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A fuzzy group multi-criteria enterprise architecture framework selection model

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ABSTRACT

A large body of intuitive and analytical models has evolved over the last several decades to assist decision makers (DMs) in enterprise architecture (EA) framework selection. While these models have made great strides in EA framework evaluation, the intuitive models lack a structured framework and the analytical models do not capture intuitive preferences of multiple DMs. Furthermore, crisp data are fundamentally indispensable in traditional EA framework selection methods. However, the data in real-world problems are often imprecise or ambiguous. The prior research in EA framework selection does not embrace both qualitative and quantitative criteria exhibiting imprecise and ambiguous value judgments. In this paper, we propose a novel fuzzy group multi-criteria model for EA framework evaluation and selection. The contribution of the proposed model is fourfold: (1) it takes into consideration the qualitative and quantitative criteria and their respective value judgments; (2) it considers verbal expressions and linguistic variables for qualitative judgments which lead to ambiguity in the decision process; (3) it handles imprecise or vague judgments; and (4) it uses a meaningful and robust multi-criteria model to aggregate both qualitative and quantitative data. We use a real-world case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms.

1. Introduction

The increasing global competition and the rapid advances in information systems have led organizations to search for more effective and efficient ways to manage their business. The enterprise architecture (EA) frameworks can ensure interoperability of information systems and improve the effectiveness and efficiency of business organizations. However, the increasing turbulence in the business environment and the larger number of alternatives with conflicting criteria has made the selection of EA frameworks a difficult and complex task. The EA framework selection problems are multi-criteria problems that embrace both qualitative and quantitative criteria. Nevertheless, the traditional selection methods overemphasize quantitative and economic analysis and often neglect to consider qualitative and non-economic data in the formal selection process. When facing such multi-criteria problems, the literature and research show that the following difficulties may be encountered in the decision process:

1. Decision makers (DMs) often use verbal expressions and linguistic variables for qualitative judgments which lead to ambiguity in the decision process (Poyhonen, Hamalainen, & Salo, 1997).
2. DMs often provide imprecise or vague information due to lack of expertise or unavailability of data (Kim & Ahn, 1999).
3. Meaningful and robust aggregation of qualitative and quantitative data causes difficulties in the decision process (Valls & Torra, 2000).
4. A decision process is not complete without fully taking into consideration all the criteria and their respective value judgments (Belton & Stewart, 2002; Yang & Xu, 2002).

Before an organization takes up a particular EA framework, there is need to consider and evaluate the possible alternative frameworks, and then select an appropriate one through a collaborative effort involving all key stakeholders (Gammelgêard, Simonsson, & Lindstrèom, 2007). Over the past several years, the selection of EA frameworks has garnered considerable attention from both practitioners and academics. Fayad and Hamu (2000) have presented a detailed list of guidelines and attributes for selection of EA frameworks. Tang, Han, and Chen (2004) have studied and compared the EA frameworks analytically and provided a model of understanding through analyzing the goals, inputs and outcomes of six architecture frameworks. Nonetheless, these studies did not consider any uncertainties such as uncertainty in the

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subjective judgments or uncertainties due to lack of data and incomplete information.

Multi-criteria decision making methods have also been successfully applied in various decision making situations that have many similar features with EA framework selection problems. The multi-criteria methods used to evaluate EA frameworks based on quantitative measurements include Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang & Yoon, 1981; Kahraman, Ateş, Çevik, Gülbay, & Erdoğan, 2007; Shih, 2008); Simple Additive Weighting (SAW) (Chou, Chang, & Shen, 2008; Zavadskas, Turskis, Dejus, & Viteikiene, 2007); Linear Programming Techniques for Multidimensional Analysis of Preference (LINMAP) (Xia, Li, Zhou, & Wang, 2006); COmplex PRoportional Assessment (COPRAS) (Kaklauskas et al., 2006; Zavadskas, Turskis, Tamošaitienė, & Marina, 2008). The multi-criteria methods used to evaluate EA frameworks based on qualitative measurements not converted to quantitative variables include methods of verbal decision-making analysis (Berkeley, Humphreys, Larichev, & Moshkovich, 1991; Andre'eva, Larichev, Flanders, & Brown, 1995; Larichev, 1992; Larichev, Brown, & Andre'eva, 1995; Larichev & Moshkovich, 1997; Flanders, Brown, Andre'eva, & Larichev, 1998). Comparative preference methods based on pairwise comparison of alternatives include ELECTRE (Costa, Almeida, & Miranda, 2003; Roy, 1996) and PROMETHEE I and II (Brans, Vincke, & Mareschal, 1986; Diakoulaki & Koumoutsos, 1991; Wang & Yang, 2007). The multi-criteria methods used to evaluate EA frameworks based on qualitative measurements converted to quantitative variables include two widely known groups of methods, i.e. Analytic Hierarchy Process (AHP) (Ghodsypour & O'brien, 1998; Saaty, 1994) and fuzzy set theory methods (Roztocki & Weistroffer, 2006; Zimmermann, 2000).

Traditional assessment techniques overemphasize quantitative and economic analysis and often neglect to consider qualitative and non-economic factors in the formal selection process. Furthermore, crisp data are fundamentally indispensable in traditional EA framework selection methods. However, the data in real-world problems are often imprecise or ambiguous. The prior research in EA framework selection does not embrace both qualitative and quantitative criteria exhibiting imprecise and ambiguous value judgments. In this paper, we propose a novel fuzzy group multi-criteria model for EA framework evaluation and selection that takes into consideration (1) the qualitative and quantitative criteria and their respective value judgments; (2) the verbal expressions and linguistic variables for qualitative judgments which lead to ambiguity in the decision process; and (3) imprecise or vague judgments. The five EA frameworks considered in this study include: Federal Enterprise Architecture Framework (FEAF), Zachman Framework for Enterprise Architecture (ZACHMAN), The Open Group Architecture Framework (TOGAF), Treasury Enterprise Architecture Framework (TEAF), and Department of Defense Architecture Framework (DoDAF). See Urbaczewski and Mrdalj (2006) for an excellent review of the five EA frameworks considered in our study.

The next section presents the mathematical notations and definitions used in our model. In Section 3, we illustrate the details of the proposed model followed by a real-life case study to demonstrate the applicability of the proposed model and exhibit the efficacy of the procedures and algorithms. In Section 5, we conclude with our conclusions and future research directions.

