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Research Article

A Hybrid Fuzzy AHP-TOPSIS Technique for Open-Source Software Selection

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ABSTRACT

The dissemination of OSS within corporate environments has been shaped by a range of factors that could be perceived either as impediments or catalysts in the process of adoption. This research employs the integrated Fuzzy-AHP-TOPSIS model to construct an evaluation framework for selecting open-source software. this study employed the FUZZY AHP method to examine the importance levels of criteria for enterprises when adopting OSS. Alongside the OSS evaluation hierarchy identified by fuzzy AHP, fuzzy TOPSIS has been employed to select what is arguably the most suitable open-source software for an e-commerce website available in the market today. The framework facilitates the assessment of objects based on various criteria while mitigating the subjectivity inherent in human evaluations. An application of the model has been implemented in the context of Vietnam. The ranking results indicate that Magento is the most suitable, followed by OpenCart and WooCommerce, respectively. This paper has provided valuable contributions not solely to the academic community but also to the community of practitioners. While this study has yielded valuable insights, several limitations also acknowledged, which could impact the broader applicability and effectiveness of the proposed hybrid fuzzy AHP-TOPSIS framework.

Keywords: Open-Source Software Selection; Fuzzy AHP; Fuzzy TOPSIS, MCDM.

INTRODUCTION

Open source software (OSS) is a type of software labeled open source in which the source code must be accessible and editable. Distributors or developers may charge for additional services such as specialized training, installation, programming, and technical support. According Sarrab and Rehman (2014), the development of open source has been strongly promoted in recent years due to the impact of the media. The standards for choosing OSS may vary among different stakeholders within these organizations. Consequently, users might develop a partial viewpoint regarding the attributes or problem-solving capabilities of an OSS product during the selection process [2]. Various factors hinder the broader adoption of open-source software (OSS). Firstly, a considerable number of OSS projects lack comprehensive and current user documentation, causing potential end-users frustration during the evaluation phase..

Despite its widespread use, AHP often has limitations in its ability to incorporate the inherent uncertainty and imprecision in reflecting the decision maker's perceptions and judgments into the precise numbers used in the AHP model. Therefore, since fuzziness is a common feature of decision-making problems, the FAHP method was developed to address this issue. It allows the decision-maker to express an approximation or closeness of the input factors using fuzzy numbers [3]. TOPSIS is commonly used in the situation of identifying the best alternative and ranking order of alternatives. However, the pure AHP and TOPSIS methods tend to be less effective when dealing with the uncertainty in the decision-making process. As a result, fuzzy AHP and fuzzy TOPSIS were introduced to address uncertainty in evaluation processes. Since its introduction, fuzzy AHP has gained widespread adoption among researchers for tackling diverse decision-making challenges across multiple domains, including agile software development [4], solar power in Pakistan [5], wine industry [6]. Several remarkable works utilizing fuzzy TOPSIS are project manager selection [7], selection of possible suppliers in dairy industry [8].

Recognizing that the foundation of the evaluation process lies in the development of an appropriate evaluation index system, this study focuses on constructing such a system with rational and objective attribute weights. To achieve a high degree of consensus in determining the weights of criteria within the index system, a framework incorporating fuzzy AHP in group MCDM is proposed. In the framework, fuzzy AHP method [9], [10] proposed by Buckley is utilized to obtain the criteria weights in the OSS evaluation index system. Based on the evaluation index system and fuzzy TOPSIS procedure, the selection can be conducted. By combination of fuzzy AHP and fuzzy TOPSIS, this study aims to:

(1) Determine the relative importance of criteria and sub-criteria within the OSS evaluation index system.

(2) Rank the OSS alternatives as part of a case study application.

The structure of this paper is outlined as follows: Section 2 provides a literature review. Section 3 introduces fuzzy AHP, fuzzy TOPSIS, and relevant concepts. Section 4 and 5 presents the results and corresponding discussions. Lastly, conclusions are summarized in Section 6.

LITERATUREREVIEW

The investigation delved into prior studies concerning the criteria utilized in the selection of OSS products. Numerous scholars have proposed models and frameworks outlining their favored set of significant criteria for the selection of OSS. It is noteworthy that, in formulating the selection criteria for this study, primary emphasis was placed on four key sources: (i) the DeLone and McLean Information System Success Model [11], (ii) literature concerning the quality model of OSS [1], [2], [12], [13], [14], [15], [16], and (iii) widely accepted standards for software quality, such as ISO 25010 [17].

System quality: System quality pertains to the favorable attributes inherent in the OSS product, encompassing key elements such as availability, reliability, performance, usability, and functionality [1], [15].

