Available online at : http://josi.ft.unand.ac.id/

Jurnal Optimasi Sistem Industri

| ISSN (Print) 2088-4842 | ISSN (Online) 2442-8795 |

Research Article

A Fuzzy Multi-Criteria Approach for Selecting Open-Source ERP Systems in SMEs Using Fuzzy AHP and TOPSIS

Dana Marsetiya Utama [a,*], Muhammad Faisal Ibrahim [b], Ahmed Nedal Abid Al Kareem Jabari [c]

[a] Department of Industrial Engineering, Universitas Muhammadiyah Malang, Malang, Indonesia
[b] Department of Logistics Engineering, Universitas International Semen Indonesia, Gresik, Indonesia
[c] Department of Mechanical Engineering, Palestine Polytechnic University, Hebron, Palestine

* Corresponding Author: dana@umm.ac.id

DOI: 10.25077/josi.v23.n2.p167-187.2024 **Submitted** : September 4, 2024; **Accepted** : November 28, 2024; **Published** : January 30, 2025

ABSTRACT

In a rapidly growing and competitive business era, selecting an open-source Enterprise Resource Planning (ERP) system is a critical step to support the efficiency and effectiveness of company operations. This research aims to propose an innovative methodology by integrating the fuzzy Analytical Hierarchy Process (fuzzy AHP) and fuzzy Technique for Order Preference by Similarity to the Ideal Solution (fuzzy TOPSIS) to improve the open-source ERP selection process. The method involves eight criteria and 26 sub-criteria to comprehensively evaluate 11 open-source ERP alternatives, specifically for SMEs in the transportation services sector in Indonesia. System quality has been identified as a critical factor in the selection of an open-source ERP system, with particular emphasis on aspects such as security and reliability. These sub-criteria are considered the most influential in determining the suitability of a system. The analysis further indicates that the 10th ERP alternative as the best choice, consistently outperforming others in meeting the defined criteria. Additionally, sensitivity analysis confirmed the robustness of this choice, demonstrating its stability and effectiveness despite changes in criteria weights. Beyond its practical implications for SMEs, this research contributes a versatile evaluation framework that can be adapted to other industries seeking effective ERP solutions. The findings emphasize the importance of structured decision-making in technology adoption, offering comprehensive and reliable guidance for organizations aiming to optimize their operations through open-source ERP systems. This study not only bridges a critical gap in ERP selection for SMEs but also establishes a methodological foundation for future research and applications across diverse industry sectors.

Keywords: Open-Source ERP, fuzzy AHP, fuzzy TOPSIS, SME, transportation service

INTRODUCTION

Enterprise Resource Planning (ERP) systems have transformed modern business by integrating various organizational processes into a unified framework [1]. These systems were initially developed to address the challenges of inventory management and resource planning. Furthermore, ERP systems have evolved into comprehensive tools for managing increasingly complex business operations [2], [3]. In today's rapidly changing market landscape, characterized by global competition and dynamic customer demands, the need for efficient and scalable ERP systems is more significant than ever [4], [5]. ERP systems offer significant advantages by enabling efficient operations, data integration, and better decision-making for small and medium-sized enterprises (SMEs) [6], [7]. In addition, a successful ERP implementation can drive business process automation and improve supply chain management, making it an essential factor for competitiveness in the digital economy [8], [9] ,10].

In recent decades, SMEs have driven Indonesia's rapid economic growth, creating jobs, local economic development, and national economic resilience [11], [12]. However, SMEs face several critical challenges, including inefficient inventory management, ineffective financial data, and ineffective supply chain activities, which often hinder their ability to scale up operations effectively. These challenges are especially pressing in the digital transformation era, where real-time data access and efficient operations are crucial to competitiveness [13]. Flexibility and cost efficiency make open-source ERP systems appealing to Indonesian SMEs [14]. Open-source ERP solutions allow SMEs to customize features based on their operational needs and industry scale, overcoming challenges such as limited budgets and diverse operational requirements [15]. Open-source ERP systems allow SMEs to customize features based on their operational needs and industry scale, overcoming budget constraints and diverse operational requirements [16]. Open-source ERP's strong community support promotes knowledge exchange and quick troubleshooting, helping SMEs overcome technical implementation barriers. This approach supports technological independence, allowing SMEs to develop in-house expertise and reduce vendor costs [15]. Open-source ERP systems help SMEs improve operational efficiency, competitiveness, and adaptability in a fast-changing business environment [16].

