A Fuzzy AHP Based Approach Towards Enterprise Architecture Evaluation

Mahsa Razavi¹, Fereidoon Shams Aliee² and Amir Esmaeil Sarabadani Tafreshi¹
¹Islamic Azad University, Tehran, Iran
²Shahid Beheshti University, Tehran, Iran
Mahsa_r_d@yahoo.com
F_shams@sbu.ac.ir
amirs.tafreshi@gmail.com

Abstract: Enterprise Architecture (EA) as a discipline with numerous and enterprise-wide models, has pervasive impact across the enterprise. Due to expensive implementation of enterprise-wide scenarios, it is critical to perform an architecture assessment before any decision about choosing a scenario. In order to provide such support, EA models should be amenable to analysis of various utilities and quality attributes. This paper provides an approach based on Fuzzy Analytical Hierarchy Process towards EA analysis. It proposes a quantitative method of measuring quality attribute achievement of different scenarios using AHP based on the knowledge and experience of EA experts and domain experts. Due to the vagueness and uncertainty in the judgments of participants, the crisp pair wise comparison in the conventional AHP is insufficient and imprecise to capture the right judgments. Therefore, a fuzzy logic is introduced in the pairwise comparison of AHP to make up for this deficiency. In this method, the situation of the enterprise is considered in giving weight to the different criteria and sub criteria of each quality attribute. The applicability of the proposed approach is demonstrated using a practical case study.

Keywords: Enterprise Architecture analysis, quality attribute, Analytical Hierarchy Process, fuzzy logic

1. Introduction

Enterprise Architecture (EA), as an enterprise-wide discipline which considers the improvement of different aspects of the enterprise, can deliver exceptional benefits. Because the risk and impact of EA are pervasive across the enterprise, it is critical to perform an architecture assessment before any decision about choosing a scenario.

EA analysis is the application of property assessment criteria on EA models (Johnson 2007c).

Considering EA, same as software architecture (Bass 1998, 2001), we generally believe that quality attributes (such as security, and modifiability) of an enterprise system are primarily achieved through EA. In other words, most of the design decisions embodied by EA are strongly influenced by the need to achieve quality attributes.

In software engineering the aim of analyzing the architecture is to predict the quality of a system before it has been built and not to establish precise estimates but the principal effects of an architecture (Kazman 1993). Similarly, our ultimate goal is to provide a framework to analyze EA scenarios, predict their levels of quality attributes achievement, based on related criteria, and assist the process of decision making between them according to the analysis results before implementing expensive enterprise-wide scenarios.

For this purpose, we need to do the following tasks:

1. To define and represent EA quality attributes explicitly
2. To provide a mechanism for measuring the level of quality attributes achievement in different EA scenarios.

The first task has been addressed in (Razavi 2009).

The aim of this paper is to propose a quantitative measurement method of EA quality attribute achievement for different EA scenarios, based on the enterprise’s situation. This approach can help enterprises compare and decide about different scenarios according to the utilities and qualities they provide. This problem is also illustrated in Figure 1.
Due to the fact that the evaluation process of EA scenario candidates is a multiple-criteria decision-making (MCDM) problem in the presence of many criteria and alternatives, a decision-maker(s) needs to use one of current MCDM methods. In this paper, we utilized analytic hierarchy process (AHP).

The AHP is widely used for multi-criteria decision-making and has successfully been applied to many practical decision-making problems (Saaty 1988). In spite of its popularity, this method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker’s perception to exact numbers (Deng 1999).

A natural way to cope with such uncertain judgments is to express the comparison ratios as fuzzy sets or fuzzy numbers, which incorporate the vagueness of the human thinking.

In this paper we propose a new method based on fuzzy AHP towards EA analysis.

This framework consists of several steps, that fuzzy AHP is used in three of the steps to prioritize the EA scenarios according to the knowledge and experience of the participants.

The proposed method has the additional benefit that the identification of which scenario to use is based on the situation of the enterprise and also the experience of groups of EA and domain experts. The participants are forced to systematically consider all possible combinations. This ensures a broader decision base.

