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# Providing Priority Degrees for the Challenges of Cloud-Based Outsource Software Development Projects via Fuzzy Analytic Hierarchy Process Methods

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***Abstract*— Cloud-based outsource software development (COSD) is a fairly new and popular software development methodology, which is enabled by the enormous growth of the cloud computing services in the last decade. The key idea of the methodology is to support software development processes of companies having software development team members from all around the world work collaboratively via cloud services. While there are quite some benefits a company could draw, there are also some challenges associated with the execution of a COSD project. It is intuitively essential to have a reliable way to assess a COSD project for its success. In this study, using Magnitude Based Fuzzy Analytic Hierarchy Process (MFAHP) as a method to prioritize and weight the challenges of a COSD project is presented. MFAHP is a fuzzy extension of the classical AHP which is shown to produce comparable results to other Fuzzy AHP (FAHP) methods with much smaller number of computations. The performance of the suggested methodology is evaluated and compared to Chang's Fuzzy Extent Analysis on AHP (FEA) and Geometric Mean (GM) Methods, which are two other established FAHP methods. The results show that MFAHP and GM perform quite similar, whereas FEA gives inconsistent outputs. Among 21 different subcategories of COSD project challenges determined, "compatibility issues" are anticipated to have the highest weight individually while "organization management" is the most important of 4 main categories.**

***Keywords*— *criteria prioritization, magnitude based fuzzy analytic hierarchy process, challenges of cloud-based outsource software development projects.***

## I. Introduction

The computer technologies advance very rapidly and virtually all kinds of modern business processes require high-end IT capabilities to be successful in a competitive market. With newer generations of computer hardware are released every year and software even more frequently, maintaining a secure and up-to-date IT infrastructure is likely one of the most critical challenges an organization inevitably faces. Cloud computing offers an appropriate solution to this problem with little to no risk. Using cloud computing services, IT resources are purchased in a pay-as-you-use fashion. Also, the users are given the freedom to expand or shrink the size of their resource usage and change service configurations effortlessly.

A very rapid growth is observed in the cloud computing marketplace, as using a cloud service is such a convenient and low-risk way to satisfy computing needs of a business process. Cloud-based outsource software development (COSD) is a fairly new and popular methodology that allows companies to reap full benefits of cloud computing services while outsourcing development processes [1]–[3].COSD also enables a continuous and productive development process as it allows hiring skilled developers at a global scope, who can work together on the same project at a variety of time zones [4]. On the other hand, sharing cloud infrastructure while developing a software project has its exclusive challenges [5]. In summary, for the successful execution of COSD projects, various challenges including geographical, temporal, and intercultural differences should be well evaluated and processes should be controlled accordingly [6]–[8]. Prioritizing and weighting those challenges could be of critical importance for the success of a COSD project.

The analytic hierarchy process (AHP) is a well-studied method used to assign weights to a set of criteria, which then can be used to make a decision. Incorporating fuzzy sets with AHP helps to improve the method to better deal with the inaccuracy of individual judgments. In fact, a fuzzy AHP (FAHP) method was applied to the problem of determining COSD challenges in [5]. However, the method used in that study, which is Chang's Fuzzy Extent Analysis on AHP (FEA) [9], has some flaws that could be detrimental to the process of assessing a COSD project. In this study, Magnitude Based Fuzzy Analytic Hierarchy Process (MFAHP) is used to present a refined and reliable method to prioritize and weight the challenges of a COSD project, while dealing with the shortcomings of the previous studies on COSD. MFAHP is a fuzzy extension of the classical AHP which is shown to produce comparable results to other FAHP methods with much smaller number of computations [10]. Application of the presented methodology with MFAHP as well as two other FAHP, i.e. FEA and the Geometric Mean method (GM), using the data laid out in [5] are realized.

The following section provides the definitions of fundamental concepts of FAHP and the algorithms used in the methods. The details of the applications of the methods and a discussion on their results are given in the third section. Finally, the fourth section concludes the paper.

## II. Fundamental Concepts and Algorithms

The fuzzy set theory, which allows better expression of the uncertainties in the data, was proposed by Zadeh in 1965 [11].

