A Fuzzy Quality Function Deployment Approach to Enterprise Resource Planning Software Selection

Mohammad Reza Zahedi, Same Yousefi and Mohsen Cheshmberah

Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

Member of Young Researchers Club, Islamic Azad University, Central Branch, Tehran, Iran

Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

Corresponding Author: Mohammad Reza Zahedi, Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

ABSTRACT

This study presents a comprehensive framework for selecting a suitable ERP system which can be aligned with the needs of the company. This study suggests a method that transfers the House Of Quality (HOQ) approach typical of Quality Function Deployment (QFD) problems to the ERP software selection process. To test its efficacy, the method is applied to an ERP software selection process for an assembling company that manufactures engine of automobiles. The study starts by identifying the features that the ERP system should have (“WHATs”) in order to satisfy the company’s needs, then it seeks to establish the relevant ERP systems criteria (“HOWs”) in order to come up with a final ranking based on the fuzzy suitability index (FSI). The whole procedure was implemented using fuzzy numbers; the application of a fuzzy algorithm allowed the company to define by means of linguistic variables the relative importance of the “WHAT”, the “HOW”-“WHAT” correlation scores, the resulting weights of the “HOW” and the impact of each potential ERP software. Special attention is paid to the various subjective assessments in the HOQ process and symmetrical triangular fuzzy numbers are suggested to capture the vagueness in people’s verbal assessments.

Key words: Software selection process, Enterprise Resource Planning (ERP), House of Quality (HOQ), Quality Function Deployment (QFD), Triangular Fuzzy Numbers (TFNs), Fuzzy Suitability Index (FSI)

INTRODUCTION

An ERP is a packaged enterprise-wide information system that integrates all necessary business functions, such as product planning, purchasing, inventory control, sales, financial and human resources, into a single system with a shared database (Soffer et al., 2003). A large software purchase like an ERP system is a project with significant financial impact and involves making a decision based on both qualitative and quantitative information. In these types of problems, quantitative tools are extremely valuable; however, accurately combining fundamentally different data into a single model in such a way that the answers reflect the correct relative importance is a challenge (Erol and Ferrell, 2003). As enterprises experience an increase in data, many look towards implementing enterprise-wide data automation software, in order to organize data and assist in making sensible business decisions. Software selection is not a technical procedure, but is rather, a subjective and uncertain decision process (Stamelos et al., 2000). Selecting a suitable
SOFTWARE SELECTION

Software selection review: Decision making in the field of software selection has become more complex due to a large number of software products in the market, ongoing improvements in technology and multiple and sometimes conflicting objectives.

A variety of methodologies and frameworks for software selection and evaluation have been developed. Lucas and Moore (1976) used a scoring method to determine the importance of software, Buss (1983) proposed a ranking approach to compare computer projects. This method also has the same limitation with scoring method. Mathematical optimization such as goal programming, 0-1 programming and nonlinear programming have been applied to resource optimization for IS selection. Santhanam and Kyparisis (1996) developed a nonlinear zero-one programming model which considered technical interdependencies among Information System (IS) projects. The model is transformed to a linear mixed integer programming model through a linearization procedure. Although both of these models improved upon earlier studies by considering interdependencies inherent in the IS selection process, the solution procedure is likely to get complicated as the number of IS alternatives and interactions among them increase. Teltumbde (2000) proposed a
methodology framework for evaluating ERP projects based on the Nominal Group Technique NGT and AHP. Badri et al. (2001) presented a 0-1 goal programming model to select an IS project considering multiple criteria including benefits, hardware, software and other costs, risk factors, preferences of decision makers and users, completion time and training time constraints. Wei and Wang (2004) proposed an AHP-based approach to ERP system selection. This study uses the analytical framework of AHP to synthesize decision maker’s tangible and intangible measures with respect to numerous competing objective inherent in ERP system selection and facilitate the group decision-making process. Bernroeder and Stix (2006) combined the utility ranking method and the DEA to overcome the limitations of DEA in software selection.