2. The mathematical notations and definitions

Let us introduce the following mathematical notations and definitions:

$\tilde{I}$	The fuzzy weighted collective impact matrix with respect to the impact of m risk criteria
$\tilde{L}$	The fuzzy weighted collective likelihood matrix with respect to the likelihood of m risk criteria
$\tilde{D}$	The fuzzy weighted collective detection matrix with respect to the detection of m risk criteria
$\tilde{I}^K$	The individual fuzzy impact matrix with respect to the impact of m risk criteria evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{L}^K$	The individual fuzzy likelihood matrix with respect to the likelihood of $m$risk criteria evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{D}^K$	The individual fuzzy detection matrix with respect to the detection of m risk criteria evaluated by the EA framework selection team member $(EAFT)_k$
$w(vp)_K$	The voting power of the EA framework selection team member $(EAFT)_k$ for scoring $(K = 1,2,\ldots,l)$
w_j	The importance weight of the jth criterion
$\tilde{e}_{ij}(I)$	The fuzzy weighted collective impact value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{e}_{ij}(L)$	The fuzzy weighted collective likelihood value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{e}_{ij}(D)$	The fuzzy weighted collective detection value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{e}^k_{ij}(I)$	The individual fuzzy impact value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{e}^k_{ij}(L)$	The individual fuzzy likelihood value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
$\tilde{e}^k_{ij}(D)$	The individual fuzzy detection value of the EA framework with respect to the risk criterion j evaluated by the EA framework selection team member $(EAFT)_k$
c_j	The jth criterion
A_i	The ith EA framework
m	The number of risk criteria
l	The number of EA framework selection team members
n	The number of EA frameworks
$R\tilde{P}N$	The fuzzy risk priority numbers (RPN) matrix
R	The ordinal rank matrix
$R[E(r\tilde{p}n_{ij})]$	The ordinal rank of $E(r\tilde{p}n_{ij})$
$E(r\tilde{p}n_{ij})$	The possibilistic mean value of $r\tilde{p}n_{ij}$
$r\tilde{p}n_{ij}$	The fuzzy risk priority number (RPN) for the ith EA framework with respect to the risk criterion j
$\underline{V}$	The vector of the EA frameworks risks
v_i	The risk of the jth EA framework

3. The proposed model

The model depicted in Fig. 1 is proposed to assess the alternative EA frameworks and consists of several steps modularized into five phases:

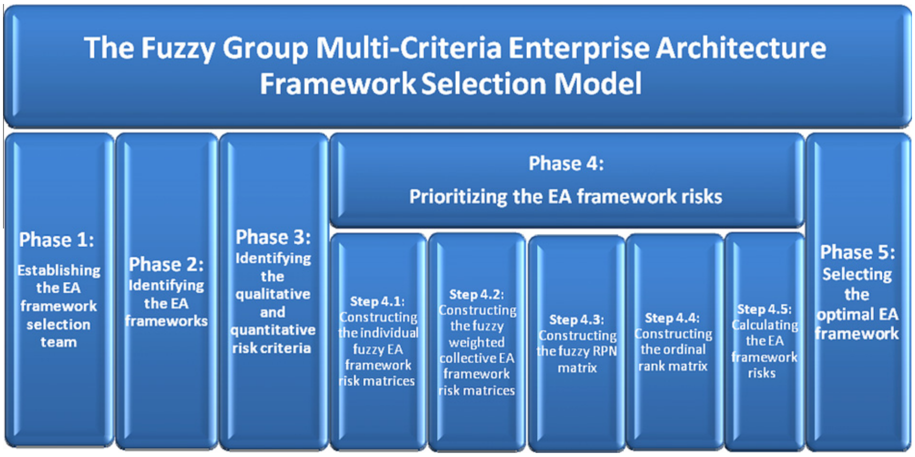

Fig. 1. The proposed framework.

In summary, we.

- have group members estimate the impact, probability of occurrence and probability of detection of certain risks involved in the selection of EA frameworks,
- aggregate across group members by forming a weighted average,
- calculate expected impact by multiplying impact and probabilities,
- use an additive weighting scheme to aggregate across impact categories,
- defuzzify results by forming expected values,
- transform evaluations into Borda scores, and
- select the alternative with the lowest risk score.

Phase 1: Establishing the EA framework selection team. In the first phase, we establish an EA framework selection team. Let us assume that l EA framework selection team members are chosen to rank the EA frameworks:

$$\underline{EAFT} = [(EAFT)_1, (EAFT)_2, \ldots, (EAFT)_k, \ldots, (EAFT)_l]$$

Phase 2: Identifying the EA frameworks. In this phase, the selection team identifies a set of EA frameworks. Let us further assume that the selection team has identified n EA frameworks:

$$\underline{A} = [A_1, A_2, \ldots, A_n]$$

Phase 3: Identifying the qualitative and quantitative risk criteria. In this step, the EA framework selection team identifies a set of qualitative and quantitative risk criteria associated with the EA frameworks. Let $c_1, c_2, \ldots, c_m$ and $w_1, w_2, \ldots, w_m$ be the risk criteria and their importance weights, respectively.

Phase 4: Prioritizing the EA framework risks. In this phase, the EA framework selection team prioritizes the EA frameworks according to the following five steps:

Step 4.1: Constructing the individual fuzzy EA framework risk matrices. In this step, the fuzzy individual EA framework risks are assessed based on the following three attributes associated with a risk event: the impact, likelihood and detection of the qualitative and quantitative risks identified in Phase 3. The goal is to identify, quantify and remove or reduce risks in an EA framework.

4.1.1. Calculating the impact value of the EA frameworks. A project risk is defined as "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives" (PMI, 2009). The EA framework risk is represented by the impact attribute in our model. The EA framework selection team uses a fuzzy set [1–10] to assign an impact number (I) to each EA framework. The impact value guidelines in Table 1 suggested by Carbone and Tippett (2004) are used to assign the impact values.