In this framework, the term “EA scenario” is used to denote an architecture, an architecture proposal, or a solution for an enterprise, which can be on any level of granularity. But of course the architecture scenario candidates to be compared should have the same level of granularity.

The case study provided at the end of this paper is an abbreviated version of a study under development in Ports and Maritime Organization of Iran (PMO). This is done to give a more comprehensive presentation of how the method can be used and to demonstrate the efficacy of our approach.

The remainder of the paper is outlined as follows:

In the next section, related works are introduced. Section 2 is devoted to the explanation of the method in a step by step manner. In section 3, we present a case study where the proposed method is used. Finally in section 4 the paper is concluded and possible future work is introduced.

1 We have specified four main aspects (sub architectures) for EA based on (FCIO 1999) and (Spewak 1992), while some references such as (Sowa 1992) define 6 main aspects for EA, function, data, network, people, time and motivation. The above classification can be customized for different views on EA.
The related work to this paper can be classified into three groups:

1. Analysis methods and tools for software quality, including (Kazman 1996), (Clements 2001), (Gacek 1998), (Allen 1998) and (Medvidovic 1999). None of these methods are applicable in the EA domain (Närman 2007). These methods are focused on evaluating a single architecture to find out if and where there may be problems in it. The method in this paper is more aimed towards finding out which architecture candidate, of a set of architecture candidates, has the most potential to support the mix of quality attributes for a particular enterprise to build.

2. Software quality attribute measurement methods based on MCDM methods, including (Svahnberg 2003, 2002), (Al-Naeem 2005), (Davidsson 2005), (Buyukozkan 2008), (Mikhailov 2004), (Lee 2005), (Zhu 2005) and (Reddy 2007).

These methods focus on prioritizing and selecting the most appropriate software architecture candidate that supports the desired quality attributes. In this paper, we extended the idea of these methods in the EA domain.

3. The analysis methods in the EA community including (Johnson 2007a, 2007b, 2007c, 2007d), (Närman 2007), (Lagerström 2007, 2006), which have used formal methods, such as Influence Diagrams, Extended Influence Diagrams, and Abstract Models for EA analysis. Because of lack of space, we can’t describe these methods here but the main contributions of our approach which makes it different from the above mentioned approaches are as below:

- In our approach, the hierarchy of criteria and sub-criteria of a quality attribute is customized according the situation of the enterprise. This customization is done by giving different weights to different criteria/sub-criteria. In above mentioned approaches, each quality attribute is assessed based on different criteria with equal level of importance. Considering the importance of a criteria/sub-criteria in assessing a utility in an enterprise makes the assessment more accurate.

- Through our approach, we use the knowledge and experience of two groups of experts in our assessment; EA experts and domain experts. This ensures a broader decision base according to different points of view and allows identification of differences in participants’ experiences.

- All above methods use formal languages such as Influence Diagrams or their extended version to support the analysis of EA, but we have used Analytical Hierarchy Process (AHP) as a multi criteria decision making method, which is the first experience of using this method in the field of EA analysis.

2. The proposed method

The objective of this paper is to help the decision makers of an enterprise to decide about different scenarios according to their level of quality attribute achievement.

This method can be used when making any decision about EA issues in the enterprise in each of the phases of target EA design, transition planning and development and also EA maintenance. In other words, this method is usable after gathering complete information about the current EA of the enterprise.

In this approach, each quality attribute is composed of several criteria and sub criteria which are specified in the quality attribute definition (Razavi 2009).

The approach uses Analytical Hierarchy Process (AHP) for analysis and prioritization of different elements.

One of the advantages of AHP is that it can also be extended to group decision making (Saaty 1980, 1988). e.g., (Bryson 1999), (Forman 1998) and (Saaty 1983).