Liao et al. (2007) presented a new model, which is based on the 2-tuple linguistic information processing, for dealing with the problem of ERP system selection. In that study, a similarity degree based algorithm is proposed to aggregate the objective information about ERP systems from some external professional organizations, which may be expressed by different linguistic term sets. The consistency and inconsistency indices are defined by considering the subject information obtained from internal interviews with ERP vendors and then a linear programming model is established for selecting the most suitable ERP system. Karsak and Ozogul (2007) developed a decision framework for ERP software selection based on Quality Function Deployment (QFD), fuzzy linear regression and zero-one goal programming. The proposed framework enables both company demands and ERP system characteristics to be considered and provides the means for incorporating not only the relationships between company demands and ERP system characteristics but also the interactions between ERP system characteristics through adopting the QFD principles. Kutlu and Akpinar (2009) applied fuzzy logic for Enterprise Resource Planning software selection. This study has been concentrated on a shipping company as the case.

Fuzzy-based decision-making method has been successful employed on a great diversity of applications. The use of fuzzy set theory improves decision-making procedure by accommodating the vagueness and ambiguity occurred during human decision makings. The decision makers can use linguistic terms to evaluate criteria and alternatives easily and intuitively. Thus, the objective of this study is to propose a comprehensive vendor ERP software selection procedure, in which the objectives structure is constructed and the appropriate criteria are specified to provide detailed guidance for ERP software evaluation based on fuzzy set theory.

FUZZY QFD
Quality function deployment: QFD belongs to the sphere of quality management methods, offering us a linear and structured guideline for converting the customer's needs into specifications for and characteristics of new products and services. The method involves developing four matrixes, or 'houses', that we enter by degrees as a project for a given product or production process is developed on increasingly specific levels (Akao, 1990; Venkatachalam et al., 2008). In the present article, our attention focuses on the Planning Matrix, or (HOQ) (Hauser and Clausing, 1988) (Fig. 1) details of the fuzzy method is available in appendix.

The HOQ provides the specifications for product design (or engineering characteristics) in terms of their relative importance and of target values that have to be reached in design and production. In a sense, the HOQ is the hub of the whole QFD method: its construction enables us to precede from the customer's requirements to the design specifications (Schmidt, 1997; Fariborz and Rafael, 2002; Bier and Cornesky, 2001).
Fig. 1: House of quality

This study describes the HOQ and its process following the approaches suggested by Brown (1991). Step 1: Identify the WHATs. The wanted benefits in a product or service in the customer's own words are customer needs and are usually called customer attributes (CA) or "WHATs", area (A) in Fig. 1. In assigning priorities to WHATs, it is necessary to balance efforts in order to accomplish those needs that add value to the customer. The priorities are usually indicated in the area designated as (B) in Fig. 1. Step 2: Determination of HOWs. Engineering characteristics are specified as the "HOWs" of the HOQ and also called measurable requirements. HOWs are identified by a multidisciplinary team (Hauser, 1993) and positioned on the area marked as (C) on the matrix diagram, Fig. 1. Step 3: Preparation of the relationship matrix (D). A team judges which WHATs impact which HOWs and to what degree. Step 4: Elaboration of the correlation matrix. The physical relationships among the technical requirements are specified on an array known as "the roof matrix" and identified as (E) in Fig. 1. Step 5: Action plan. The weights of the HOWs, identified as area (F), are placed at the base of the quality matrix. These weights are one of the main outputs of the HOQ and are determined by:

\[ \text{Weight}(\text{HOW})_i = V(\text{HOW})_{i1} \times \text{imp}(\text{WHAT}_1) + \ldots + V(\text{HOW})_{in} \times \text{imp}(\text{WHAT}_n) \]

where, \( V(\text{HOW})_{in} \) is the correlation value of \( \text{HOW}_i \) with \( \text{WHAT}_n \) and \( \text{imp}(\text{WHAT}_n) \) represents the importance or priority of \( \text{WHAT}_n \).