These fuzzy numbers are used to prioritize the EA frameworks with respect to the impact of the risk criteria. The individual fuzzy impact matrix with respect to the impact of m risk criteria evaluated by the EA framework selection team member $(EAFT)_k$ will be as follows:

$$\tilde{I}^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \left[\begin{array}{cccc} \tilde{e}^k_{11}(I) & \tilde{e}^k_{12}(I) & \cdots & \tilde{e}^k_{1m}(I) \\ \tilde{e}^k_{21}(I) & \tilde{e}^k_{22}(I) & \cdots & \tilde{e}^k_{2m}(I) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}^k_{n1}(I) & \tilde{e}^k_{n2}(I) & \cdots & \tilde{e}^k_{nm}(I) \end{array}\right] \end{array} \tag{1}$$

Let $\tilde{e}^k_{ij}(I)$be the following trapezoidal fuzzy number:

$$\tilde{e}^k_{ij}(I) = \left(\left(e^k_{ij}(I)\right)^{o}, \left(e^k_{ij}(I)\right)^{\alpha}, \left(e^k_{ij}(I)\right)^{\beta}, \left(e^k_{ij}(I)\right)^{\gamma}\right) \tag{2}$$

Consequently, substituting Eq. (2) into matrix (1), it can be rewritten as:

$$\tilde{I}^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \left[\begin{array}{cccc} \left((e^k_{11})^{o}, (e^k_{11})^{\alpha}, (e^k_{11})^{\beta}, (e^k_{11})^{\gamma}\right)_I & \left((e^k_{12})^{o}, (e^k_{12})^{\alpha}, (e^k_{12})^{\beta}, (e^k_{12})^{\gamma}\right)_I & \cdots & \left((e^k_{1m})^{o}, (e^k_{1m})^{\alpha}, (e^k_{1m})^{\beta}, (e^k_{1m})^{\gamma}\right)_I \\ \left((e^k_{21})^{o}, (e^k_{21})^{\alpha}, (e^k_{21})^{\beta}, (e^k_{21})^{\gamma}\right)_I & \left((e^k_{22})^{o}, (e^k_{22})^{\alpha}, (e^k_{22})^{\beta}, (e^k_{22})^{\gamma}\right)_I & \cdots & \left((e^k_{2m})^{o}, (e^k_{2m})^{\alpha}, (e^k_{2m})^{\beta}, (e^k_{2m})^{\gamma}\right)_I \\ \vdots & \vdots & \cdots & \vdots \\ \left((e^k_{n1})^{o}, (e^k_{n1})^{\alpha}, (e^k_{n1})^{\beta}, (e^k_{n1})^{\gamma}\right)_I & \left((e^k_{n2})^{o}, (e^k_{n2})^{\alpha}, (e^k_{n2})^{\beta}, (e^k_{n2})^{\gamma}\right)_I & \cdots & \left((e^k_{nm})^{o}, (e^k_{nm})^{\alpha}, (e^k_{nm})^{\beta}, (e^k_{nm})^{\gamma}\right)_I \end{array}\right] \end{array} \tag{3}$$

4.1.2. Calculating the likelihood values of the EA frameworks. Next, we consider the risk occurrence frequencies in our model by assigning a likelihood ranking (L) to each EA framework

Table 1
The impact value guidelines.

Very low	Low	Average	High	Very high
Fuzzy number 1 or 2	Fuzzy number 3 or 4	Fuzzy number 5 or 6	Fuzzy number 7 or 8	Fuzzy number 9 or 10

Table 2
The likelihood value guidelines.

Very unlikely	Probably will not occur	Equal chance of occurring or not	Will probably occur	Very likely to occur
Fuzzy number 1 or 2	Fuzzy number 3 or 4	Fuzzy number 5 or 6	Fuzzy number 7 or 8	Fuzzy number 9 or 10

using fuzzy numbers 1–10. The likelihood value guidelines in Table 2 suggested by Carbone and Tippett (2004) are used to assign the impact values.

These fuzzy numbers are used to prioritize the EA frameworks with respect to the impact of the risk criteria. The individual fuzzy likelihood matrix with respect to the likelihood of m risk criteria evaluated by the EA framework selection team member $(EAFT)_k$ will be as follows:

$$\widetilde{L}^k = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \tilde{e}_{11}^k(L) & \tilde{e}_{12}^k(L) & \cdots & \tilde{e}_{1m}^k(L) \\ \tilde{e}_{21}^k(L) & \tilde{e}_{22}^k(L) & \cdots & \tilde{e}_{2m}^k(L) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}_{n1}^k(L) & \tilde{e}_{n2}^k(L) & \cdots & \tilde{e}_{nm}^k(L) \end{bmatrix} \end{array} \tag{4}$$

Let $\tilde{e}_{ij}^k(L)$ be the following trapezoidal fuzzy number:

$$\tilde{e}_{ij}^k(L) = \left(\left(e_{ij}^k(L)\right)^o, \left(e_{ij}^k(L)\right)^\alpha, \left(e_{ij}^k(L)\right)^\beta, \left(e_{ij}^k(L)\right)^\gamma \right) \tag{5}$$

Consequently, substituting Eq. (5) into matrix (4), it can be rewritten as:

$$\widetilde{L}^k = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \left((e_{11}^k)^o, (e_{11}^k)^\alpha, (e_{11}^k)^\beta, (e_{11}^k)^\gamma\right)_L & \left((e_{12}^k)^o, (e_{12}^k)^\alpha, (e_{12}^k)^\beta, (e_{12}^k)^\gamma\right)_L & \cdots & \left((e_{1m}^k)^o, (e_{1m}^k)^\alpha, (e_{1m}^k)^\beta, (e_{1m}^k)^\gamma\right)_L \\ \left((e_{21}^k)^o, (e_{21}^k)^\alpha, (e_{21}^k)^\beta, (e_{21}^k)^\gamma\right)_L & \left((e_{22}^k)^o, (e_{22}^k)^\alpha, (e_{22}^k)^\beta, (e_{22}^k)^\gamma\right)_L & \cdots & \left((e_{2m}^k)^o, (e_{2m}^k)^\alpha, (e_{2m}^k)^\beta, (e_{2m}^k)^\gamma\right)_L \\ \vdots & \vdots & \cdots & \vdots \\ \left((e_{n1}^k)^o, (e_{n1}^k)^\alpha, (e_{n1}^k)^\beta, (e_{n1}^k)^\gamma\right)_L & \left((e_{n2}^k)^o, (e_{n2}^k)^\alpha, (e_{n2}^k)^\beta, (e_{n2}^k)^\gamma\right)_L & \cdots & \left((e_{nm}^k)^o, (e_{nm}^k)^\alpha, (e_{nm}^k)^\beta, (e_{nm}^k)^\gamma\right)_L \end{bmatrix} \end{array} \tag{6}$$

4.1.3. Calculating the detection values of the EA frameworks. Detection values represent the organization's ability to detect the risk event with enough time to plan for a contingency and act upon the risk (Carbone & Tippett, 2004). The detection value is a measure of being able to predict the specific risk event in the future. The goal is to detect the risk as early as possible. Those risks with high detection values may need one additional control mechanism for early warning. Each EA framework is assigned a detection value (D), again using fuzzy numbers 1–10. This ranks the ability of planned tests in each EA framework to detect risk events in time. The detection value guidelines in Table 3 suggested by Carbone and Tippett (2004) are used to assign the detection values.