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It is the expression of the data with the degree of belonging in the range [0,1] instead of belonging to a certain cluster or not.

The triangular membership function, which is one of the membership functions frequently used in fuzzy set theory, is as follows.

**Definition 1.** $A = (l, m, u)$ on $U = (-\infty, \infty)$ is expressed as a triangular fuzzy number, and its membership function $\mu_A: U \rightarrow [0,1]$ is given as:

$$\mu_A(x) = \begin{cases} \frac{(x-l)}{(m-l)}, & l < x < m \\ 1 \quad, & x = m \\ \frac{(u-x)}{(u-m)}, & m < x < u \\ 0 \quad, & otherwise \end{cases} \tag{1}$$

In the Fuzzy Analytic Hierarchy Process (FAHP), fuzzy pairwise comparison matrices are created, as are the matrices with pairwise comparisons of criteria and/or alternatives in the Analytic Hierarchy Process (AHP) proposed by Saaty [9]. Then, method-specific FAHP calculations are made using these matrices and hierarchical structure. Naturally, in FAHP methods, comparisons in these matrices are expressed as fuzzy numbers (usually triangular) as in (2), and a typical workflow for FAHP methods is also illustrated in Fig 1.

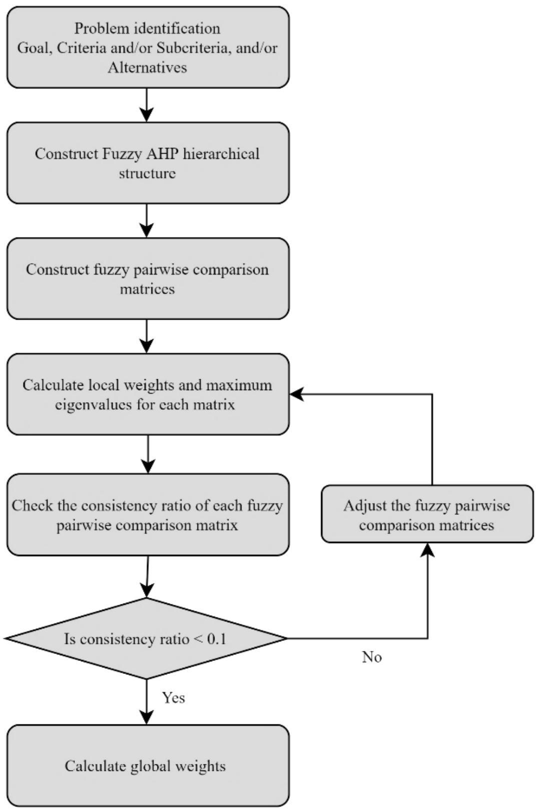


Fig. 1. A typical FAHP workflow.

$$\boldsymbol{A} = (a_{ij})_{n\times n} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \dots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \dots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \dots & (1,1,1) \end{bmatrix} \tag{2}$$

In fuzzy pairwise comparison matrices, as in classical AHP, if $a_{ij} = (l_{ij}, m_{ij}, u_{ij})$ then $a_{ji} = a_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij})$, for $i, j = 1, \dots, n,\ i \neq j$.

In order to determine the weights of the COSD challenges, the first of the three FAHP methods used in this study is the algorithm of the GM method, which is known to obtain consistent results. Secondly, the algorithm of the FEA method, which is frequently used in studies but unfortunately causes wrong results, is mentioned. Finally, the algorithm of the MFAHP method, which can produce results close to the GM method in a shorter time, is briefly explained.