**Fuzzy logic:** In dealing with a decision process, the decision-maker is often faced with doubts, problems and uncertainties. To cope with and “handle” such uncertainties and inaccuracies, he generally relies on tools provided by probability theory, accepting the principle that an inaccuracy, whatever its nature, is governed by random law. In a real decision-making process, however, we
have to deal with different types of uncertainty and inaccuracy, each of which needs to be treated with the aid of a specific tool. Probability theory is fine for representing the stochastic nature of decisional analysis, but is unable to measure the inaccuracies or uncertainty that stem from human behavior, which is neither stochastic nor random. The fundamental role of the decision-maker or other parties involved in the decisional process poses a number of problems that cannot be handled appropriately by probability theory.

Referring specifically to a multi-criterion analysis, this means that the values of a certain alternative concerning a given attribute often cannot be precisely defined, the decision-maker is unable (or unwilling) to express his preferences precisely, the evaluations or opinions are expressed in linguistic terms and so on. To deal with this type of uncertainty correctly we can resort to fuzzy logic (Zadeh, 1965). The logical tools that people can rely on are generally considered the outcome of a bivalent logic (yes/no, true/false), but the problems posed by real-life situations and human thought processes and approaches to problem-solving are by no means bivalent (Tong and Bonissone, 1980). Just as conventional, bivalent logic is based on classic sets, fuzzy logic is based on fuzzy sets. A fuzzy set is a set of objects in which there is no clear-cut or predefined boundary between the objects that are or are not members of the set. The key concept behind this definition is that of “membership”; each element in a set is associated with a value indicating to what degree the element is a member of the set. This value comes within the range \([0, 1]\), where 0 and 1, respectively, indicate the minimum and maximum degree of membership, while all the intermediate values indicate degrees of “partial” membership.

Nature of decisional analysis, but is unable to measure the inaccuracies or uncertainty that stem from human behavior, which is neither stochastic nor random. The fundamental role of the decision-maker or other parties involved in the decisional process poses a number of problems that cannot be handled appropriately by probability theory.

There are various types of fuzzy number, each of which may be more suitable than others for analyzing a given ambiguous structure; the present analysis uses triangular fuzzy numbers. These numbers are represented by triplets of the type \(A = (x^l, x^m, x^u)\) where \(x^l\) and \(x^u\) are respectively the lower and upper limits of the fuzzy number considered, while \(x^m\) is the element that denotes the closest fit. Triangular fuzzy numbers are often used to quantify linguistic data. The use of triangular fitness functions is fairly common in the literature (Karsak, 2004; Chan and Wu, 2005), because triangular fuzzy numbers are among the few fuzzy number forms that are easy to manage from the computational point of view.

For instance, let \(U = (VL, L, M, H, VH)\) a linguistic set used to express opinions on a group of attributes (\(VL = \) very low, \(L = \) low, \(M = \) medium, \(H = \) high, \(VH = \) very high). The linguistic variables of \(U\) can be quantified using triangular fuzzy numbers as Table 1 (Fig. 2).

The linguistic variable \(M\) for example means that the decision-maker’s assessment contains elements of grades \(x^l = 4\) up to a grade \(x^u = 6\) with a maximum degree of membership in \(x^m = 5\).

**Fuzzy-QFD:** Research on fuzzy-QFD has received a certain amount of attention (Tempioni et al., 1999; Harding et al., 2001) and made substantial progress. Khoo and Ho (1996) proposed an approach centered on the application of possibility theory and fuzzy arithmetic to address the ambiguity in QFD operations. Fung et al. (1998) developed a hybrid system to incorporate the principles of QFD, AHP and fuzzy set theory to determine design targets. Wang (1999) proposed a fuzzy outranking approach to prioritize HOWs. Shen et al. (2001) proposed a fuzzy procedure to examine the sensitivity of the ranking of HOWs to the defuzzification strategy and degree of
Fig. 2: Linguistic scale for relative

Table 1: Quantified linguistic variables by triangular fuzzy numbers

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<th>Linguistic variables</th>
<th>Triangular fuzzy numbers</th>
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<tr>
<td>VL = Very low</td>
<td>(0,1,2)</td>
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<td>L = Low</td>
<td>(2,3,4)</td>
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<tr>
<td>M = Medium</td>
<td>(4,5,6)</td>
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<tr>
<td>H = High</td>
<td>(6,7,8)</td>
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<tr>
<td>VH = Very high</td>
<td>(8,9,10)</td>
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</table>

fuzziness of fuzzy numbers. All these works aim to determine a rating of the HOWs. In this study we propose for the first time the fuzzy-QFD methodology for ERP software vendor selection.