Certainly, the detection assignment is subjective, but no more so than the assignment of the likelihood and impact values for the common risk matrix method. The individual fuzzy detection matrix with respect to the detection of m risk criteria evaluated by the EA framework selection team member $(EAFT)_k$ will be as follows:

$$\widetilde{D}^k = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \tilde{e}_{11}^k(D) & \tilde{e}_{12}^k(D) & \cdots & \tilde{e}_{1m}^k(D) \\ \tilde{e}_{21}^k(D) & \tilde{e}_{22}^k(D) & \cdots & \tilde{e}_{2m}^k(D) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}_{n1}^k(D) & \tilde{e}_{n2}^k(D) & \cdots & \tilde{e}_{nm}^k(D) \end{bmatrix} \end{array} \tag{7}$$

Let $\tilde{e}_{ij}^k(D)$ be the following trapezoidal fuzzy number:

$$\tilde{e}_{ij}^k(D) = \left(\left(e_{ij}^k(D)\right)^o, \left(e_{ij}^k(D)\right)^\alpha, \left(e_{ij}^k(D)\right)^\beta, \left(e_{ij}^k(D)\right)^\gamma \right) \tag{8}$$

Consequently, substituting Eq. (8) into matrix (7), it can be rewritten as:

$$\widetilde{D}^k = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \left((e_{11}^k)^o, (e_{11}^k)^\alpha, (e_{11}^k)^\beta, (e_{11}^k)^\gamma\right)_D & \left((e_{12}^k)^o, (e_{12}^k)^\alpha, (e_{12}^k)^\beta, (e_{12}^k)^\gamma\right)_D & \cdots & \left((e_{1m}^k)^o, (e_{1m}^k)^\alpha, (e_{1m}^k)^\beta, (e_{1m}^k)^\gamma\right)_D \\ \left((e_{21}^k)^o, (e_{21}^k)^\alpha, (e_{21}^k)^\beta, (e_{21}^k)^\gamma\right)_D & \left((e_{22}^k)^o, (e_{22}^k)^\alpha, (e_{22}^k)^\beta, (e_{22}^k)^\gamma\right)_D & \cdots & \left((e_{2m}^k)^o, (e_{2m}^k)^\alpha, (e_{2m}^k)^\beta, (e_{2m}^k)^\gamma\right)_D \\ \vdots & \vdots & \cdots & \vdots \\ \left((e_{n1}^k)^o, (e_{n1}^k)^\alpha, (e_{n1}^k)^\beta, (e_{n1}^k)^\gamma\right)_D & \left((e_{n2}^k)^o, (e_{n2}^k)^\alpha, (e_{n2}^k)^\beta, (e_{n2}^k)^\gamma\right)_D & \cdots & \left((e_{nm}^k)^o, (e_{nm}^k)^\alpha, (e_{nm}^k)^\beta, (e_{nm}^k)^\gamma\right)_D \end{bmatrix} \end{array} \tag{9}$$

Table 3
The detection value guidelines.

Highly effective and it is almost certain that the risk will be detected with adequate time	Moderately high effectiveness	Medium effectiveness	Unproven or unreliable; or effectiveness of detection method is unknown to detect in time	There is no detection method available or known that will provide an alert with enough time to plan for a contingency
Fuzzy number 1 or 2	Fuzzy number 3 or 4	Fuzzy number 5 or 6	Fuzzy number 7 or 8	Fuzzy number 9 or 10

Step 4.2: Constructing the fuzzy weighted collective EA framework risk matrices. In this step, the fuzzy weighted collective EA framework risks are assessed based on the likelihood, impact and detection of the identified risks as follows:

4.2.1. Calculating the impact values of the EA frameworks. The fuzzy weighted collective impact matrix with respect to the impact of m risk criteria will be as follows:

$$\widetilde{I}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} ((e_{11})^{o},(e_{11})^{\alpha},(e_{11})^{\beta},(e_{11})^{\gamma})_I & ((e_{12})^{o},(e_{12})^{\alpha},(e_{12})^{\beta},(e_{12})^{\gamma})_I & \cdots & ((e_{1m})^{o},(e_{1m})^{\alpha},(e_{1m})^{\beta},(e_{1m})^{\gamma})_I \\ ((e_{21})^{o},(e_{21})^{\alpha},(e_{21})^{\beta},(e_{21})^{\gamma})_I & ((e_{22})^{o},(e_{22})^{\alpha},(e_{22})^{\beta},(e_{22})^{\gamma})_I & \cdots & ((e_{2m})^{o},(e_{2m})^{\alpha},(e_{2m})^{\beta},(e_{2m})^{\gamma})_I \\ \vdots & \vdots & \cdots & \vdots \\ ((e_{n1})^{o},(e_{n1})^{\alpha},(e_{n1})^{\beta},(e_{n1})^{\gamma})_I & ((e_{n2})^{o},(e_{n2})^{\alpha},(e_{n2})^{\beta},(e_{n2})^{\gamma})_I & \cdots & ((e_{nm})^{o},(e_{nm})^{\alpha},(e_{nm})^{\beta},(e_{nm})^{\gamma})_I \end{bmatrix} \end{array} \tag{10}$$

or:

$$\widetilde{I}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \tilde{e}_{11}(I) & \tilde{e}_{12}(I) & \cdots & \tilde{e}_{1m}(I) \\ \tilde{e}_{21}(I) & \tilde{e}_{22}(I) & \cdots & \tilde{e}_{2m}(I) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}_{n1}(I) & \tilde{e}_{n2}(I) & \cdots & \tilde{e}_{nm}(I) \end{bmatrix} \end{array} \tag{11}$$

where:

$$\tilde{e}_{ij}(I)=\frac{\sum_{k=1}^{l}(w(vp)_k)\left[\tilde{e}_{ij}^{k}(I)\right]}{\sum_{k=1}^{l}w(vp)_k} \tag{12}$$