In order to apply AHP to group decisions, two scenarios have to be considered: Aggregating of Individual Judgments (AIJ) and Aggregating Individual Preferences (AlP). The first approach applies where experts act as a unit and a consensus has to be reached to represent the group’s judgments. Group synthesis is obtained by an additional aggregation procedure for combining individual judgments into a single group priority. The second approach, applies where experts are significantly different in opinions and a consensus on judgments cannot be reached. Here a group synthesis is
obtained but an additional aggregation procedure for combining the individual priorities into a group preference is required. The group synthesis stage for both AIJ and AIP is commonly achieved by applying either of the 2 techniques, Geometric Mean technique (GM), or a Weighted Average Mean technique (WAM). According to (Forman 1998) and (Saaty 1983), GM is more suitable for AIJ while for AIP both procedures are meaningful.

Also in this study, triangular fuzzy numbers, \( \mathbf{1} \) to \( \mathbf{9} \), are used to represent subjective pairwise comparisons of selection process (equal to extremely preferred) in order to capture the vagueness. A triangular fuzzy number denoted as \( \mathbf{A}=(l,m,u) \), where \( l=m=u \), has the following triangular type membership function which is depicted in Figure 2.

\[
\mu_F(x) = \begin{cases} 
0, & x < l \\
\frac{x-l}{m-l}, & l \leq x \leq m \\
\frac{u-x}{u-m}, & m \leq x \leq u \\
0, & x > u 
\end{cases}
\]

**Figure 2:** Triangular membership function for linguistic values

By using triangular fuzzy numbers, the decision-maker(s) are asked to respond to a series of pairwise comparisons with respect to an upper level "control" criterion. These are conducted with respect to their relevant importance towards the control criterion. Then, the fuzzy judgment matrix, \( A(\tilde{a}_j) \) is constructed via pair wise comparison as given below:

\[
A = \begin{bmatrix}
1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\
\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1
\end{bmatrix}
\]

where \( \tilde{a}_{ij} = 1 \), if i is equal to j, and \( \tilde{a}_{ij} = \mathbf{1}; 3; 5; 7; 9 \) or \( \mathbf{1}^{-1}; 3^{-1}; 5^{-1}; 7^{-1}; 9^{-1} \), if i is not equal to j.

Alternatively, by defining the interval of confidence level \( \alpha \), the triangular fuzzy number can be characterized using the following equation:

\[
\forall \alpha \in [0,1] \quad M_{\alpha} = \left[ l^\alpha, u^\alpha \right] = \left[ (m-l)\alpha + l, -(u-m)\alpha + u \right]
\]

While \( \alpha \) is fixed, the following judgment matrix can be obtained after setting the index of optimism, \( \mu \), in order to estimate the degree of satisfaction. The eigenvector is calculated by fixing the \( \mu \) value and identifying the maximal eigenvalue:

\[
\tilde{A} = \begin{bmatrix}
1 & \tilde{a}_{12}^\alpha & \cdots & \tilde{a}_{1n}^\alpha \\
\tilde{a}_{21}^\alpha & 1 & \cdots & \tilde{a}_{2n}^\alpha \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{a}_{n1}^\alpha & \tilde{a}_{n2}^\alpha & \cdots & 1
\end{bmatrix}
\]

where \( \alpha \)-cut is known to incorporate the experts or decision-maker(s) confidence over his/her preference or the judgments. Degree of satisfaction for the judgment matrix is estimated by the index of optimism \( \mu \) determined by the decision-maker. The index of optimism is a linear convex combination as defined in the following equation (Lee 1999):
\[
\tilde{a}_{ij}^\alpha = \mu a_{ij}^\alpha + (1-\mu)a_{ij}^\alpha, \quad \forall \mu \in [0,1]
\]  
(2)

Once the pairwise comparisons are completed, the local priority vector \( w \) is computed using the following equation as the unique solution:

\[
Aw = \lambda_{\text{max}}w
\]

where \( \lambda_{\text{max}} \) is the largest eigenvalue of \( A \).

After constructing all required pairwise judgment matrices between criteria and alternatives levels, for each, the consistency ratio (CR) should be calculated by using the following equation:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

(3)

where \( n \) is matrix size.

The CR is used to estimate directly the consistency of pairwise comparisons, and computed by dividing the CI by a value obtained from a table of random consistency index (RI), the average index for randomly generated weights (Saaty 1980), as shown in the following equation:

\[
CR = \frac{CI}{RI}
\]

(4)

If the CR is less than 10\%, the comparisons are acceptable, otherwise they should be done again with more precise information or by other participants with more experience.