The conceptual and procedural approach of the HOQ remains, though the roles have been inverted: in traditional QFD applications, the company has to identify its customers’ expectations and their relative importance (external variables) in order to identify which design characteristics (internal variables) should be allocated the most resources; when the HOQ is used in ERP software vendor selection, on the other hand, the company starts with the features that the ERP software systems must have in order to meet certain requirements that the company has established—and consequently knows very well (so the customer’s expectations become internal variables, since the company itself is the customer)—and then tries to identify which of the alternative attributes (external variables) have the greatest impact on the achievement of its established objectives. Finally, we have used fuzzy suitability index FSI to express the degree to which each supplier satisfies a given requirement (Teng and Tzeng, 1996).

ERP SOFTWARE SELECTION PROCEDURE WITH A CASE STUDY

To test the efficacy of the proposed method, it was applied to an ERP software selection process for an automotive parts assembling company at the end of Oct. 2009 to Feb. 2010. The data used as input to implement the proposed software selection method were collected by means of interviews with a team that consist of three experts that involve General Manager and senior Management Information System (MIS) and Purchasing manager.

The whole ERP software selection procedure is characterized by the following steps:

- Identifying the characteristics or criteria that the ERP software being purchased must have (internal variables or “WHAT”) in order to meet the Company’s Needs (CNs)
- Identifying the technical attributes of the ERP software (TAs) relevant to vendor assessment (external variables or “HOW”)
Identifying the ("WHATs"): There are some fundamental criteria required of ERP software purchased from outside vendors, that recommended by some experts and studies (Teltumbde, 2000; Erol and Ferrell, 2003; Wei et al., 2005; Karsak and Ozogul (2007)), total cost of ownership, functional fit of the system, user friendliness, flexibility, vendor’s reputation and service and support quality are identified as the company needs (CNs or WHATs), in the ERP system selection study. The definition of each company needs is as follow:

- Total cost of ownership (TCW) consists of cost components including software, hardware, consulting, training, implementation team, etc.
- Functional fit of the ERP system (FF) shows the amount of customization and additional development needed for a close fit to intended processes or customer requirements. Functional fit is preferred over functionality since superfluous functionalities bring nothing but unnecessary complexity to user
- User Friendliness (UF) is essential since intuitive and self-explained screens and menus would shorten the adaptation process for end-users and reduce the required basic trainings
- Flexibility Implies (FI) not only the ease of adapting the system to optimal business processes but also the ease of add-on development, system administration and platform independence. A flexible ERP system should offer multiple languages support and conformity to country specific accounting and costing schemes
- Vendor’s Reputation (VR), internationality, sales references and in particular, completed successful projects in the same industry is a key factor to be considered for customers
- Service and Support Quality (SSQ), Customers also assign high importance to reliable and rapid responsive support. Partner networks are crucial to constituting vendor’s service and support infrastructure

Identifying the ("HOW"): In this section we should determine the technical attributes (TAs) of the ERP software relevant to vendor assessment. By a careful review of the ERP software selection literature and the opinions of experts and on the base of Karsak and Ozogul (2007), this study identified seven technical attributes as follow:

- Percentage of Supported Needs (PSN)
- Percentage of Supported Needs via customization (PSNC)
- Number Of Customers (NOC)
- Vendor’s Total Revenues (VTR)
- Number of Solution Partners (NSP)
- Average duration of User Training (AVUT)
- Vendor’s Operating Countries (VOC)
Determining the relative importance of the "WHATs": Each of the three decision-makers established the level of importance (or weight) of each "what" by means of a linguistic variable. Five different levels of importance were used in this study, i.e. very low, low, medium, high and very high, subsequently indicated as VL, L, M, H and VH. The linguistic variables were translated into fuzzy numbers by defining appropriate fitness functions. Triangular fuzzy numbers were used, characterized as in Table 1 showed. The outcome of this stage is shown in Table 2 and Table 3.