4.2.2. Calculating the likelihood values of the EA frameworks. The fuzzy weighted collective likelihood matrix with respect to the likelihood of m risk criteria will be as follows:

$$\widetilde{L}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} ((e_{11})^{o},(e_{11})^{\alpha},(e_{11})^{\beta},(e_{11})^{\gamma})_L & ((e_{12})^{o},(e_{12})^{\alpha},(e_{12})^{\beta},(e_{12})^{\gamma})_L & \cdots & ((e_{1m})^{o},(e_{1m})^{\alpha},(e_{1m})^{\beta},(e_{1m})^{\gamma})_L \\ ((e_{21})^{o},(e_{21})^{\alpha},(e_{21})^{\beta},(e_{21})^{\gamma})_L & ((e_{22})^{o},(e_{22})^{\alpha},(e_{22})^{\beta},(e_{22})^{\gamma})_L & \cdots & ((e_{2m})^{o},(e_{2m})^{\alpha},(e_{2m})^{\beta},(e_{2m})^{\gamma})_L \\ \vdots & \vdots & \cdots & \vdots \\ ((e_{n1})^{o},(e_{n1})^{\alpha},(e_{n1})^{\beta},(e_{n1})^{\gamma})_L & ((e_{n2})^{o},(e_{n2})^{\alpha},(e_{n2})^{\beta},(e_{n2})^{\gamma})_L & \cdots & ((e_{nm})^{o},(e_{nm})^{\alpha},(e_{nm})^{\beta},(e_{nm})^{\gamma})_L \end{bmatrix} \end{array} \tag{13}$$

or:

$$\widetilde{L}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \tilde{e}_{11}(L) & \tilde{e}_{12}(L) & \cdots & \tilde{e}_{1m}(L) \\ \tilde{e}_{21}(L) & \tilde{e}_{22}(L) & \cdots & \tilde{e}_{2m}(L) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}_{n1}(L) & \tilde{e}_{n2}(L) & \cdots & \tilde{e}_{nm}(L) \end{bmatrix} \end{array} \tag{14}$$

where:

$$\tilde{e}_{ij}(L)=\frac{\sum_{k=1}^{l}(w(vp)_k)\left[\tilde{e}_{ij}^{k}(L)\right]}{\sum_{k=1}^{l}w(vp)_k} \tag{15}$$

4.2.3. Calculating the detection values of the EA frameworks. The fuzzy weighted collective detection matrix with respect to the detection of m risk criteria will be as follows:

$$\widetilde{D}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \left((e_{11})^{o},(e_{11})^{\alpha},(e_{11})^{\beta},(e_{11})^{\gamma}\right)_D & \left((e_{12})^{o},(e_{12})^{\alpha},(e_{12})^{\beta},(e_{12})^{\gamma}\right)_D & \cdots & ((e_{1m})^{o},(e_{1m})^{\alpha},(e_{1m})^{\beta},(e_{1m})^{\gamma})_D \\ ((e_{21})^{o},(e_{21})^{\alpha},(e_{21})^{\beta},(e_{21})^{\gamma})_D & ((e_{22})^{o},(e_{22})^{\alpha},(e_{22})^{\beta},(e_{22})^{\gamma})_D & \cdots & ((e_{2m})^{o},(e_{2m})^{\alpha},(e_{2m})^{\beta},(e_{2m})^{\gamma})_D \\ \vdots & \vdots & \cdots & \vdots \\ ((e_{n1})^{o},(e_{n1})^{\alpha},(e_{n1})^{\beta},(e_{n1})^{\gamma})_D & ((e_{n2})^{o},n^{\alpha},(e_{n2})^{\beta},(e_{n2})^{\gamma})_D & \cdots & ((e_{nm})^{o},(e_{nm})^{\alpha},(e_{nm})^{\beta},(e_{nm})^{\gamma})_D \end{bmatrix} \end{array} \tag{16}$$

or:

$$\widetilde{D}=\begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} & \begin{bmatrix} \tilde{e}_{11}(D) & \tilde{e}_{12}(D) & \cdots & \tilde{e}_{1m}(D) \\ \tilde{e}_{21}(D) & \tilde{e}_{22}(D) & \cdots & \tilde{e}_{2m}(D) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{e}_{n1}(D) & \tilde{e}_{n2}(D) & \cdots & \tilde{e}_{nm}(D) \end{bmatrix} \end{array} \tag{17}$$

where:

$$\tilde{e}_{ij}(D) = \frac{\sum_{k=1}^{l}(w(v p)_k)\left[\tilde{e}_{ij}^{k}(D)\right]}{\sum_{k=1}^{l} w(v p)_k} \tag{18}$$

Step 4.3: Constructing the fuzzy RPN matrix. Next, we calculate the fuzzy RPN by multiplying the three fuzzy impact, likelihood and detection values. This has to be done for each EA framework with respect to the risk criteria. The EA frameworks that have the highest RPN should be given the lowest selection priority and those with the lowest RPN should be given the highest selection priority. Therefore, the fuzzy RPN matrix will be as follows:

$$R\widetilde{P}N = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{bmatrix} ((rpn_{11})^o,(rpn_{11})^\alpha,(rpn_{11})^\beta,(rpn_{11})^\gamma) & ((rpn_{12})^o,(rpn_{12})^\alpha,(rpn_{12})^\beta,(rpn_{12})^\gamma) & \cdots & ((rpn_{1m})^o,(rpn_{1m})^\alpha,(rpn_{1m})^\beta,(rpn_{1m})^\gamma) \\ ((rpn_{21})^o,(rpn_{21})^\alpha,(rpn_{21})^\beta,(rpn_{21})^\gamma) & ((rpn_{22})^o,(rpn_{22})^\alpha,(rpn_{22})^\beta,(rpn_{22})^\gamma) & \cdots & ((rpn_{2m})^o,(rpn_{2m})^\alpha,(rpn_{2m})^\beta,(rpn_{2m})^\gamma) \\ \vdots & \vdots & \cdots & \vdots \\ ((rpn_{n1})^o,(rpn_{n1})^\alpha,(rpn_{n1})^\beta,(rpn_{n1})^\gamma) & ((rpn_{n2})^o,(rpn_{n2})^\alpha,(rpn_{n2})^\beta,(rpn_{n2})^\gamma) & \cdots & ((rpn_{nm})^o,(rpn_{nm})^\alpha,(rpn_{nm})^\beta,(rpn_{nm})^\gamma) \end{bmatrix} \end{array} \tag{19}$$