Source code quality : The source code quality of software refers to the overall excellence of the programming code that constitutes the software. It involves assessing various aspects of the code, such as maintainability, Reusability, Testability and Security to coding standards [1], [12].

Service quality is often related to commercial support ; community support; documentation: and Developer skills [1], [12], [14], [15].

Cost: Expenditure pertains to the overall financial outlay incurred by enterprises in deploying a particular open-source software. Cost stands as a pervasive determinant influencing the selection of software by prospective users. While open-source software is devoid of licensing fees, it is imperative to recognize that organizations are not exempt from incurring expenses in the course of software implementation. From the standpoint of open-source software, it mitigates the aggregate cost for the software adopter. Nonetheless, enterprises are still obligated to shoulder additional associated costs. It comprises the following elements: IT team; IT infrastructure and other cost [12], [13], [16].

The criteria, sub-criteria and the hierarchy of evaluation index system are shown in Table 1 and Figure 1.

Table 1: Criteria and sub-criteria

Criteria	Sub-criteria	Definition	Source
System quality (C1)	Availability (C11)	Ensuring software services are readily available, along with the periodic release of new versions that introduce additional features.	[1], [15]
	Reliability (C12)	Reliability denotes the software's capacity to provide reliability to the customer, along with the extent of that reliability.	[1], [13]
	Performance (C13)	Performance criteria often encompass factors such as response time, throughput, resource utilization, and overall system efficiency.	[1], [12]
	Usability (C14)	Usability refers to the extent to which the software is user-friendly and can be easily understood, learned, and operated by its intended users.	[1], [14]
	Functionality (C15)	The functionality of software refers to its ability to fulfill and meet the expected requirements of users.	[1]
Source code quality (C2)	Maintainability (C21)	Maintainability is the measure of how simple it is to update, modify, or enhance software throughout its lifecycle.	[1], [12]

Criteria	**Sub-criteria**	**Definition**	**Source**
	Reusability (C22)	Reusability describes the process of designing and developing software components so they can be utilized in various parts of the same software or integrated into other applications.	[1], [13]
	Testability (C23)	Testability is the degree to which a software system can be effectively tested to confirm its functionality, reliability, and performance.	[1], [12]
	Security (C24)	Security refers to safeguarding the software system and its data against unauthorized access, cyberattacks, or potential damage.	[1], [12], [14]
Service quality (C3)	Commercial support (C31)	Commercial support for software refers to the availability of professional assistance, services, and expertise provided by commercial entities to users of a particular software product.	[1], [12], [13], [14]
	Community support (C32)	Community support for software refers to the assistance, collaboration, and resources provided by the user community surrounding a particular software product.	[1], [12], [14], [15]
	Documentation (C33)	Documentation refers to the collection of written materials that provide information about the software's design, functionality, installation, configuration, and usage.	[1], [12]
	Developer skills (C34)	Developer skills in the context of software refer to the capabilities, knowledge, and proficiencies possessed by individuals involved in the design, creation, and maintenance of OSS.	[1]
Cost (C4)	IT team (C41)	The cost is incurred by hiring external resources or investing in the existing IT staff to implement open-source software.	[12], [13], [16]
	IT infrastructure (C42)	The adoption of a new OSS might entail the need for a company to enhance or expand its existing IT infrastructure in order to facilitate the installation of the new software.	[12], [13], [15], [16]
	Other costs (C43)	It may involve expenses for consulting services throughout the implementation phase, if deemed necessary by the organizations, or costs related to end-user training, and similar considerations.	[12], [13], [16]