In this study the weights assigned by the decision-makers were aggregated using the average operator, as described by the following equation:

\[ \text{Weights}_{\text{WHAT}} = \{w_i\}, \text{ where } i = 1, \ldots, k, w_i = 1/n \times (w_{i1} + w_{i2} + \ldots + w_{in}) \]

where, \( k \) is the number of "WHATs" and \( n \) is the number of decision-makers (\( k = 6 \) and \( n = 3 \) in our case). Each element on the Weights\(_{\text{WHAT}}\) vector is a triangular fuzzy number defined by the triplet \( w_i = (w_{iL}, w_{iM}, w_{iH}) \). The weights obtained by aggregating the opinions expressed by each decision maker are shown in the Table 4.

**Determining the "HOWs"-"WHATs" correlation scores and weighting the "HOWs":** Each decision-maker was asked to express an opinion, using one of the five linguistic variables, on the impact of each "HOW" on each "WHAT". The opinions expressed by the five decision-makers are shown in Table 5.
Table 6: Correlation between HOWs and WHATs

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<tr>
<th>WHATs</th>
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Table 6: The matrix of “HOWs-WHATs” correlation as triangular fuzzy numbers

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<td>7.67</td>
<td>8.67</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
<td>6.00</td>
<td>6.67</td>
<td>7.67</td>
<td>8.67</td>
</tr>
</tbody>
</table>

Here again, triangular fuzzy numbers were used to quantify the linguistic variables and, as in the previous case, the fuzzy numbers obtained for each decision-maker were aggregated by means of the following equation:

\[ \text{Rating} = \{ r_{ij} \}, \text{where } i = 1,...,k \text{ and } j = 1,...,m, r_{ij} = 1/n \times (r_{i1} + r_{i2} + ... + r_{im}) \]

where, \( k \) = number of the “WHATs”, \( m \) = number of the “HOWs” and \( n \) = number of the decision-makers (in this example, \( k = 6 \), \( m = 7 \) and \( n = 3 \)). This time, the RATING is the matrix of the “how”-“what” correlation scores, whose rij elements represent an aggregate correlation score between the ith “what” and the jth “how”. Here again, the rij elements are triangular fuzzy numbers defined by the triplets \( r_{ij} = (r_{ijs}, r_{ijm}, r_{ijl}) \) as shown in Table 6.

We can now complete the HOQ, calculating the weights of the “HOWs”, averaging the aggregate weighted \( r_{ij} \) correlation scores with the aggregate weights of the “WHATs” \( w_{i} \) according to the equation:

\[ \text{Weight}_{i} = \{ W_{j} \}, \text{where } j = 1,...,m, W_{j} = 1/k \times \left[ (r_{ij} \times w_{i}) + ... + (r_{im} \times w_{m}) \right] \]

where, the usual conventions are assumed for \( k \) and \( m \). Each \( W_{j} \) on the \( \text{Weight}_{i} \) vector represents the weight of each technical attribute (matrix F of Fig. 3). The \( W_{j} \) are, once again, triangular fuzzy numbers defined by means of the triplets \( W_{j} = (W_{j1}, W_{j2}, W_{j3}) \). The fuzzy values for the weights of the “HOWs” are shown in Table 7.

Developing the matrix of correlations between the “HOWs”: The correlations between the technical attributes (“HOWs”) are contained in the “root” of the HOQ (matrix E of Fig. 3). This step
in the construction of the HOQ enables the team members to keep track of pairs of “HOWs” needing parallel improvements and/or comprising “HOWs” in potentially difficult relationships that consequently imply measures that are inconsistent with each other. This matrix contains positive and negative correlations between pairs of “HOWs” using the same symbols as Hines et al. (1998). The completed fuzzy-HOQ is illustrated in Fig. 3.