*A. Geometric mean method (GM)*

The calculation procedure of the method proposed by Buckley [13] in 1985 is as follows. (For each step, $i = 1, \dots, n$)

**Step 1.** Calculate the geometric mean of each criterion or alternative from each fuzzy pairwise comparison matrix expressed as in (2).

$$z_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \tag{3}$$

**Step 2.** Obtain fuzzy weight values $r_i$ of each criterion or each alternative.

$$r_i = z_i \otimes [z_1 \oplus z_2 \oplus \dots \oplus z_n]^{-1} \tag{4}$$

**Step 3.** Defuzzify the $r_i$ values by using Center of Area (COA) method.

$$S_i = \frac{l_i + m_i + u_i}{3} \tag{5}$$

**Step 4.** Normalize the defuzzified $S_i$ weight values.

$$w_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{6}$$

*B. Chang's extent analysis on FAHP (FEA)*

The calculation procedure of the method proposed by Chang [9] in 1996 is as follows. (For each step, $i = 1, \dots, n$)

**Step 1.** Obtain the row sums for each fuzzy pairwise comparison matrix.

$$RS_i = \sum_{j=1}^{n} a_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \tag{7}$$

**Step 2.** Calculate the $S_i$ values.

$$S_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right) \tag{8}$$

**Step 3.** Calculate the degree of possibility of $S_i \geq S_j$ values.

$$V(S_i \geq S_j) = \begin{cases} 1 & , m_i \geq m_j \\ \frac{(u_i - l_j)}{(u_i - m_i) + (m_j - l_j)}, & l_j \leq u_i, i, j = 1, \dots, n;\ j \neq i \\ 0 & , otherwise \end{cases} \tag{9}$$

where $S_i = (l_i, m_i, u_i)$ and $S_j = (l_j, m_j, u_j)$ and the visual representation of $V(S_i \geq S_j)$ is shown in Fig. 2.

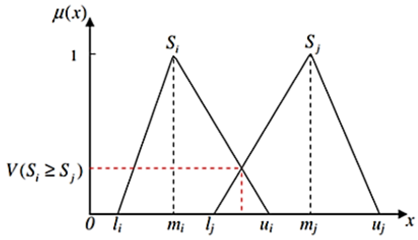


Fig. 2. Visual representation of $V(S_i \geq S_j)$.

**Step 4.** Calculate the degree of possibility of each $S_i$ over all other $(n-1)$ fuzzy numbers.

$$V(S_i \geq S_j \mid j = 1, \dots, n; j \neq i) = \min_{j \in \{1,\dots,n\}, j \neq i} V(S_i \geq S_j) \quad (10)$$

**Step 5.** Normalize the calculated values in Step 4.

$$w_i = \frac{V(S_i \geq S_j \mid j=1,\dots,n; j\neq i)}{\sum_{k=1}^{n} V(S_k \geq S_j \mid j=1,\dots,n; j\neq k)} \quad (11)$$

where the weight values are crisp values.

*C. Magnitude based fuzzy analytic hierarchy process (MFAHP)*

Ranking of alternatives is the knowledge sought to be achieved in FAHP methods. Therefore, the MFAHP method [10] has emerged with the thought that integrating this ranking step into the method for the correct calculation of local and global weights will provide a significant improvement in the final decision. For this reason, many of the proposed [14]–[18] fuzzy number ranking approaches have been examined. Among these methods, the magnitude information of the numbers, where effective results can be obtained due to the nature of fuzzy comparisons used in pairwise comparison matrices, has been added to the steps of the FAHP method. The calculation procedure of the method is as follows. (For each step, $i = 1, \dots, n$)

**Step 1.** Obtain the row sums for each fuzzy pairwise comparison matrix by using (7).

**Step 2.** Apply the normalization process as stated in [19].

$$S_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left( \frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} l_{kj}} \right) \quad (12)$$

**Step 3.** Calculate the magnitude value of each $S_i$ value.

$$Mag(S_i) = \frac{l_i + 10m_i + u_i}{12} \quad (13)$$

**Step 4.** Normalize the magnitude value of each $S_i$ value.

$$w_i = \frac{Mag(S_i)}{\sum_{j=1}^{n} Mag(S_j)} \quad (14)$$

where the weight values are crisp values.

## III. Methodology and Application

In this section, the decision making problem discussed in [5],that is determining the importance weights (priority degress) of challenges in COSD projects, is solved using 3 different FAHP methods. There are 4 main categories, and under those, a total of 21 subcategories of challenges in the decision making problem.