Figure 3 illustrates the proposed method. In this Figure, the brighter boxes represent the steps that directly use Fuzzy AHP.

**Figure 3: Illustration of solution**

### 2.1 Steps of the proposed approach

In the proposed framework, Fuzzy AHP is used in steps 2.2, 3 and 5.1. Also the group decision scenario used in step 2.2 and 3 is AIJ with GM technique and in step 5.1 is AIP with weighted average mean technique.

**Step 1: Identify EA quality attributes of the enterprise to be considered in the assessment:** The important utilities and goals of the enterprise that affect the selection of EA scenarios should be extracted and explicitly specified. In this paper we have only considered EA quality attributes as utilities of the enterprise, but the approach can be extended to include other kinds of utilities, such as different goals and objectives.
Step 2: Identify the enterprise-specific criteria and sub-criteria of quality attributes and their level of importance (weight); Each EA quality attribute is characterized by some criteria and sub-criteria (Razavi 2009). These criteria are general for enterprises. We propose an approach to specialize quality attribute criteria and sub-criteria according to the areas of focus in the enterprise. In this approach, as described by the following steps, each criteria and sub-criteria of a quality attribute is given a weight according to the enterprise architectural layers it belongs to and the importance of EA layers in the enterprise:

Step 2.1: Identify the EA layer that each criteria/sub-criteria belongs to; As described before, we have specified four main aspects (sub architectures layers) for EA based on (FCIO 1999) and (Spewak 1992), which are Business Architecture layer (BAL), Data Architecture layer (DAL), Software Architecture layer (SAL) and Technology Architecture layer (TAL). In this step an EA expert should specify the EA layer(s) that each criteria/sub-criteria belongs to. One criteria/sub-criteria of the quality attribute can belong to more than one EA layer.

Step 2.2: Determine the importance of each EA layer in the context of the utility;

Step 2.2.1: Obtain Individual data about the comparison between EA Layers in the context of the utility (construct the pairwise comparison matrices); For this purpose a questionnaire is designed for each quality attribute. In this questionnaire a description of the most important and tangible criteria of the quality attribute in each EA layer is presented. Then some of the domain experts of the enterprise are asked to fill the questionnaire and assign one of the five triangular fuzzy numbers ($1; 3; 5; 7; 9$) to each comparison between two layers according to Figure 2.

Also the value of $\alpha$ and $\mu$ are determined and each $a_{ij}^{\alpha}$ will be computed according to Eq. (2) and as explained before, the consistency index of each generated comparison matrix should be checked.

Step 2.2.2: Synthesize data; As the output of the previous step, we have few pairwise comparison matrices $A_k$:

$$
A_k = \begin{bmatrix}
1 & a_{12k} & \ldots & a_{1nk} \\
a_{21k} & 1 & \ldots & a_{2nk} \\
\vdots & \vdots & \ddots & \vdots \\
a_{nk} & a_{n2k} & \ldots & 1
\end{bmatrix}
$$

Where $k= 1,2,\ldots,K$ represents the number of decision makers.

In order to aggregate these entries and derive one judgment $a_{ij}$, geometric mean technique is applied. The geometric mean takes the average of a set of numbers expressing the same judgment by applying their product such that:

$$
a_{ij} = \left( \prod_{k=1}^{K} a_{ijk} \right)^{1/k}, \quad k = 1,2,\ldots,K
$$

(5)

In this model, for simplicity, we have assumed that all participants have equal power and haven’t assigned different weights to them.

Step 2.2.3: Prioritize the EA layers Then the eigenvalue and eigenvector of the output matrix of previous step is computed. The eigenvector of the matrix is called PEAL (Prioritized list of EA Layers).

Step 2.3: Specify the weight of each criteria/sub-criteria; The weight of each criteria/sub-criteria of the quality attribute is equal to the weight of the EA layer it belongs to and:

If a criteria/sub-criteria belongs to more than one EA layer, then its weight will be the maximum weight of the EA layers.