**Determining the impact of each ERP systems on the attributes considered:** Having completed the weighting of each attribute, all we have to do is assess each ERP systems versus the attribute in question and combine said assessments with the weight of each attribute in order to establish a final ranking. Table 8 shows each decision-maker’s opinions on the various ERP systems in relation to each attribute.

In the same way as before, the linguistic variables were quantified by means of triangular fuzzy numbers, then the five decision-makers’ assessments were aggregated according to the following equation:

\[
\text{Vendor Rating} = \{ VR_{hj} \mid \text{where } h = 1, \ldots, p, j = 1, \ldots, m \}, \quad VR_{hj} = 1/n \times (VR_{hj1} + \ldots + VR_{hnj})
\]

where, \( m \) is the number of attributes (“HOWs”), \( p \) is the number of vendors, \( n \) is the number of decision-makers and \( VR_{hnj} \) is the (fuzzy) evaluation expressed by the \( n \)th decision maker for the \( h \)th
vendor as regards the jth attribute. The Vendor Rating matrix will contain the aggregate assessments VR_{ij} of the hth vendor for the jth attribute; the elements in this matrix are also triangular fuzzy numbers identified by the triplets VR_{ij} = (VR_{ihj}, VR_{ihk}, VR_{ihl}).

**Vendor ranking:** The last step in the procedure involves calculating the FSI for each vendor; this index expresses the degree to which each vendor satisfies a given requirement. The FSI index is a triangular fuzzy number obtained from the previously calculated aggregate scores, multiplied by the weights for each assessment criterion (Bevilacqua et al., 2006). The Eq. is as follows:

\[
FSI = [FSI_h, h = 1, \ldots, p], FSI_h = 1/m \times [(VR_{ihj} \times W_j) + \ldots + (VR_{ihl} \times W_l)]
\]

where, the previously adopted conventions apply for p and m. The FSI vector contains the FSI\_h indexes for each vendor, which is triangular fuzzy numbers as usual, defined by the triplets FSI\_h = (FSI\_h\_a, FSI\_h\_b, FSI\_h\_c), the components of which can be calculated as follows:

\[
FSI_{h_a} = 1/m \sum VR_{h_{ij}} \cdot W_{jk}, j = 1, \ldots, m
\]

\[
FSI_{h_b} = 1/m \sum VR_{h_{ij}} \cdot W_{kj}, j = 1, \ldots, m
\]

\[
FSI_{h_c} = 1/m \sum VR_{h_{ij}} \cdot W_{lj}, j = 1, \ldots, m
\]
For the case in point, the FSIₙ indexes are given in Table 9.

Applied to a triangular fuzzy number FN = (FNₐ, FNₙ, FN₉), the Facchinetti et al. (1998) approach produces a score identified by the value:

\[
(FNₐ + 2FNₙ + FN₉) / 4
\]

So, the final scores are shown in Table 10.

Using the fuzzy ranking principle, these fuzzy ratings produce the following ranking order for the ERP systems:

Sys 10>Sys 1>Sys 4>Sys 3>Sys 8>Sys 9>Sys 6>Sys 2>Sys 5>Sys 7

CONCLUSION

Selecting a suitable ERP system is the basis of implementing ERP project successfully.

This study presents a new model for ERP selection, which is based on fuzzy QFD approach. The main characteristics of this model are:

- As a tool for the identification of the best criteria to ERP software selection
- As a decision model for the final-choice phase in ERP software selection process

The conceptual approach proposed in this study is based on the distinction between the company needs about the ERP software and the technical attributes of ERP software. It becomes evident, in fact that the company’s ultimate aim is to have access to ERP systems that ensure certain standards. It is equally clear, however, that achieving these objectives depends largely on the characteristics of the ERP system itself. It becomes impossible, or at least conceptually unwise, to attempt to achieve such objectives by restricting the assessment to only one of these two categories of attributes.