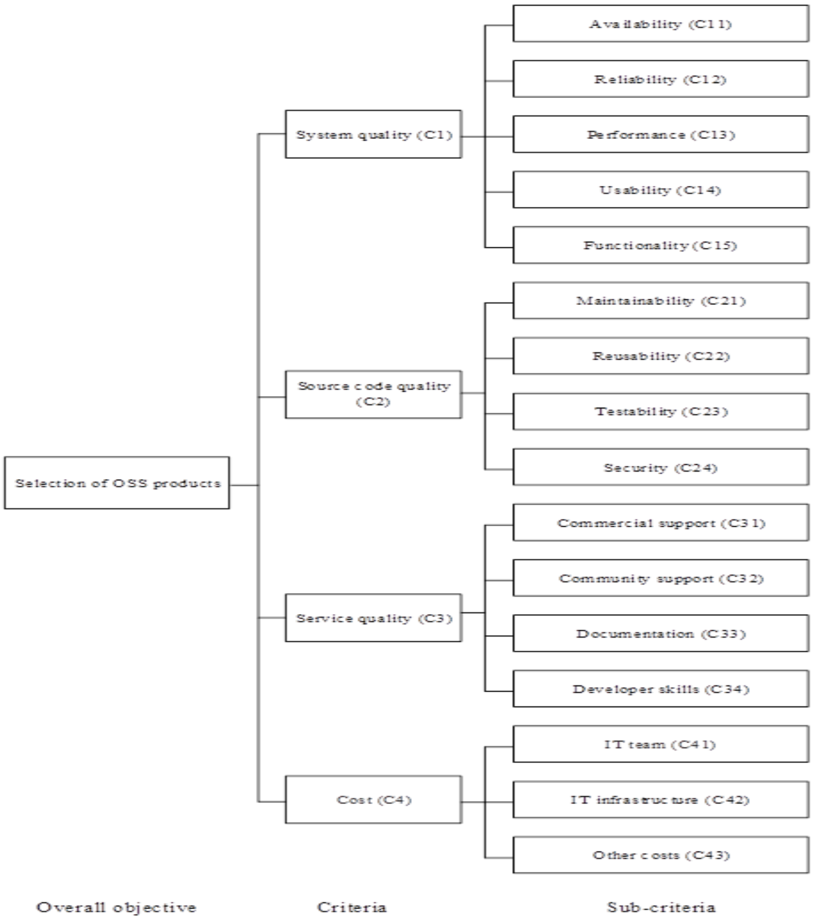

Figure 1: The hierarchy of criteria in OSS evaluation index system

METHODS

3.1. Triangular fuzzy number (TFN)

A fuzzy event can be characterized using the triplet (l, m, u), which encapsulates the uncertainty associated with the evaluation process. A triangular fuzzy number (TFN) is denoted as $\tilde{A} = (l, m, u)$, with its membership function defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l); & l \leq x \leq m \\ (u-x)/(u-m); & m \leq x \leq u \\ 0; & otherwise \end{cases} \quad (1)$$

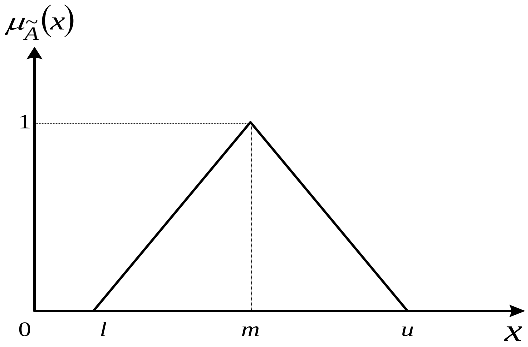

Figure 2: A TFN, $\tilde{A} = (l, m, u)$

Consider two TFNs $\widetilde{A_1}$ and $\widetilde{A_2}$, $\widetilde{A_1} = (l_1, m_1, u_1)$ and $\widetilde{A_2} = (l_2, m_2, u_2)$. The fundamental operational rules for triangular fuzzy numbers [18] are as follows:

Addition: $\tilde{A}_1 \oplus \tilde{A}_2 = (l_1+l_2, m_1+m_2, u_1+u_2)$ (2)

Multiplication: $\tilde{A}_1 \otimes \tilde{A}_2 \approx (l_1l_2, m_1m_2, u_1u_2)$ for $l_i > 0, m_i > 0, u_i > 0, i = 1, 2$ (3)

Division: $\tilde{A}_1/\tilde{A}_2 = (l_1/u_2, m_1/m_2, u_1/l_2)$ for $l_i > 0, m_i > 0, u_i > 0, i = 1, 2$ (4)

Reciprocal: $\tilde{A}_1^{-1} \approx (1/u_1, 1/m_1, 1/l_1)$ for $l_1 > 0, m_1 > 0, u_1 > 0$ (5)

3.2. Fuzzy AHP

A matrix $\tilde{A}$ is established based on fuzzy pairwise comparison evaluations.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (6)$$

where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is the fuzzy comparison value of criterion i to criterion j

The consistence index, CI, for a comparison matrix can be computed with the use of the following equation.

$$CI = \frac{\lambda_{max}}{n-1} \quad (7)$$

where, λ_{max} is the largest eigenvalue of the comparison matrix, and n is the dimension of the matrix.

According to Davies [19] , the consistency ratio is calculated as the proportion of the consistency index of an evaluation matrix to that of a randomly generated matrix.

$$CR = \frac{CI}{RI(n)} \quad (8)$$

where, $RI(n)$ is a random index that depends on n, as shown in Table 2.

Table 2: Random index (RI) of random matrices.

n	3	4	5	6	7	8	9
$RI(n)$	0.58	0.9	1.12	1.24	1.32	1.41	1.45

When the consistency ratio (CR) is 0.1 or below, the comparison matrix is deemed valid. However, if the CR is higher, the decision-maker is advised to reassess and adjust the pairwise comparisons.