If the weight of a criteria/sub-criteria is zero, then the criteria/sub-criteria and all its sub-criteria should be omitted.
The output of this step is a number of vectors called iWQAC (Individual Weight list for each Quality Attribute sub-Criteria).

Step 3: Prioritize the EA quality attributes of the enterprise

For this purpose, we use the opinion of domain experts of the enterprise and perform Fuzzy AHP as the prioritization technique.

Step 3.1: Obtain Individual data about the comparison between EA quality attributes (construct the pairwise comparison matrices); For this purpose some domain experts of the enterprise are asked to do pairwise comparison between EA quality attributes of the enterprise and assign one of the five triangular fuzzy numbers \((1; 3; 5; 7; 9)\) to each comparison between two quality attributes. Also the value of \(\alpha\) and \(\mu\) are determined and each \(\tilde{a}_{ij}\) will be computed according to Eq. (2) and the consistency of each comparison matrix will be checked.

Step 3.2: Synthesize data; In this step we aggregate the few pairwise comparison matrices into one matrix by applying geometric mean technique (same as section 2.2.2)

Also in this model, for simplicity, we have assumed that all participants have equal power.

Step 3.3: Prioritize the EA quality attributes

Then the eigenvalue and eigenvector of the output matrix of the previous step are computed. The eigenvector of the matrix is called PQA (Prioritized list of Quality Attributes).

Step 4: Introduce different EA scenarios (candidates) to be assessed;

In this step, different EA scenarios should be described completely so that participants understand the differences and similarities between them.

Step 5: Identify which candidate best fits the list of prioritized quality attributes;

In this final step, different EA scenarios are assessed and prioritized using fuzzy AHP by using the opinion of different EA experts.

Step 5.1: Obtain individual data about the weight/priority of criteria and architecture candidates for each quality attribute;

In this step, we have the AHP hierarchy of step 2 for each quality attribute and the EA candidate scenarios are added to the lowest levels of all hierarchies.

In step 2, we specified the global weight of each node of the hierarchy. These weights were not normalized, so in this step, first the weights of the leaf sub-criteria of the hierarchy should be normalized. For this purpose the following equation is used (leaf sub-criteria are those sub-criteria located at the lowest level of the criteria/subcriteria hierarchy of each quality attribute):

\[
NW_x = \frac{W_x}{\sum_{j=1}^{L} W_j}
\]  

(6)

Where \(L\) is the number of leaf sub-criteria in the hierarchy.

Then few EA experts are asked to do pairwise comparison between different architecture candidates according to the leaf sub-criteria of each quality attribute hierarchy and assign one of the five triangular fuzzy numbers \((1; 3; 5; 7; 9)\) to each comparison between two elements.

For each pairwise comparison matrix, the value of \(\alpha\) and \(\mu\) are determined, and the largest eigenvalue and its related eigenvector are computed. Also the consistency of each comparison matrix will be checked.

Next, the priorities should be synthesized using AHP method and a new vector called individual Prioritized vector of Candidates for each Quality Attribute (iPCQA) is produced by each EA expert according to the following equation:
\[ \text{iPCQA} = (NW_1 \ W_2 \ \cdots \ NW_L) \begin{pmatrix} p_{11} & \cdots & p_{1n} \\ p_{21} & \cdots & p_{2n} \\ \vdots & \ddots & \vdots \\ p_{L1} & \cdots & p_{Ln} \end{pmatrix} \tag{7} \]

Where \( p_{ij} \) is the local priority of scenario \( j \) according to sub-criteria \( i \) and \( n \) is the number of architecture candidates and \( L \) is the number of leaf sub-criteria.

The output of this step is one iPCQA vector set for each EA expert, where each vector represents the priority of architecture candidates according to each quality attribute.

**Step 5.2: Synthesize data:** As explained before, in this step we have used AIP scenario with weighted average mean technique for aggregating the opinions of different decision makers. For simplicity, we have not considered any difference between EA experts so their weights are equal. So in this step, Prioritized vector of Candidates for each Quality Attribute (PCQA) is computed as below:

\[ \text{PCQA} = \frac{\sum_{i=1}^{K} \text{iPCQA}_i}{K} \tag{8} \]

where \( K \) is the number of EA experts participating in the decision process.