Constructing an HOQ enables these two groups of attributes to be correlated, so that we can identify how well each ERP system succeeds in meeting the requirements established for the company; having done so, we can go on to draw up a ERP systems rating list. The use of fuzzy logic enables the decision-makers to eliminate, or at least contain the problems stemming from the subjective and ambiguous nature of their information, so that they can formally treat (and thus implement in calculation systems) even those variables that conventional techniques cannot
manage without sacrificing the expressive power typical of verbal language, that still cannot be reproduced by artificial intelligence. Whenever it is impossible to establish clearly distinct constraints due to the variables that define the problem, decision-makers interpret their values on the strength of their experience and understanding of the problem and then draw appropriate decisions.

APPENDIX

**Fuzzy methods:** Fuzzy set theory was developed for solving problems in which descriptions of objects are subjective, vague and imprecise, i.e., no boundaries for the objects can be well defined. Let \( X = \{x\} \) be a traditional set of objects, called the universe. A fuzzy set \( \tilde{E} \) in \( X \) is characterized by a membership function \( \mu_{E}(x) \) that associates each object in \( X \) with a membership value in the interval \([0,1]\), indicating the degree of the object belonging to \( \tilde{E} \).

A fuzzy number is a special fuzzy set when the universe \( X \) is the real line \( \mathbb{R}^1 \): \(-8 \leq x \leq 8\). A Symmetrical Triangular Fuzzy Number (STFN), denoted as \( \tilde{E} = [0,1] \), is a special fuzzy number with the following symmetrical triangular type of membership function:

\[
\mu_{\tilde{E}}(x) = 1 - |x - (c + a)/2|/[(c - a)/2], \quad a \leq x \leq c
\]

STFN is widely used in practice to represent a fuzzy set or concept \( \tilde{E} = \) "approximately b" where \( b = (a + c)/2 \). For example, if an ERP criterion TCW is rated as having "very high" importance by a decision maker, then traditionally we may assign TCW a number 9 using crisp scale. To capture the vagueness of the decision maker's subjective assessment, we can according to the same scale assign TCW an STFN \([8,10]\) which means "approximately 9" and is represented by the following membership function:

\[
\mu_{[8,10]}(x) = 1 - |x - 9|, \quad 8 \leq x \leq 10
\]

This means that, for example, the membership value or "possibility" that TCW is assigned a number 9 is \( \mu_{[8,10]}(9) = 1 \), the "possibility" that TCW is assigned a number 8.5 or 9.5 is \( \mu_{[8,10]}(8.5) = 0.5 \) or \( \mu_{[8,10]}(9.5) = 0.5 \). So assigning TCW a number 8.5 or 9.5 is acceptable or "possible" to the degree of 50%. The basic arithmetic rules for STFNs are as follows:

- **Addition:** \([a, b] + [c, d] = [a+c, b+d]\),
- **Subtraction:** \([a, b] - [c, d] = [a-c, b-d]\),
- **Scalar multiplication:** \(k \times [a, b] = [ka, kb]\) \(k \geq 0\),
- **Multiplication:** \([a, b] \times [c, d] = [ac, bd]\), \(a \geq 0, c \geq 0\),
- **Division:** \([a, b] \div [c, d] = [ac/bd], a \leq 0, c > 0\).

For any two STFNs, \( \tilde{E}_1 = [a, b] \) and, \( \tilde{E}_2 = [c, d] \), if one interval is not strictly contained by another then their ranking order can be easily and intuitively determined. That is:

- If \( d > b \) and \( c \geq a \), or \( d \geq b \) and \( c > b \), then \( \tilde{E}_2 \succ \tilde{E}_1 \), where "\( \succ \)" means "is more importance or preferred than".
- If \( a = c \), \( b = d \), then \( \tilde{E}_2 = \tilde{E}_1 \).
But if one interval is strictly contained by another, i.e., if d<b and c>a, or d>b and c<a, then the ranking problem becomes complex and many possibilities may occur. For more details about fuzzy set theory, STFNs and fuzzy ranking methods, Zimmermann (1987).

REFERENCES