The fuzzy weights of each criterion are calculated as

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{1/n} \text{ for } i = 1,2,\dots,n \quad (9)$$

$$\widetilde{w}_i = \frac{\tilde{r}_i}{\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n} \text{ for } i = 1,2,\dots,n \quad (10)$$

where $\widetilde{r}_i$ represents the geometric mean of the fuzzy comparison values for criterion i relative to all other criteria, while $\widetilde{w}_i$ denotes the fuzzy weight of the ith criterion.

The fuzzy weight vector $\widetilde{W}$ is defined as:

$$\widetilde{W} = (\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n)^T \quad (9)$$

3.3. Fuzzy TOPSIS

The process of fuzzy TOPSIS includes the following steps:

Step 1: Determine the set of alternatives and evaluation criteria.

Step 2: Compute the weight of each criterion, with this study employing the fuzzy AHP approach.

Step 3: Construct the decision matrix based on the identified criteria and alternatives.

$$\widetilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} \widetilde{x_{11}} & \widetilde{x_{12}} & \dots & \widetilde{x_{1n}} \\ \widetilde{x_{21}} & \widetilde{x_{22}} & \cdots & \widetilde{x_{2n}} \\ \dots & \vdots & \ddots & \vdots \\ \widetilde{x_{m1}} & \widetilde{x_{m1}} & \cdots & \widetilde{x_{mn}} \end{bmatrix} \end{array} \tag{16}$$

$i = 1,2, \dots , m; j = 1,2, \dots , n$

$$\tilde{x}_{ij} = \frac{1}{K} (\tilde{x}_{ij}^{-1} \oplus \dots \oplus \tilde{x}_{ij}^{-k} \dots \oplus \tilde{x}_{ij}^{-K})$$

where $\tilde{x}_{ij}^{-k}$ is the rating of alternative A_i with respect to criterion C_j performed by the k^{th} expert and $\tilde{x}_{ij}^{-k} = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$

Step 4: The decision matrix is normalized.

The normalized fuzzy decision matrix is represented by $\tilde{R}$ as follows:

$$\widetilde{R} = [\widetilde{r_{ij}}]_{m\times n}, i = 1,2, \dots , m; j = 1,2, \dots n \tag{17}$$

The normalization can be done by the following equation:

$$\widetilde{r_{ij}} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right), u_j^+ = max\{u_{ij} | i = 1,2, \dots , n\} \tag{18}$$

The best aspired level u_j^+ can be set, and $j = 1,2, \dots , n$ is equal to one; otherwise, the worst is zero [20]. The weight of the fuzzy normalized decision matrix $\tilde{V}$ can be obtained as follows:

$$\tilde{V} = \left[\widetilde{v_{ij}}_{n\times n}\right], i = 1,2, \dots , m; j = 1,2, \dots , n \tag{19}$$

Where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \widetilde{w}_j$

Step 5: Identify the fuzzy positive-ideal solution (FPIS) and the fuzzy negative-ideal solution (FNIS)

The positive triangular fuzzy numbers (PTFNs) are normalized into the range of closed interval $[0,1]$. The FPIS A^+ (aspiration levels) and FNIS A^- can be obtained as the following equations:

$$A^+ = (\tilde{v}_1^+, \dots , \tilde{v}_j^+, \dots , \tilde{v}_n^+) \tag{20}$$

$$A^- = (\tilde{v}_1^-, \dots , \tilde{v}_j^-, \dots , \tilde{v}_n^-) \tag{21}$$

Where $\tilde{v}_j^* = (1,1,1) \otimes \widetilde{w_j} = (lw_j, mw_j, uw_j)$ and $\tilde{v}_j^- = (0,0,0), j = 1,2, \dots , n$

Step 6: Calculating the distance of each alternative from FPIS and FNIS.

The distances ($\widetilde{d_i^+}$ and $\widetilde{d_i^-}$) of each alternative from A^+ and A^- can be identified as follows:

$$\tilde{d}_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), i = 1,2, \dots , m; j = 1,2, \dots , n \tag{22}$$

$$\tilde{d}_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), i = 1,2, \dots , m; j = 1,2, \dots , n \tag{23}$$

where $d(,)$ is the distance between two fuzzy numbers.

Step 7: Compute the closeness coefficients

$$CC_i = \frac{\tilde{d}_i^-}{\tilde{d}_i^+ + \tilde{d}_i^-} \tag{24}$$

Step 8: Establish the ranking based on preference order.

The alternatives are arranged in descending order according to the CC_i index.

3.4. Proposed framework

To ensure consensus, a representative and democratic decision-making approach is necessary for evaluating OSS alternatives. The proposed framework combines fuzzy AHP and fuzzy TOPSIS, comprising two key stages: (1) utilizing fuzzy AHP to determine criteria weights and (2) applying fuzzy TOPSIS to evaluate OSS alternatives and derive the final ranking. Figure 4 presents the structure of this framework.