The authors of [5] conducted an extensive literature review to eventually designate 78 primary studies. They extracted the data from those selected studies and created a list of COSD challenges categories. The list were then validated via a pilot study assessment using Kendall's non-parametric coefficient of concordance test[20] performed involving 5 experts. Following that, a questionnaire survey was conducted with 119 participants who worked in the international software development environments. The participants of the survey were asked to grade challenges regarding their importance on a five-scale Likert scale. It is worth noting that the participants were also provided with an open-ended section in the questionnaire to elicit more challenge categories, but no additional challenges were reported. The determined challenge categories are given in Table I, and their hierarchical structure is displayed in Fig. 3.

The pairwise comparisons of the challenges were obtained via a secondary questionnaire survey with a sub-group of experts who also participated in the first survey. The sample of the questionnaire, the bibliographic information of participants, a sample of FAHP questionnaire, and fuzzy pairwise comparison matrices of the mentioned surveys are shared in the appendices of [5].

In [5], the FEA method was used to obtain the weights of the set of COSD challenges from the fuzzy pairwise comparison matrices. However, FEA has some flaws, which were investigated and laid out in [21] and confirmed by many following studies [19], [22]–[25].The results of the applications given in this paper also support that FEA is a faulty method for the particular case of weighting COSD challenges. Among a variety of FAHP methods, the GM and MFAHP are shown to be the ones to yield the highest quality results [10]. Between these two methods, MFAHP has an additional advantage when it comes to a real-world application like weighting a COSD project's challenges. MFAHP is quite simple to actually use as it abstracts the fuzzy computations from the user by providing a single concise formula, i.e. (13), to directly calculate crisp weight values. It is also shown that a less computation intensive than any other FAHP method [10]. Thus, we suggest and adopt MFAHP as the preferred method for criteria weighting in COSD projects.

TABLE I. List of main COSD challenges and their subcategories

| | |
|---|---|
| **C1** | **Organizational Management** |
| C11 | Data security issues |
| C12 | Lack of coordination between business goals and IT goals |
| C13 | Conflict management issues |
| C14 | Less control over overseas development activities |
| C15 | Hidden costs |
| C16 | Fuzzy focus |
| C17 | Issues of intellectual property protection |
| C18 | Legal issues |
| **C2** | **Process** |
| C21 | Lack of standardization |
| C22 | Dubious accessibility |
| C23 | Quality control and compliance issues |
| C24 | Problems with consistency and oversight |
| **C3** | **Technology Factor** |
| C31 | Compatibility issues (connecting legacy systems with cloud applications) |
| C32 | Outdated technology skills |
| C33 | Limited control on cloud servers |
| C34 | Operational and transaction risk |
| **C4** | **Coordination** |
| C41 | Vendor lock-in |
| C42 | Communication problems between overseas practitioners |
| C43 | Lack of knowledge management and transfer among teams |
| C44 | Lack of time differences management |
| C45 | Lack of trust and trustworthiness |

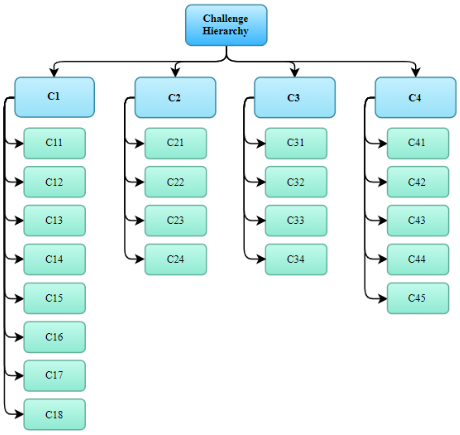


Fig. 3. Hierarchical structure of the problem.

All three FAHP methods presented in the previous section are applied to the problem using fuzzy pairwise comparison matrices of COSD challenges. The triangular linguistic terms used in fuzzy pairwise comparison matrices are given in Table II. The entire fuzzy pairwise comparison matrices involving main categories and subcategories –as expressed in (2)– were originally shared in [5]. The matrices relevant to this study, which were checked for consistency (but not shared in the text for the sake of conciseness) are given in Tables III-VII. However, it is worth noting that our matrices are slightly modified because the source material involved a few small errors.

