	**Rank**
A1(Single-system)	(0.066,0.095,0.111)	0.090897	3
A2(Cloud-based)	(0.105,0.125,0.132)	0.120737	1
A3(Operational)	(0.017,0.035,0.61)	0.037984	5
A4(Peer)	(-0.007,0.002,0.029)	0.008107	6
A5(Hybrid)	(0.073,0.103,0.12)	0.098553	2
A6(Multi-level)	(0.025,0.038,0.061)	0.041262	4

Table8. The fuzzy ratio method results (heterogeneous)

	c11	c12	c13	c21	c22	c23	c24	c31	c32	c41	c42	$\max_j(\tilde{r}_j,\tilde{x}_{ij}^*)$	Rank
A1(Single-system)	0.240	0	0.242	0.145	0.130	0.348	0.152	0.041	0.092	0	0.257	0.348	3
A2(Cloud-based)	0	0.072	0	0.106	0.071	0	0	0.156	0.092	0.174	0	0.174	1
A3(Operational)	0.303	0.030	0.111	0.067	0.262	0.348	0.249	0.251	0.092	0.292	0.127	0.348	4
A4(Peer)	0.260	0.203	0.392	0.067	0.340	0.300	0.317	0.251	0.092	0.377	0.279	0.392	5
A5(Hybrid)	0.339	0	0.244	0.148	0	0.277	0.336	0	0	0.219	0.163	0.339	2
A6(Multi-level)	0.260	0.257	0.285	0	0.352	0.300	0.317	0.134	0.059	0.462	0.186	0.462	6

Table9. The fuzzy reference point approach results (Homogeneous)

	c11	c12	c13	c21	c22	c23	c24	c31	c32	c41	c42	$\max_j(\tilde{r}_j,\tilde{x}_{ij}^*)$	Rank
A1(Single-system)	0.229	0.041	0.208	0.136	0.140	0.329	0.150	0.0374	0.104	0	0.212	0.329	2
A2(Cloud-based)	0	0.051	0	0.100	0.065	0	0	0.124	0.104	0.144	0	0.144	1
A3(Operational)	0.310	0.055	0.079	0.090	0.246	0.329	0.214	0.288	0.104	0.286	0.091	0.329	3
A4(Peer)	0.259	0.201	0.376	0.090	0.376	0.289	0.272	0.288	0.104	0.376	0.222	0.376	5
A5(Hybrid)	0.333	0	0.221	0.108	0	0.255	0.308	0	0	0.202	0.124	0.333	4
A6(Multi-level)	0.259	0.280	0.255	0	0.340	0.289	0.272	0.138	0.046	0.446	0.147	0.446	6

Table10. The fuzzy reference point approach results (Heterogeneous)

	$\tilde{U}_i'$	BNP	Rank
A1(Single-system)	(0.000029,0.0137,1.336)	0.44987	3
A2(Cloud-based)	(0.0016,0.119,3.264)	1.128175	1
A3(Operational)	(0.00000985,0.0033,0.34)	0.115204	5
A4(Peer)	(0.0000171,0.000169,0.054)	0.018067	6
A5(Hybrid)	(0.0000171,0.0127,2.92)	0.977692	2
A6(Multi-level)	(0.00000331,0.0022,0.4037)	0.135312	4

Table11. "The fuzzy multiplicative form" results (Homogeneous)

	$\tilde{U}_i'$	BNP	Rank
A1(Single-system)	(0.0000253,0.0115,1.161)	0.390912	3
A2(Cloud-based)	(0.00156,0.109,3.11)	1.075024	1
A3(Operational)	(0.00000753,0.0026,0.247)	0.083367	5
A4(Peer)	(0.000022,0.00014,0.0417)	0.013966	6
A5(Hybrid)	(0.000022,0.0145,2.99)	1.001887	2
A6(Multi-level)	(0.00000363,0.0022,0.397)	0.132992	4

Table12. "The fuzzy multiplicative form" results (Heterogeneous)

IV. DISCUSSION

In this study, an integrated fuzzy model is investigated to select a suitable ERP deployment strategy for a furniture company by fuzzy extension of AHP, fuzzy group decision technique, and fuzzy MOORA. Multiple decision-makers are better than only one decision-maker to prevent prejudice in decisions and eliminate occasions of siding with a party in the decision-making process. For this reason, a novel group decision-making technique is implemented in this study. Furthermore, this paper proposes valuable ranking of ERP deployment strategies by using fuzzy MOORA. Selection of a suitable ERP deployment strategy for a manufacturing company is a sophisticated MCDM problem that includes both quantitative and qualitative objectives. Because, it is difficult to measure the performance of ERP deployment strategies. In this study, performance measurement is done by getting help from experts of an ERP consulting company, managers and academicians. Implementation of a practical decision-making method for assessment and selection of ERP deployment strategies are the major contributions of this study. Finally, Cloud-based deployment strategy is selected as the best ERP deployment strategy for the furniture company. Eventually, proposed model is comprehensible and easy to specialize through various areas. This method opens up a horizon to study on proper alternatives in different decision making problems.

This study could be developed in some ways. First of all, the MULTIMOORA method may be implemented in the second technique of the fuzzy MOORA method. Additionally, an appropriate type-2 fuzzy MCDM may be used in another study. Finally, the weights of criteria and sub-criteria may be calculated with different methods such as DEMATEL.

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