or:

$$R\widetilde{P}N = \begin{array}{c|cccc} & c_1 & c_2 & \cdots & c_m \\ \hline A_1 & r\tilde{p}n_{11} & r\tilde{p}n_{12} & \cdots & r\tilde{p}n_{1m} \\ A_2 & r\tilde{p}n_{21} & r\tilde{p}n_{22} & \cdots & r\tilde{p}n_{2m} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ A_n & r\tilde{p}n_{n1} & r\tilde{p}n_{n2} & \cdots & r\tilde{p}n_{nm} \end{array} \tag{20}$$

where:

$$r\tilde{p}n_{ij} = \tilde{e}_{ij}(I).\tilde{e}_{ij}(L).\tilde{e}_{ij}(D) \tag{21}$$

Step 4.4: Constructing the ordinal rank matrix. Next, we rank the n EA frameworks based on Borda's score. That is, for each strategic criterion of preference ordering of the EA frameworks, scores of $n-1, n-2, \ldots, 1, 0$ are assigned to the first, second ... and the last ranked framework:

$$R = \begin{array}{c|cccc} & c_1 & c_2 & \cdots & c_m \\ \hline A_1 & R[E(r\tilde{p}n_{11})] & R[E(r\tilde{p}n_{12})] & \cdots & R[E(r\tilde{p}n_{1m})] \\ A_2 & R[E(r\tilde{p}n_{21})] & R[E(r\tilde{p}n_{22})] & \cdots & R[E(r\tilde{p}n_{2m})] \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ A_n & R[E(r\tilde{p}n_{n1})] & R[E(r\tilde{p}n_{n2})] & \cdots & R[E(r\tilde{p}n_{nm})] \end{array} \tag{22}$$

Since $r\tilde{p}n_{ij}$ is a trapezoidal fuzzy number, $r\tilde{p}n_{ij} = ((rpn_{ij})^o, (rpn_{ij})^\alpha, (rpn_{ij})^\beta, (rpn_{ij})^\gamma)$, its expected value can be derived as follows:

$$E(r\tilde{p}n_{ij}) = \frac{(rpn_{ij})^o + (rpn_{ij})^\alpha}{2} + \frac{(rpn_{ij})^\gamma - (rpn_{ij})^\beta}{6} \tag{23}$$

Step 4.5: Calculating the EA frameworks risks. The vector of the EA frameworks risks will be calculated as follows:

$$\underline{V} = [\, v_1 \quad v_2 \quad \cdots \quad v_n \,]^T \tag{24}$$

where:

$$\tilde{v}_i = \frac{\sum_{j=1}^{m}(w_j)R[E(r\tilde{p}n_{ij})]}{\sum_{i=1}^{n}\sum_{j=1}^{m} w_j R[E(r\tilde{p}n_{ij})]} \tag{25}$$

Phase 5: Selecting the optimal EA framework. In this phase, the optimal EA frameworks ranking is determined based on the risks values obtained in phase (4). For this purpose, these values are considered as the coefficients of the objective functions in the following proposed mathematical model with a series of applicable constraints such as critical impact and RPN values.

$$\begin{aligned} &\text{Min } Z_2 = v_1.x_1 + v_2.x_2 + \cdots + v_n.x_n \quad (\text{Model } P) \\ &\text{Subject to}: f_1(x_1, x_2, \ldots, x_n) \leqslant 0 \\ &f_2(x_1, x_2, \ldots, x_n) \leqslant 0 \\ &\vdots \\ &f_r(x_1, x_2, \ldots, x_n) \leqslant 0 \\ &x_1 + x_2 + \cdots + x_n = 1 \\ &x_i = 0, 1 (i = 1, 2, \ldots, n) \end{aligned}$$

where: $f_i(x_1, x_2, \ldots, x_n)$ is a given function of the n EA frameworks. In the next section, we present a real-life case study to demonstrate the applicability of the proposed model and exhibit the efficacy of the procedures and algorithms.

4. The case study

The Institute for Energy and Hydro Technology (IEHT) is the largest energy institute in Iran. IEHT is located on a 65 acre campus and has a 50,000 person training capacity per month. The institute employs over 80 full-time and 100 part-time faculties. We used the group EA approach proposed in this study to select an EA for IEHT. A committee of nine DMs from marketing, finance, and information technology was formed to participate to evaluate the following five frameworks: ZACHMAN, TEAF, TOGAF, DoDAF and FEAF.

Phase 1: In this phase, we worked with the management team and established an EA framework selection team which included:

$(ITPT)_1$: The information technology manager
$(ITPT)_2$: The research and development manager
$(ITPT)_3$: The capital budgeting manager
$(ITPT)_4$: The quality assurance manager

Phase 2: In this phase, the EA framework selection team agreed to consider the following five EA frameworks suggested by Urbaczewski and Mrdalj (2006):

A_1: ZACHMAN
A_2: TEAF
A_3: TOGAF
A_4: DoDAF
A_5: FEAF

Phase 3: In this phase, the selection team decided to consider the strategic criteria presented in Table 4 for the evaluation and selection of the EA frameworks.