TABLE II. TRIANGULAR LINGUISTIC TERMS

| **Linguistic term** | **Triangular fuzzy scale** | **Triangular fuzzy reciprocal scale** |
|---|---|---|
| Just equal | (1, 1, 1) | (1, 1, 1) |
| Equally important | (1/2, 1, 3/2) | (2/3, 1, 2) |
| Weakly important | (1, 3/2, 2) | (1/2, 2/3, 1) |
| Strongly more important | (3/2, 2, 5/2) | (2/5, 1/2, 2/3) |
| Very strongly more important | (2, 5/2, 3) | (1/3, 2/5, 1/2) |
| Absolutely more important | (5/2, 3, 7/2) | (2/7, 1/3, 2/5) |

TABLE III. FUZZY PAIRWISE COMPARISON MATRIX OF MAIN COSD CHALLENGE CATEGORIES

| | **C1** | **C2** | **C3** | **C4** |
|---|---|---|---|---|
| **C1** | (1, 1, 1) | (2, 5/2, 3) | (1, 3/2, 2) | (3/2, 2, 5/2) |
| **C2** | (1/3, 2/5, 1/2) | (1, 1, 1) | (2/5, 1/2, 2/3) | (1/2, 2/3, 1) |
| **C3** | (1/2, 2/3, 1) | (3/2, 2, 5/2) | (1, 1, 1) | (1, 3/2, 2) |
| **C4** | (2/5, 1/2, 2/3) | (1, 3/2, 2) | (1/2, 2/3, 1) | (1, 1, 1) |

TABLE IV. FUZZY PAIRWISE COMPARISON MATRIX OF SUBCATEGORIES FOR C1

| | **C11** | **C12** | **C13** | **C14** |
|---|---|---|---|---|
| **C11** | (1, 1, 1) | (1, 3/2, 2) | (5/2, 3, 7/2) | (2/3, 1, 2) |
| **C12** | (1/2, 2/3, 1) | (1, 1, 1) | (1/2, 2/3, 1) | (1, 3/2, 2) |
| **C13** | (2/7, 1/3, 2/5) | (1, 3/2, 2) | (1, 1, 1) | (1/2, 1, 3/2) |
| **C14** | (1/2, 1, 3/2) | (1/2, 2/3, 1) | (2/3, 1, 2) | (1, 1, 1) |
| **C15** | (2/5, 1/2, 2/3) | (3/2, 2, 5/2) | (1, 3/2, 2) | (5/2, 3, 7/2) |
| **C16** | (1/2, 2/3, 1) | (1/2, 2/3, 1) | (1, 3/2, 2) | (1/3, 2/5, 1/2) |
| **C17** | (1, 3/2, 2) | (1/3, 2/5, 1/2) | (1/2, 2/3, 1) | (2/3, 1, 2) |
| **C18** | (2, 5/2, 3) | (1/2, 2/3, 1) | (1, 3/2, 2) | (1/3, 2/5, 1/2) |

| | **C15** | **C16** | **C17** | **C18** |
|---|---|---|---|---|
| **C11** | (3/2, 2, 5/2) | (1, 3/2, 2) | (1/2, 2/3, 1) | (1/3, 2/5, 1/2) |
| **C12** | (2/5, 1/2, 2/3) | (1, 3/2, 2) | (2, 5/2, 3) | (1, 3/2, 2) |
| **C13** | (1/2, 2/3, 1) | (1/2, 2/3, 1) | (1, 3/2, 2) | (1/2, 2/3, 1) |
| **C14** | (2/7, 1/3, 2/5) | (2, 5/2, 3) | (1/2, 1, 3/2) | (2, 5/2, 3) |
| **C15** | (1, 1, 1) | (2/5, 1/2, 2/3) | (2/7, 1/3, 2/5) | (1, 3/2, 2) |
| **C16** | (3/2, 2, 5/2) | (1, 1, 1) | (2/5, 1/2, 2/3) | (2, 5/2, 3) |
| **C17** | (5/2, 3, 7/2) | (3/2, 2, 5/2) | (1, 1, 1) | (2/5, 1/2, 2/3) |
| **C18** | (1/2, 2/3, 1) | (1/3, 2/5, 1/2) | (3/2, 2, 5/2) | (1, 1, 1) |