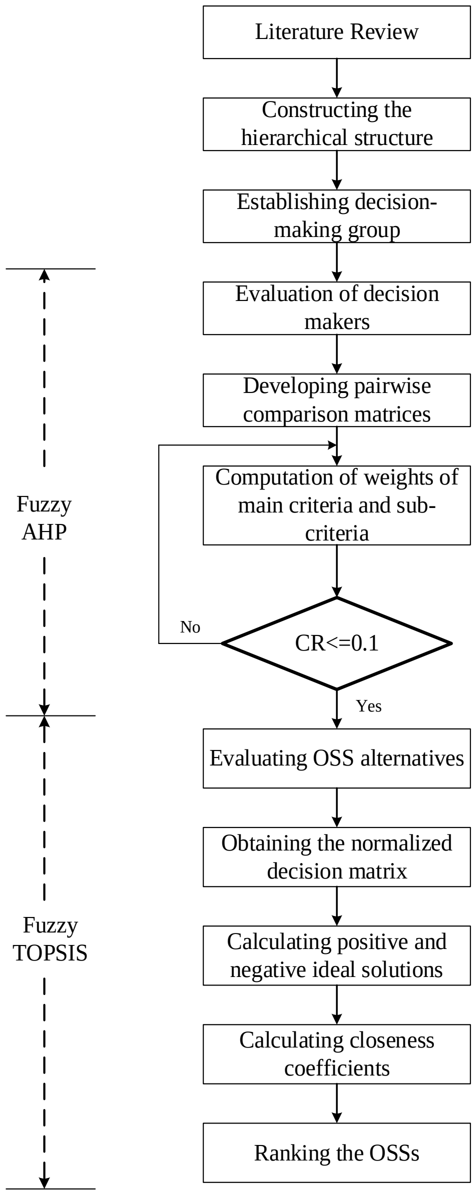

Figure 4: Proposed framework

RESULTS

The first step is to establish the importance of criteria and sub-criteria through the application of the Fuzzy AHP method. Based on input from a committee of 42 representatives—including 4 Chief Information Officers, 12 IT managers, 21 software developers, and 5 system administrators—pairwise comparison matrices are constructed to assess the relative importance of these factors. The corresponding fuzzy weights are then derived, as presented in Tables 3-12.

Table 3: Combined comparison matrix for criteria

	C1	C2	C3	C4
C1	(1,1,1)	(1,2.71,11)	(1,3.709,11)	(0.091,0.585,5)

C2	(1,0.369,1)	(1,1,1)	(0.111,0.568,1)	(1,2.924,7)
C3	(0.091,0.27,1)	(1,1.761,9)	(1,1,1)	(0.111,0.568,1)
C4	(0.2,1.709,11)	(0.143,0.342,1)	(1,1.761,9)	(1,1,1)

Table 4: Fuzzy weights of criteria

Criteria	Fuzzy Weights
C1	(0.048,0.373,2.674)
C2	(0.05,0.212,0.877)
C3	(0.028,0.173,0.934)
C4	(0.036,0.242,1.701)

Table 5: Combined comparison matrix for sub-criteria under the System quality (C1)

	C11	C12	C13	C14	C15
C11	(1,1,1)	(1,1.777,7)	(1,1,1)	(1,2.951,7)	(0.111,0.434,1)
C12	(0.143,0.563,1)	(1,1,1)	(1,1.233,5)	(0.2,1.082,5)	(1,2.371,5)
C13	(1,1,1)	(0.2,0.811,1)	(1,1,1)	(1,3.092,7)	(1,3.542,7)
C14	(0.143,0.339,1)	(0.2,0.925,5)	(0.143,0.323,1)	(1,1,1)	(0.111,0.265,1)
C15	(1,2.302,9)	(0.2,0.422,1)	(0.143,0.282,1)	(1,3.776,9)	(1,1,1)

Table 6: Fuzzy weights of sub-criteria within System quality (C1)

Sub- criteria	Fuzzy Weights
C11	(0.06,0.221,0.849)
C12	(0.046,0.21,1.024)
C13	(0.067,0.29,0.849)
C14	(0.02,0.091,0.538)
C15	(0.046,0.189,0.939)

Table 7: Combined comparison matrix for sub-criteria under the Source code quality (C2)

	C21	C22	C23	C24
C21	(1,1,1)	(0.143,0.624,9)	(0.111,0.249,1)	(0.111,0.688,7)
C22	(1,1.604,7)	(1,1,1)	(0.2,0.731,1)	(0.2,0.77,1)
C23	(1,4.015,9)	(1,1.369,5)	(1,1,1)	(0.2,0.901,5)
C24	(0.143,1.454,9)	(1,1.299,5)	(0.2,1.11,5)	(1,1,1)