Then all PCQA vectors are synthesized in one PCQA vector set.

**Step 5.3: Select the most suitable candidate:** The aim of this step is to select the most suitable EA scenario candidate that best meets the desired blend of quality attributes for the enterprise. For this purpose we suggest to select the candidate that results in a greater Level of Suitability, which can be computed as below:

\[ \text{Level of Suitability of EA scenario candidate j for the enterprise} = \sum_{i} (\text{PQA}_i \times \text{PCQA}_{i,j}) \tag{9} \]

**Step 6: Determine the uncertainty in the selection:** In order to obtain the uncertainty in our selection we need to calculate the variance for each EA scenario candidate \( i \) given the PQA-vector and the variance of PCQA vector sets. The variance of PCQA vector sets is a vector set called VAR. \( \text{VAR}_{ij} = \frac{1}{K} \sum_{i,j} (\text{iPCQA}_i - \text{PCQA}_{i,j})^2 \tag{10} \)

From the rules of variance propagation we know that the variance for architecture candidate \( i \) which represents the level of uncertainty in our selection is obtained in the following way:

\[ \text{Uncertainty for EA scenario candidate i} = \sum_{j} (\text{PQA}_j)^2 \text{VAR}_{ij} \tag{11} \]

If there is high uncertainty, this may indicate that the architecture candidates and quality attributes are not so well understood by the participants, and that further investigations are necessary before the final architecture decision is taken.

3. A case study using the method

In order to illustrate the method described in this paper, we present a summary of an experiment conducted using the method.

Our case study is conducted in Ports & Maritime Organization of Iran (PMO). For more information about this enterprise please refer to [www.pmo.ir](http://www.pmo.ir). Below, we describe how each step of the method is applied in the study.
**Step 1:** (Razavi 2009) proposes the idea of EA quality attributes and their characterization by using EA quality attribute general scenarios. Here we use the same structure and terminology to characterize our quality attributes.

For PMO, one of the important EA quality attributes we want to consider is maintainability. For simplicity we only consider one quality attribute in the enterprise.

Detailed definition of EA maintainability is presented in (Razavi 2009). Figure 4 illustrates EA maintainability criteria and sub-criteria.

![Figure 4: EA maintainability measures (criteria and subcriteria) (Razavi 2009)](image)

**Step 2:**

**Step 2.1:** According to an EA expert’s opinion, the EA layer(s) that each maintainability criteria belongs to are specified as below:
- Quality of Maintenance Policy → BAL
- Maturity of EA Development and Maintenance Personnel → BAL
- Maturity of EA Development and Maintenance Processes → BAL
- Quality of Supporting Documentation → All Sub-Architecture layers
- Business Architecture Quality → BAL
- Data Architecture Quality → DAL
- Software Architecture Quality → SAL
- Technology Architecture Quality → TAL

**Step 2.2:**

**Step 2.2.1:** For this purpose, a questionnaire was designed in which it described maintainability by using the most important and tangible criteria in each EA layer.

Also in this step, 5 triangular fuzzy numbers \( \{1; 3; 5; 7; 9\} \) were used to express the preference in the pairwise comparisons. The related membership functions are the same as figure 2 and their lower limit and upper limit were defined by applying Eq. (1) as follows:
\[
\tilde{1}_a = [1, 2 - \alpha] \\
\tilde{3}_a = [\alpha + 2, 4 - \alpha] \\
\tilde{5}_a = [\alpha + 4, 6 - \alpha] \\
\tilde{7}_a = [\alpha + 6, 8 - \alpha] \\
\tilde{9}_a = [\alpha + 8, 10 - \alpha]
\]
\[
\tilde{3}_a^- = \left[\frac{1}{4 - \alpha}, \frac{1}{\alpha + 2}\right] \\
\tilde{5}_a^- = \left[\frac{1}{6 - \alpha}, \frac{1}{\alpha + 4}\right] \\
\tilde{7}_a^- = \left[\frac{1}{8 - \alpha}, \frac{1}{\alpha + 6}\right] \\
\tilde{9}_a^- = \left[\frac{1}{10 - \alpha}, \frac{1}{\alpha + 8}\right]
\]

And we determined $\alpha = 0.5$ and $\mu = 0.5$.