TABLE V. FUZZY PAIRWISE COMPARISON MATRIX OF SUBCATEGORIES FOR C2

| | **C21** | **C22** | **C23** | **C24** |
|---|---|---|---|---|
| **C21** | (1, 1, 1) | (1/3, 2/5, 1/2) | (1, 3/2, 2) | (1/2, 2/3, 1) |
| **C22** | (2, 5/2, 3) | (1, 1, 1) | (1/2, 2/3, 1) | (3/2, 2, 5/2) |
| **C23** | (2/5, 1/2, 2/3) | (1, 3/2, 2) | (1, 1, 1) | (1, 3/2, 2) |
| **C24** | (1, 3/2, 2) | (2/5, 1/2, 2/3) | (1/2, 2/3, 1) | (1, 1, 1) |

TABLE VI. FUZZY PAIRWISE COMPARISON MATRIX OF SUBCATEGORIES FOR C3

| | **C31** | **C32** | **C33** | **C34** |
|---|---|---|---|---|
| **C31** | (1, 1, 1) | (3/2, 2, 5/2) | (3/2, 2, 5/2) | (3/2, 2, 5/2) |
| **C32** | (2/5, 1/2, 2/3) | (1, 1, 1) | (1/2, 2/3, 1) | (1/2, 2/3, 1) |
| **C33** | (2/5, 1/2, 2/3) | (1, 3/2, 2) | (1, 1, 1) | (1, 3/2, 2) |
| **C34** | (2/5, 1/2, 2/3) | (1, 3/2, 2) | (1/2, 2/3, 1) | (1, 1, 1) |

TABLE VII. FUZZY PAIRWISE COMPARISON MATRIX OF SUBCATEGORIES FOR C4

| | **C41** | **C42** | **C43** | **C44** | **C45** |
|---|---|---|---|---|---|
| **C41** | (1, 1, 1) | (1/3, 2/5, 1/2) | (3/2, 2, 5/2) | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) |
| **C42** | (2, 5/2, 3) | (1, 1, 1) | (2, 5/2, 3) | (1/2, 1, 3/2) | (1, 3/2, 2) |
| **C43** | (2/5, 1/2, 2/3) | (1/3, 2/5, 1/2) | (1, 1, 1) | (2, 5/2, 3) | (5/2, 3, 7/2) |
| **C44** | (3/2, 2, 5/2) | (2/3, 1, 2) | (1/3, 2/5, 1/2) | (1, 1, 1) | (1/2, 2/3, 1) |
| **C45** | (3/2, 2, 5/2) | (1/2, 2/3, 1) | (2/7, 1/3, 2/5) | (1, 3/2, 2) | (1, 1, 1) |

The results of the applications are given in Table VIII-X. Table VIII contains local weights for the main categories of COSD challenges. It is seen that the weight values obtained by MFAHP are very similar to the results of the GM while FEA results are notably different, as expected. The fact that some values seen in the results of FEA method are actually zero (like the result of the C2 main COSD challenge) implies that the criterion is totally irrelevant, which is false. Also note that the numerical results we obtained using FEA are slightly different than the ones given in [5], due to the small numerical errors as previously mentioned.

TABLE VIII. LOCAL WEIGHTS OF MAIN COSD CHALLENGES

| | **MFAHP** | **GM** | **FEA** | **Rank** |
|---|---|---|---|---|
| **C1** | 0.3783 | 0.3779 | *0.5070* | 1 |
| **C2** | 0.1410 | 0.1423 | ***0.0000*** | 4 |
| **C3** | 0.2805 | 0.2800 | *0.3403* | 2 |
| **C4** | 0.2002 | 0.1998 | *0.1527* | 3 |