Phase 4: In this phase, we used Eqs. (1)–(18) and calculated the impact, likelihood and detection values of the EA frameworks presented in Tables 5–7:

In step 4.3, we used Eqs. (19)–(21) and calculated the possibilistic mean values of the fuzzy risk priority numbers (RPN) provided in Table 8. In step 4.4, we used Eqs. (22) and (23) and constructed the ordinal rank matrix given in Table 9:

In step 4.5, we used Eqs. (24) and (25) and calculated the vector of the EA framework risks given in Table 10. These risks values were determined according to the following importance weight vector:

$$(w_1, w_2, \ldots, w_8) = (0.15, 0.5, 0.5, 0.1, 0.13, 0.1, 0.17, 0.25)$$

Phase 5: In this phase, the selection team identified the following constraints for each EA framework with respect to the risk impacts. All constraints were set less than or equal to the critical impact value (8). Next, the optimal EA framework was identified using the following mathematical model:

$$\begin{array}{l}
\text{Max.}Z = 0.29x_{FEAF} + 0.21x_{ZACHMAN} + 0.16x_{TOGAF} + 0.06x_{TEAF} + 0.28x_{DODAF} \quad (\text{Model } P)\\
\text{Subject to}:\\
E(\tilde{e}_{ZACHMAN1}(I)).x_{ZACHMAN} \leqslant 8, E(\tilde{e}_{ZACHMAN2}(I)).x_{ZACHMAN} \leqslant 8, E(\tilde{e}_{ZACHMAN3}(I)).x_{ZACHMAN} \leqslant 8,\\
E(\tilde{e}_{ZACHMAN4}(I)).x_{ZACHMAN} \leqslant 8, E(\tilde{e}_{ZACHMAN5}(I)).x_{ZACHMAN} \leqslant 8, E(\tilde{e}_{ZACHMAN6}(I)).x_{ZACHMAN} \leqslant 8,\\
E(\tilde{e}_{ZACHMAN7}(I)).x_{ZACHMAN} \leqslant 8, E(\tilde{e}_{ZACHMAN8}(I)).x_{ZACHMAN} \leqslant 8,\\
E(\tilde{e}_{TEAF1}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF2}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF3}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF4}(I)).x_{TEAF} \leqslant 8,\\
E(\tilde{e}_{TEAF5}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF6}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF7}(I)).x_{TEAF} \leqslant 8, E(\tilde{e}_{TEAF8}(I)).x_{TEAF} \leqslant 8,\\
E(\tilde{e}_{TOGAF1}(I)).x_{TOGAF} \leqslant 8, E(\tilde{e}_{TOGAF2}(I)).x_{TOGAF} \leqslant 8, E(\tilde{e}_{TOGAF3}(I)).x_{TOGAF} \leqslant 8,\\
E(\tilde{e}_{TOGAF4}(I)).x_{TOGAF} \leqslant 8, E(\tilde{e}_{TOGAF5}(I)).x_{TOGAF} \leqslant 8, E(\tilde{e}_{TOGAF6}(I)).x_{TOGAF} \leqslant 8,\\
E(\tilde{e}_{TOGAF7}(I)).x_{TOGAF} \leqslant 8, E(\tilde{e}_{TOGAF8}(I)).x_{TOGAF} \leqslant 8,\\
E(\tilde{e}_{DODAF1}(I)).x_{DODAF} \leqslant 8, E(\tilde{e}_{DODAF2}(I)).x_{DODAF} \leqslant 8, E(\tilde{e}_{DODAF3}(I)).x_{DODAF} \leqslant 8,\\
E(\tilde{e}_{DODAF4}(I)).x_{DODAF} \leqslant 8, E(\tilde{e}_{DODAF5}(I)).x_{DODAF} \leqslant 8, E(\tilde{e}_{DODAF6}(I)).x_{DODAF} \leqslant 8,\\
E(\tilde{e}_{DODAF7}(I)).x_{DODAF} \leqslant 8, E(\tilde{e}_{DODAF8}(I)).x_{DODAF} \leqslant 8,\\
E(\tilde{e}_{FEAF1}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF2}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF3}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF4}(I)).x_{FEAF} \leqslant 8,\\
E(\tilde{e}_{FEAF5}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF6}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF7}(I)).x_{FEAF} \leqslant 8, E(\tilde{e}_{FEAF8}(I)).x_{FEAF} \leqslant 8,\\
x_{FEAF} + x_{ZACHMAN} + x_{TOGAF} + x_{TEAF} + x_{DODAF} = 1\\
x_{FEAF}, x_{ZACHMAN}, x_{TOGAF}, x_{TEAF}, x_{DODAF} = 0, 1
\end{array}$$

The results from model (P) identified TEAF framework as the optimal EA framework. We communicated our findings to the IEHT management who proceeded with the implementation of our recommendation.

5. Conclusions and future research directions

In this paper, we proposed a novel fuzzy group multi-criteria model for EA framework evaluation and selection. The contribution of the proposed model is fourfold: (1) it takes into consideration the qualitative and quantitative criteria and their respective value judgments; (2) it considers verbal expressions and linguistic variables for qualitative judgments which lead to ambiguity in the decision making process; (3) it handles imprecise or vague judgments; and (4) it uses a meaningful and robust multi-criteria model to aggregate both qualitative and quantitative data.

We applied the model to select the best EA framework in a complex system with multiple and competing criteria and values. Organizations often fail in practice to follow a systematic and well-structured decision-making process for assessing potential EA frameworks. We have shown that our model considers the multi-dimensional nature of such problems and generates vital

Table 4
Strategic risk criteria associated with the enterprise architecture frameworks.

Risk criteria	Description
Organizational risk	The stability of the management; organizational support for development of the Enterprise Architecture
User risk	The lack of user involvement during the EA framework development; unfavorable attitudes of users towards a new enterprise architecture
Requirement risk	Frequently changing requirements; incorrect, unclear, inadequate, or ambiguous requirements
Structural risk	The strategic orientation of the application; quite number of department are to be involved; the business process needs to be changed a lot
Team risk	Insufficient knowledge or inadequate experience among team members
Complexity risk	Whether new the enterprise architecture is used; the complexity of the processes being automated; whether a large number of links to existing systems is required
Competition risk	Strong competitor reactions that may prevent the enterprise from obtaining the expected outcome
Market risk	The acceptance of customers, vendors and business partners of the application; unanticipated change in the industry or market; the application become obsolete due to the introduction of new enterprise architecture

Table 5
The impact values of the EA frameworks.