Table 8: Fuzzy weights of sub-criteria within Source code quality (C2)

Sub-criteria	Fuzzy Weights
C21	(0.017,0.135,1.627)
C22	(0.037,0.23,0.939)
C23	(0.055,0.352,2.236)
C24	(0.034,0.284,2.236)

Table 9: Combined comparison matrix for sub-criteria under the Service quality (C3)

	C31	C32	C33	C34
C31	(1,1,1)	(0.143,0.624,9)	(0.111,0.249,1)	(0.111,0.688,7)
C32	(1,1.604,7)	(1,1,1)	(0.2,0.731,1)	(0.2,0.77,1)
C33	(1,4.015,9)	(1,1.369,5)	(1,1,1)	(0.2,0.901,5)

C34	(0.143,1.454,9)	(1,1.299,5)	(0.2,1.11,5)	(1,1,1)

Table 10: Fuzzy weights of Service quality (C3)

Sub-criteria	Fuzzy Weights
C31	(0.017,0.135,1.627)
C32	(0.037,0.23,0.939)
C33	(0.055,0.352,2.236)
C34	(0.034,0.284,2.236)

Table 11: Combined comparison matrix for sub-criteria under the Cost (C4)

	C41	C42	C43
C41	(1,1,1)	(0.143,0.679,9)	(0.111,0.249,1)
C42	(1,1.474,7)	(1,1,1)	(1,2.31,5)
C43	(1,4.015,9)	(0.2,0.433,1)	(1,1,1)

Table 12: Fuzzy weights of sub-criteria within Cost (C4)

Sub-criteria	Fuzzy Weights
C41	(0.034,0.17,1.133)
C42	(0.135,0.461,1.782)
C43	(0.079,0.369,1.133)

Table 13: Global weight and rank of criteria and sub-criteria

Criteria	Criteria weight	Weight of sub-criteria relative to the corresponding criteria weight	Global weight	Global weight (crisp value)	Rank
System quality (C1)	**(0.048,0.373,2.674)**			**0.867**	**1**
Availability (C11)		(0.06,0.221,0.849)	(0.003,0.082,2.27)	0.609	5
Reliability (C12)		(0.046,0.21,1.024)	(0.002,0.078,2.737)	0.724	2
Performance (C13)		(0.067,0.29,0.849)	(0.003,0.108,2.27)	0.622	4
Usability (C14)		(0.02,0.091,0.538)	(0.001,0.034,1.438)	0.377	13
Functionality (C15)		(0.046,0.189,0.939)	(0.002,0.07,2.51)	0.663	3
Source code quality (C2)	**(0.05,0.212,0.877)**			**0.338**	**3**
Maintainability (C21)		(0.017,0.135,1.627)	(0.001,0.029,1.427)	0.371	14
Reusability (C22)		(0.037,0.23,0.939)	(0.002,0.049,0.824)	0.231	16
Testability (C23)		(0.055,0.352,2.236)	(0.003,0.075,1.961)	0.528	8
Security (C24)		(0.034,0.284,2.236)	(0.002,0.06,1.961)	0.521	10
Service quality (C3)	**(0.028,0.173,0.934)**			**0.327**	**4**

Criteria	Criteria weight	Weight of sub-criteria relative to the corresponding criteria weight	Global weight	Global weight (crisp value)	Rank
Commercial support (C31)		(0.017,0.135,1.627)	(0,0.023,1.519)	0.392	12
Community support (C32)		(0.037,0.23,0.939)	(0.001,0.04,0.877)	0.239	15
Documentation (C33)		(0.055,0.352,2.236)	(0.002,0.061,2.088)	0.553	6
Developer skills (C34)		(0.034,0.284,2.236)	(0.001,0.049,2.088)	0.547	7
Cost (C4)	**(0.036,0.242,1.701)**			**0.555**	**2**
IT team (C41)		(0.034,0.17,1.133)	(0.001,0.041,1.927)	0.502	11
IT infrastructure (C42)		(0.135,0.461,1.782)	(0.005,0.111,3.03)	0.814	1
Other costs (C43)		(0.079,0.369,1.133)	(0.003,0.089,1.927)	0.527	9

Utilizing the fuzzy AHP method, the weights for criteria and sub-criteria are determined, as presented in Table 14. The results indicate that System Quality (C1) holds the highest importance compared to other criteria, while Service Quality (C3) is considered less significant. Specifically, as shown in Table 14, IT Infrastructure (C42) emerges as the most influential factor in OSS adoption, with the highest weight of 0.814. while the less influential factor in OSS adoption is Reusability (C22).