TABLE IX. LOCAL WEIGHTS OF SUBCATEGORIES

| | **MFAHP** | **GM** | **FEA** |
|---|---|---|---|
| **C11** | 0.1438 | 0.1472 | 0.1446 |
| **C12** | 0.1275 | 0.1345 | 0.1287 |
| **C13** | 0.0956 | 0.1047 | 0.0910 |
| **C14** | 0.1301 | 0.1324 | 0.1317 |
| **C15** | 0.1336 | 0.1224 | 0.1348 |
| **C16** | 0.1198 | 0.1171 | 0.1193 |
| **C17** | 0.1311 | 0.1283 | 0.1322 |
| **C18** | 0.1185 | 0.1134 | 0.1176 |
| **C21** | 0.2000 | 0.1989 | 0.1588 |
| **C22** | 0.3435 | 0.3332 | 0.4029 |
| **C23** | 0.2508 | 0.2557 | 0.2641 |
| **C24** | 0.2056 | 0.2122 | 0.1742 |
| **C31** | 0.3865 | 0.3870 | 0.5275 |
| **C32** | 0.1594 | 0.1677 | 0.0297 |
| **C33** | 0.2495 | 0.2433 | 0.2779 |
| **C34** | 0.2046 | 0.2020 | 0.1649 |
| **C41** | 0.1428 | 0.1387 | 0.0834 |
| **C42** | 0.2737 | 0.3006 | 0.3186 |
| **C43** | 0.2391 | 0.2037 | 0.2665 |
| **C44** | 0.1661 | 0.1790 | 0.1618 |
| **C45** | 0.1782 | 0.1780 | 0.1696 |

Table IX contains local weights for the subcategories. When the local weights of the main COSD challenges (Table VIII) and the local weights of the subcategories of COSD challenges (Table IX) were evaluated together, global weight values were obtained for all subcategories for COSD challenges as in Table X. The comparative results in Table X are also visualized in Fig. 4. It is seen that the results of MFAHP and GM are similar. However, FEA results often produce larger or smaller weight values than MFAHP and GM results. Also, FEA produced zero weights for some criteria (C21-C24), which is an anomaly anyway.

TABLE X. GLOBAL WEIGHTS OF COSD CHALLENGES

| | | MFAHP | GM | FEA |
|---|---|---|---|---|
| C1 | C11 | 0.0544 | 0.0556 | 0.0733 |
| | C12 | 0.0482 | 0.0508 | 0.0652 |
| | C13 | 0.0362 | 0.0396 | 0.0462 |
| | C14 | 0.0492 | 0.0500 | 0.0668 |
| | C15 | 0.0505 | 0.0462 | 0.0683 |
| | C16 | 0.0453 | 0.0442 | 0.0605 |
| | C17 | 0.0496 | 0.0485 | 0.0670 |
| | C18 | 0.0448 | 0.0428 | 0.0596 |
| C2 | C21 | 0.0282 | 0.0283 | 0.0000 |
| | C22 | 0.0484 | 0.0474 | 0.0000 |
| | C23 | 0.0354 | 0.0364 | 0.0000 |
| | C24 | 0.0290 | 0.0302 | 0.0000 |
| C3 | C31 | 0.1084 | 0.1084 | 0.1795 |
| | C32 | 0.0447 | 0.0470 | 0.0101 |
| | C33 | 0.0700 | 0.0681 | 0.0946 |
| | C34 | 0.0574 | 0.0566 | 0.0561 |
| C4 | C41 | 0.0286 | 0.0277 | 0.0127 |
| | C42 | 0.0548 | 0.0601 | 0.0487 |
| | C43 | 0.0479 | 0.0407 | 0.0407 |
| | C44 | 0.0332 | 0.0358 | 0.0247 |
| | C45 | 0.0357 | 0.0356 | 0.0259 |

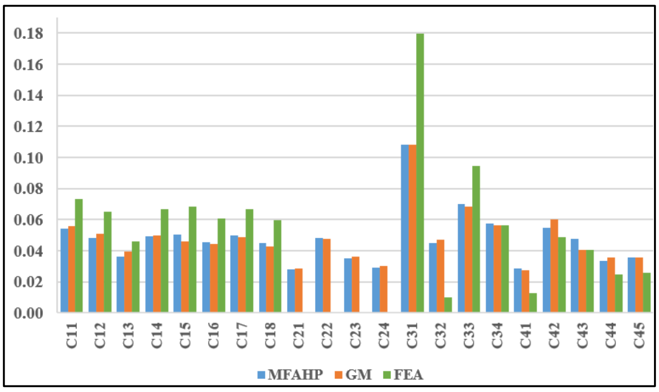


Fig. 4. Graphical representation of global weights of COSD challenges.