For the purpose of this step, ten domain experts of the enterprise were asked to fill the questionnaire and do fuzzy pair-wise comparison between the EA layers. Also the consistency of each comparison matrix was checked.

**Step 2.2.2:** In this section, we aggregated all 10 comparison matrices in one matrix by using geometric average mean.

Figure 5 presents this aggregated comparison matrix.

<table>
<thead>
<tr>
<th>Architecture Layer</th>
<th>BAL</th>
<th>DAL</th>
<th>SAL</th>
<th>TAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Architecture Layer (BAL)</td>
<td>1</td>
<td>3.1330242</td>
<td>5.34805188</td>
<td>6.43132359</td>
</tr>
<tr>
<td>Data Architecture Layer (DAL)</td>
<td>0.3329487</td>
<td>1</td>
<td>2.82874633</td>
<td>8.34639965</td>
</tr>
<tr>
<td>Software Architecture Layer (SAL)</td>
<td>0.1988864</td>
<td>0.37010167</td>
<td>1</td>
<td>2.40145005</td>
</tr>
<tr>
<td>Technology Architecture Layer (TAL)</td>
<td>0.1506471</td>
<td>0.12025607</td>
<td>0.46329036</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 5: The aggregated pairwise comparison matrix

**Step 2.2.3:** In this step, the eigenvalue and eigenvector (PEAL) of the aggregated matrix were computed (Figure 6).

<table>
<thead>
<tr>
<th>Architecture Layer</th>
<th>Eigenvector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Architecture Layer (BAL)</td>
<td>0.54551</td>
</tr>
<tr>
<td>Data Architecture Layer (DAL)</td>
<td>0.291808</td>
</tr>
<tr>
<td>Software Architecture Layer (SAL)</td>
<td>0.107078</td>
</tr>
<tr>
<td>Technology Architecture Layer (TAL)</td>
<td>0.055604</td>
</tr>
</tbody>
</table>

Figure 6: PEAL vector

**Step 2.3:** Figure 7 represents the weight of each sub-criteria of maintainability.

**Step 3:** For simplicity in representing the method, in our case study we have specified only one quality attribute, so we skip this step for our example.

**Step 4:** In recent years, one of the main concerns of PMO was the strategy of providing human resources for business process maintenance. They had two EA scenario candidates to choose from:

- To hire external consultants to carry out their business process re-engineering and maintenance. In this scenario, they could use the services of a professional consultant from the date of contract. PMO just needs a role to gather the requests of business process change and improvement and transfer them to the consultant. The consultant would then design or improve the business processes, record them in the related software platform and update the required documentation.

- To employ and train business process analysts in PMO for ongoing maintenance and re-engineering of business processes. In this scenario, an organizational unit should be defined for business process engineering. Some employees should be provided. They could be non-professional employees who should be trained for this purpose, or some professional employees.
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Of course the latter has higher ongoing cost. In this scenario, any request for business process change or improvement can be implemented instantly.

Note that the mentioned scenarios are EA scenarios because they propose a solution which affects at least one EA layer.

<table>
<thead>
<tr>
<th>Maintenance leaf sub-criteria</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Maintenance Policy</td>
<td>0.54551</td>
</tr>
<tr>
<td>Management Value</td>
<td>0.54551</td>
</tr>
<tr>
<td>Risk</td>
<td>0.54551</td>
</tr>
<tr>
<td>Staff level of experience</td>
<td>0.54551</td>
</tr>
<tr>
<td>Staff level of EA knowledge</td>
<td>0.54551</td>
</tr>
<tr>
<td>Tools used</td>
<td>0.54551</td>
</tr>
<tr>
<td>Degree of formalism</td>
<td>0.54551</td>
</tr>
<tr>
<td>Consistency of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Accuracy of the documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Availability of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Modifiability of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Competiency of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Traceability of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Readability of documentation</td>
<td>0.54551</td>
</tr>
<tr>
<td>Relations between business processes</td>
<td>0.54551</td>
</tr>
<tr>
<td>EA-Traceability to other EA components</td>
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<td>SA-Traceability to other EA components</td>
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<tr>
<td>Size of system</td>
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<tr>
<td>Age of system</td>
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<tr>
<td>Relations to other systems</td>
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<tr>
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<tr>
<td>QOCS-Level of cohesion</td>
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<tr>
<td>QOCS-Level of nesting</td>
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<tr>
<td>Level of standardization of Platform technology used</td>
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<td>Availability of platform porting tools</td>
<td>0.055604</td>
</tr>
<tr>
<td>Platform availability</td>
<td>0.055604</td>
</tr>
</tbody>
</table>