In the second phase of applying the fuzzy TOPSIS method, we conducted a case study at a Vietnamese company named HoanTech. HoanTech aims to establish an e-commerce website for the sale of mobile phones and accessories. They have chosen an open-source e-commerce platform to gain greater flexibility and control over their online store. HoanTech Corporation is presented with three alternatives for the development of its website, namely WooCommerce, OpenCart, and Magento. Each of these platforms offers unique characteristics and functionalities, catering to different business needs. WooCommerce, a WordPress plugin, is widely known for its user-friendly interface and extensive customization options, making it particularly suitable for small to medium-sized enterprises (SMEs) seeking simplicity and scalability. OpenCart, on the other hand, provides a robust and lightweight solution with a focus on performance, offering a variety of extensions and themes for businesses with specific functional requirements. Magento, recognized for its enterprise-level capabilities, excels in handling high volumes of transactions and offers advanced features such as multi-store management and extensive integrations. A detailed understanding of these platforms' distinct attributes would provide valuable context for interpreting the results of the evaluation and the rankings derived from the proposed framework.

The decision-making process requires objectivity and the active involvement of all relevant stakeholders. The primary goal of evaluating alternative OSS options is to provide managers with detailed insights and feedback, supporting the CEO in selecting the most suitable OSS solution. However, the current evaluation approach is often seen as overly formal, lacking both precision and objectivity. The inaccuracy stems from the absence of standardized criteria and a reliable evaluation method. As a result, developing a scientific evaluation approach that delivers objective and accurate results is crucial.

During the evaluation phase, an inclusive panel of 8 participants was assembled, encompassing four members from the Information Technology department, one Chief Executive Officer, a representative from the accounting department, and two representatives from the sales department. All evaluators have a group discussion and investigate OSS alternatives and related documents before making decision. The fuzzy ratings for linguistic variables (as in Table 14) are utilized in this phase.

Table 14: Fuzzy ratings corresponding to linguistic variables

Numerical rating	Linguistic variable
(1, 1, 3)	Very low (VL)
(1, 3, 5)	Low (L)
(3, 5, 7)	Average (A)
(5, 7, 9)	High (H)
(7, 9, 9)	Very high (VH)

The fuzzy TOPSIS method is applied to process the collected data. The combined decision matrix is presented in Table 16 and is subsequently normalized by dividing each decision value by the highest value within its respective category. The fuzzy normalized decision matrix and the weighted normalized fuzzy decision matrix, respectively. The distances of each alternative from the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) are outlined in Tables 18 and 19. To determine the ranking of OSS alternatives, the relative closeness coefficient (CC) of each option to the ideal and negative-ideal solutions is calculated, with alternatives ranked based on CC values, where a higher CC indicates a more suitable OSS. The results in Table 20 reveal that Magento is the most suitable option, achieving the highest CCi value of 0.991.

Table 15: Combined decision matrix

	C11	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C31**	**C32**	**C33**	**C34**	**C41**	**C42**	**C43**
WooCommerce	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(3,5,7)
OpenCart	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)	(7,9,9)	(7,9,9)	(3,5,7)
Magento	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)

Table 16: Distance from FPIS

	C11	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C31**	**C32**	**C33**	**C34**	**C41**	**C42**	**C43**	**di***
WooCommerce	0.875	1.054	0.875	0.554	0.967	0.549	0.318	0.756	0.755	0.585	0.338	0.804	0.804	0.742	1.168	0.248	11.393
OpenCart	0	0	0	0	0	0.183	0	0	0	0	0	0.268	0	0	0	0.248	0.7
Magento	0.011	0.01	0.014	0.004	0.009	0	0.006	0.01	0.008	0.003	0.005	0	0.006	0.005	0.014	0	0.105

Table 17: Distance from FNIS

	C11	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C31**	**C32**	**C33**	**C34**	**C41**	**C42**	**C43**	**di-**
WooCommerce	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OpenCart	0.875	1.054	0.875	0.554	0.967	0.366	0.318	0.756	0.755	0.585	0.338	0.536	0.804	0.742	1.168	0	10.693
Magento	0.874	1.054	0.875	0.554	0.966	0.549	0.318	0.755	0.755	0.585	0.338	0.804	0.804	0.742	1.167	0.248	11.389

Table 18: The rank of OSS alternatives

	CC_i	Rank
WooCommerce	0	3
OpenCart	0.938574	2
Magento	0.990825	1

The research results in Table 17 show the rankings of WooCommerce, OpenCart, and OpenCart based on the experts' evaluation when comparing each criterion from C11 to C43. The results show that Magento is rated the highest, followed by OpenCart, and finally WooCommerce, especially the CCi index of WooCommerce, which is still 0. This result shows the surprise in this research, so two experts, IT Director, and Chief Executive Officer, were invited to participate in the interview to confirm the authenticity of the results. Finally, both experts concluded that the results in Table 17 are entirely reasonable when all the evaluated criteria of WooCommerce are very poor.