Regardless of the FAHP method used, the main challenge categories are prioritized in the same order. Organizational management (C1) challenges are of the highest priority, followed by technology factor (C3) and coordination (C4) challenges. The development process (C2) category is the lowest ranked of main challenge priorities. Though the priority rankings are essentially indifferent, FEA generated considerably different and inconsistent weights compared to other two methods. The weights spread considerably wider in the case of FEA, such that C3 is more than twice as important than C4 and total weights of C3 and C4 are smaller than C1 alone. C2 is assigned a zero-weight by FEA, which would translate to that challenges regarding the development process are entirely effectless. Of course, this points to a flaw in the method, rather than the interpretetion. MFAHP and GM assigned very similar weight values with one another. However, though the differences between weight values are considerably small, the weight ranking is of subcategories are different even for MFAHP and GM. For example, the third highest weight value is assigned to operational and transactional risk (C34) using MFAHP, while GM gives the third plac to communication problems between overseas practitioners (C42). Considering the results of MFAHP and GM, compatibility issues (C31) are expected to pose the greatest challange in a COSD project among 21 subcategories, by quite a margin. Fig. 5 summarizes the collective outcome of the MFAHP application.

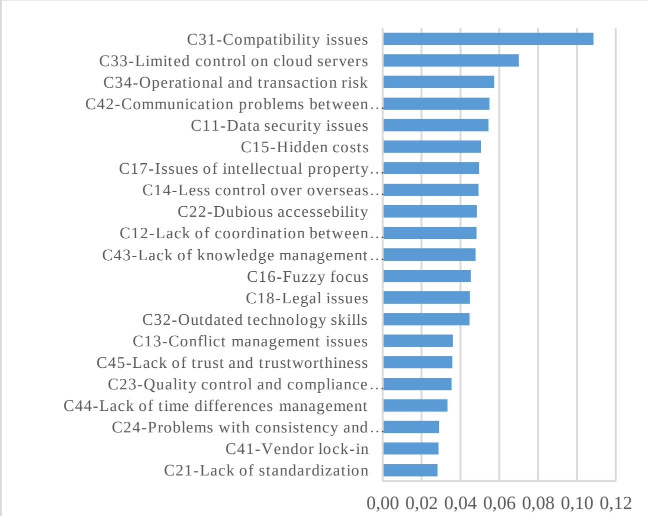


Fig. 5. Sorted global weights of COSD challenges obtained by the MFAHP.

TABLE XI. RUNNING TIMES OF EACH METHOD

| | Running times (in ms.) |
|---|---|
| MFAHP | 0.0287 |
| GM | 0.1923 |
| FEA | 0.1677 |

Finally, when the methods are examined in terms of the running times given in Table XI, it is known that GM is slow due to the calculation procedure and FEA is the fastest. For this example, MFAHP performed faster than FEA. Of course, it is not correct to generalize for a single example. However, in [10] where the methods are compared in detail, it has already been shown that MFAHP works as fast as FEA. All of the mentioned applications were programmed in C# language and run on a personal computer with a 10th Generation Intel Core i7 CPU clocked at 1.8 GHz and 16 GB of RAM.

## IV. CONCLUSION

Managing a COSD process has a variety of challenges, some of them being unique to the process. This study provides a methodology tailored for a COSD process assessment in the form of weighted criteria. The methodology combines the challenge categorization presented in [5] and the MFAHP method proposed in[10].The results of the example application indicate that choice of the FAHP method is superior in one way or another to its rivals, especially to FEA used in [5] in terms of outcome accuracy. Therefore, we believe that the study could benefit to decision makers of a COSD process in a rather simple way.

In the future, evaluating a set of real COSD projects based on the results achieved in this study is of primary importance. Also, the problem of selecting cloud service providers could be integrated into the methodology presented in this study to further assist the decision makers towards the success of their projects.

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