Criteria	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
Organizational risk	(7.6,8.4,0.1,0.1)	(8.6,9.4,0.1,0.1)	(9.6,10.4,0.1,0.1)	(6.6,7.4,0.1,0.1)	(9.6,10.4,0.1,0.1)
User risk	(9.6,10.4,0.1,0.1)	(8.6,9.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(8.6,9.4,0.1,0.1)
Requirement risk	(8.6,9.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(6.6,7.4,0.1,0.1)
Structural risk	(8.6,9.4,0.1,0.1)	(8.6,9.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(8.6,9.4,0.1,0.1)
Team risk	(6.6,7.4,0.1,0.1)	(6.6,7.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)
Complexity risk	(8.6,9.4,0.1,0.1)	(6.6,7.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(7.6,8.4,0.1,0.1)	(6.6,7.4,0.1,0.1)
Competition risk	(4.6,5.4,0.1,0.1)	(5.6,6.4,0.1,0.1)	(6.6,7.4,0.1,0.1)	(4.6,5.4,0.1,0.1)	(6.6,7.4,0.1,0.1)
Market risk	(3.6,4.4,0.1,0.1)	(4.6,5.4,0.1,0.1)	(2.6,3.4,0.1,0.1)	(2.6,3.4,0.1,0.1)	(4.6,5.4,0.1,0.1)

Table 6
The likelihood values of the EA frameworks.

Criteria	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
Organizational risk	(5.75,6.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(6.75,7.25,0.25,0.25)
User risk	(8.75,9.25,0.25,0.25)	(8.75,9.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(6.75,7.25,0.25,0.25)	(7.75,8.25,0.25,0.25)
Requirement risk	(5.75,6.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(5.75,6.25,0.25,0.25)
Structural risk	(8.75,9.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(6.75,7.25,0.25,0.25)	(8.75,9.25,0.25,0.25)
Team risk	(3.75,4.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(4.75,5.25,0.25,0.25)
Complexity risk	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(3.75,4.25,0.25,0.25)
Competition risk	(8.75,9.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(7.75,8.25,0.25,0.25)	(8.75,9.25,0.25,0.25)
Market risk	(7.75,8.25,0.25,0.25)	(6.75,7.25,0.25,0.25)	(6.75,7.25,0.25,0.25)	(6.75,7.25,0.25,0.25)	(8.75,9.25,0.25,0.25)

Table 7
The detection values of the EA frameworks.

Criteria	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
Organizational risk	(2.9,3.1,0.1,0.1)	(1.9,2.1,0.1,0.1)	(1.9,2.1,0.1,0.1)	(1.9,2.1,0.1,0.1)	(3.9,4.1,0.1,0.1)
User risk	(4.9,5.1,0.1,0.1)	(3.9,4.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(3.9,4.1,0.1,0.1)	(1.9,2.1,0.1,0.1)
Requirement risk	(1.9,2.1,0.1,0.1)	(1.9,2.1,0.1,0.1)	(0.9,1.1,0.1,0.1)	(0.9,1.1,0.1,0.1)	(2.9,3.1,0.1,0.1)
Structural risk	(5.9,6.1,0.1,0.1)	(7.9,8.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(3.9,4.1,0.1,0.1)	(6.9,7.1,0.1,0.1)
Team risk	(6.9,7.1,0.1,0.1)	(6.9,7.1,0.1,0.1)	(7.9,8.1,0.1,0.1)	(5.9,6.1,0.1,0.1)	(7.9,8.1,0.1,0.1)
Complexity risk	(6.9,7.1,0.1,0.1)	(6.9,7.1,0.1,0.1)	(5.9,6.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(4.9,5.1,0.1,0.1)
Competition risk	(5.9,6.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(5.9,6.1,0.1,0.1)
Market risk	(5.9,6.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(4.9,5.1,0.1,0.1)	(6.9,7.1,0.1,0.1)

Table 8
The possibilistic mean values of the fuzzy risk priority numbers (RPN).

Criteria	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
Organizational risk	144	90	150	42	280
User risk	450	324	320	224	144
Requirement risk	108	80	32	40	126
Structural risk	486	576	320	224	567
Team Risk	196	245	320	192	320
Complexity risk	189	98	144	80	140
Competition risk	270	240	280	200	378
Market risk	192	175	105	105	315

Table 9
The ordinal rank matrix.

Criteria	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
Organizational risk	2	1	3	0	4
User risk	4	3	2	1	0
Requirement risk	3	2	0	1	4
Structural risk	2	4	1	0	3
Team risk	1	2	3.5	0	3.5
Complexity risk	4	1	3	0	2
Competition risk	2	1	3	0	4
Market risk	3	2	0.5	0.5	4

Table 10
The vector of the EA framework risks.

The risks vector	FEAF	ZACHMAN	TOGAF	TEAF	DoDAF
$\underline{V}$	0.29	0.21	0.16	0.06	0.28

information for selecting the most appropriate framework. While previous studies have valued multi-criteria frameworks, they have failed to consider both subjective and objective judgments in a systematic and consistent model. The proposed framework supports both qualitative and quantitative decision criteria, as well as different types of risk for both quantitative and qualitative criteria.

In addition, the DMs may be able to provide only imprecise or vague information because of time constraints or lack of data. Furthermore, the DM may feel more comfortable evaluating qualitative criteria by using linguistic variables resulting in two potential problems: (1) how to reconcile quantitative and qualitative criteria and (2) how to deal with imprecise and vague information rationally and consistently. We showed that the proposed framework is able to address these problems and can assist the DMs reach a robust decision. Finally, the case study showed that a combined analysis can generate valuable insight that can help the DMs to select the most suitable framework from a range of competing alternatives.

Our model is intended to assist the DMs in the EA framework selection process. In fact, human judgment is the core input in this process. Our approach helps the DMs to think systematically about complex multi-criteria problems and improves the quality of the decisions. We decompose the EA framework selection process into manageable steps and integrate the results to arrive at a solution consistent with managerial goals and objectives. This decomposition encourages the DMs to carefully consider the elements of uncertainty. The proposed structured framework does not imply a deterministic approach in EA framework selection problems. While our approach enables the DMs to assimilate the information and organize their beliefs in a formal systematic approach, it should be used in conjunction with management experience. Managerial judgment is an integral component of EA framework selection decisions; therefore, the effectiveness of the model relies heavily on the DM's cognitive capabilities.

There are a variety of extensions to this research. First, EA is a new discipline and it will not mature without substantial new research (Langenberg & Wegmann, 2004). We hope the framework proposed in this study will stimulate new research in the fields of EA and multi-criteria decision making. Second, by identifying the unique features of the proposed framework, researchers can further study the applicability of the proposed method to other multi-criteria problems embracing both qualitative and quantitative criteria with imprecise or ambiguous value judgments. It is our hope that the discussions, issues and ideas set forth in this paper will motivate further enhancement to this framework.

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