DISCUSSION

The analysis results using the fuzzy AHP method show that System Quality (C1) plays the most important role among the evaluated criteria, while Service Quality (C3) has a lower level of importance. This result reflects that when considering the adoption of open-source software (OSS), factors related to system quality have a more significant impact than factors related to service quality. Among the sub-criteria, IT Infrastructure (C42) is the factor that has the most significant influence on adopting OSS, with the highest weight of 0.814. This suggests that the ability to deploy, maintain, and operate an OSS system depends heavily on the level of development of IT infrastructure, such as hardware, network, and system integration capabilities [12], [13], [15], [16]. In contrast, the factor with the lowest influence on OSS adoption is Reusability (C22), while studies by Sarrab and Rehman (2014); Yaseen et al. (2020) all show the influence of this factor. This result indicates that although the ability to reuse source code and software components is an important feature of open-source software, it is not a key factor in adopting OSS compared to other factors such as IT infrastructure or system quality. These findings highlight the important role of technology infrastructure in driving open-source software adoption while suggesting that service and reusability factors have a lower influence on the decision-making process. Organizations and businesses considering OSS implementation should focus on improving and investing in IT systems to maximize the benefits of OSS (Lenarduzzi et al. 2020; Sarrab and Rehman 2014; Ven et al. 2008; Zaidan et al. 2015). The analysis results show that Magento is the highest-rated among open-source e-commerce platforms, followed by OpenCart and WooCommerce. Notably, the CCi index of WooCommerce remains at 0, indicating that WooCommerce performs very poorly compared to the other two platforms. This result suggests that WooCommerce may not be a suitable choice compared to Magento and OpenCart in the context of the current evaluation criteria. Organizations or businesses need to carefully consider their specific requirements before selecting the appropriate e-commerce platform, especially when WooCommerce may not be able to meet the important criteria in this study. At the same time, this finding also opens up further research into the reasons for WooCommerce's low rating, which may include system performance, customization capabilities, or technological limitations compared to the other two platforms.

CONCLUSION

The dissemination of OSS within corporate environments has been shaped by a range of factors that could be perceived either as impediments or catalysts in the process of adoption. This research employs the integrated Fuzzy-AHP-TOPSIS model to construct an evaluation framework for selecting open-source software. Specifically, this study employed the FUZZY AHP method to examine the importance levels of criteria for enterprises when adopting OSS. Alongside the OSS evaluation hierarchy identified by fuzzy AHP, fuzzy TOPSIS has been employed to select what is arguably the most suitable open-source software for an e-commerce website available in the market today. The framework facilitates the assessment of objects based on various criteria while mitigating the subjectivity inherent in human evaluations. An application of the model has been implemented in the context of Vietnam. The ranking results indicate that Magento is the most suitable, followed by OpenCart and WooCommerce, respectively. This paper has provided valuable contributions not solely to the academic community but also to the community of practitioners. The hierarchical framework for selecting OSS, delineated within this paper, serves as a guiding model for Chief Information Officers (CIOs) or managers confronted with the challenge of choosing open-source software. This framework is a product of comprehensive consideration of relevant literature. The essential criteria have been systematically identified, precisely defined, and underpinned by a rationale that reflects the multifaceted aspects of recent open-source software deployment. Moreover, the existing open-source software (OSS) selection hierarchy serves as a valuable reference for initially identifying the criteria essential in the selection of open-source software. Practitioners can utilize this model to assess their specific OSS portfolio, substituting the alternatives with their particular choices. Moreover, they have the flexibility to tailor the model by incorporating additional criteria, sub-criteria, or attributes to better align with their specific requirements. The provision of this hierarchical framework for OSS selection aims to streamline the process for readers, enabling them to save time and effort in scrutinizing critical aspects of software and making informed choices pertinent to their organizational needs.

Although this study has provided valuable insights, it is necessary to acknowledge some limitations that may affect the applicability and effectiveness of the proposed fuzzy AHP-TOPSIS integrated framework. First, combining fuzzy AHP and TOPSIS involves many complex computational steps, such as pairwise comparison, normalization, and defuzzification. Another important limitation is the assumption that the evaluation criteria are independent, while in reality, there may be interactions between these criteria. Furthermore, although this hybrid approach addresses uncertainty and improves decision-making accuracy, the results may not significantly differ from those of more straightforward methods such as pure AHP or pure TOPSIS.

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