Figure 7: Weight of each sub-criteria of maintainability in PMO

**Step 5**: In this step, to assess and prioritize the EA scenarios, we used the opinion of five EA experts.

**Step 5.1**: The normalized weights of the leaf sub-criteria of the maintainability hierarchy are shown in Figure 8:

Then the EA experts were asked to compare the EA scenarios based on each of the leaf sub-criteria and assign one of the five triangular fuzzy numbers \(1;3;5;7;9\) to express the preference in the pairwise comparisons. The related membership functions are the same as figure 2. and the lower limit and upper limit of the aforementioned fuzzy numbers were defined same as step 2.2.1 in the case study.

We also determined \(\alpha=0.5\) and \(\mu=0.5\) and checked the consistency of all comparison matrices. Next, the iPCQA vector is produced by each EA expert:
Step 5.2: Figure 9 illustrates PCQA of PMO for EA maintainability:

Step 5.3: Level of Suitability of EA scenario 1 = 0.4
Level of Suitability of EA scenario 2 = 0.6

Step 6: Here we had only two scenarios to choose from, so the VAR vector has identical elements as shown in figure 10:

In this example, we considered only one quality attribute, so the uncertainty of our selection is identical to the VAR vector and is equal to 0.01 which represents that the results are acceptable.

<table>
<thead>
<tr>
<th>Maintenance leaf sub-criteria</th>
<th>Weight</th>
<th>Normalized weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Maintenance Policy</td>
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<tr>
<td>Management Value</td>
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</tr>
<tr>
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<tr>
<td>SUM</td>
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</table>

Figure 8: The normalized weights of the leaf sub-criteria of the maintainability hierarchy

<table>
<thead>
<tr>
<th>EA Scenario</th>
<th>Weight</th>
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</thead>
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<td>EA Scenario 1</td>
<td>0.4</td>
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<tr>
<td>EA Scenario 2</td>
<td>0.6</td>
</tr>
<tr>
<td>Sum</td>
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</tbody>
</table>

Figure 9: PCQA of PMO for EA maintainability

<table>
<thead>
<tr>
<th>EA Scenario</th>
<th>Variance</th>
</tr>
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<tbody>
<tr>
<td>EA Scenario 1</td>
<td>0.010776</td>
</tr>
<tr>
<td>EA Scenario 2</td>
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</tbody>
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Figure 10: The variance of PCQA
4. Conclusion and future work

In this paper we present a quantitative measurement method of EA quality attribute achievement for different EA scenarios, based on the enterprise’s situation. This method can be used to indicate the architecture candidates that best suits the quality attributes of a given EA. This can then be used to hold focused discussions on areas where there are disagreements, between participants of the assessment, to increase the confidence that the correct decision is taken.

The major benefits of the method are that it considers enterprises’ situation in specifying and giving weight to different criteria/sub-criteria of the quality attributes and also considers all possible combinations in assessing the quality attribute. This method also uses the experience and knowledge of EA experts and domain experts and clearly indicates disagreements between participants. As future work we can introduce the use of Analytical Network Process (ANP) as another MCDM method in EA Analysis. This method considers the interdependencies between hierarchy nodes and creates a network of nodes. This contradicts with AHP that considers each node independently.

References


Razavi, M. and Shams, F. (2009) "Enterprise Architecture Quality Attributes", submitted (can be obtained from the authors).