In modern business, ERP system selection for operational efficiency and long-term success is a necessity that needs to be met [17]. ERP system selection for SMEs is critical as they have limited budgets and resources [18]. SMEs prefer open-source ERP systems because these systems have low license fees and flexibility to meet their operational needs [15]. In contrast to licensed ERP systems, this system allows SMEs to customize and configure the software to meet their unique business needs. The engaged and cooperative open-source developer community facilitates the rapid evolution and updates of systems through technological advancements, making these systems indispensable for SMEs that aspire to compete in a dynamic market [16]. As a result, Multi-Criteria Decision Making (MCDM) is indispensable for managing the intricacies of selecting an open-source ERP system [19]. This method allows SMEs to thoroughly evaluate ERP alternatives by considering cost, functionality, scalability, and integration [20], [21]. Through MCDM, SMEs can identify ERP solutions that optimally align with their strategic and operational requirements [21], [22], [23].

In fact, MCDM models have become a common practice to support decision-making in various [24]-[30]. Several studies have explored the application of MCDM in the context of ERP system selection. Hinduja and Pandey [31] presented a hybrid fuzzy MCDM model that includes DEMATEL, IF-ANP, and IF-AHP models to assess and select cloud-based ERP systems, especially for small and medium-sized enterprises. The results show that the proposed fuzzy MCDM model can effectively address the complexity problem in ERP system selection. Meanwhile, Jafarnejad et al. [32] proposed an MCDM model that includes DEMATEL techniques and fuzzy AHP techniques to solve ERP system selection problems, especially in the context of the steel industry. This study used the Shannon entropy technique to identify the most critical criteria in ERP selection. Park and Jeong [28], in another study, combined Quality of Service (QoS) with an MCDM model for SaaS ERP applications with Social Networks, providing helpful guidance for finding a suitable SaaS ERP system based on correlation with set criteria. In addition, several studies highlighted the sensitivity of the ERP system selection area to uncertain environments, especially in a volatile economy [33].

On the other hand, research by Naveed et al. [34] proposed a group decision-making (GDM) AHP model to evaluate and rank the critical success factors of cloud ERP systems, considering five alternatives and 20 sub-criteria in the decision-making process. Correspondingly, Amirkabiri and Rostamiyan [35] developed an MCDM model for evaluating and selecting ERP systems, using AHP to obtain essential and relatively weighted criteria. Finally, Uddin et al. [36] utilized an AHP-TOPSIS integrated model based on multi-criteria investigation to select the best ERP system. Thus, these studies significantly contributed to developing MCDM approaches for ERP system selection,

 DOI:10.25077/josi.v23.n2.p167-187.2024

covering aspects such as uncertainty, complexity, and sensitivity to the changing business environment. Furthermore, Gürbüz et al. [37] present an integrative approach that utilizes Measuring Attractiveness with a Categorical-Based Evaluation Technique, ANP, and Choquet integral. An ERP system selection procedure based on grey rationale based on fuzzy ANP was offered by Ayağ and Yücekaya [38]. In addition, Kazancoglu and Burmaoglu [39] applied the TODIM method in selecting ERP software for steel and galvanized companies. Several other methods have also been offered for selecting proprietary ERP systems, including Intuitionistic Fuzzy Information [3], AHP [[40], DEMATEL and fuzzy AHP [32], Fuzzy AHP and TOPSIS [41], [42], fuzzy SWARA-COPRAS [43], and AHP-TOPSIS [35], [36], [44]. Research in ERP system selection shows the diversity of MCDM approaches, especially in the context of proprietary ERP system selection. Although many efforts have been made to understand and select ERP systems, it is unfortunate that few studies have specifically addressed the selection of open-source ERP systems. In this framework, the research by Tasnawijitwong and Samanchuen [16] is one exception, which proposes an AHP procedure to guide the selection of open-source ERP systems. Although this research makes a valuable contribution, it should be noted that the availability of MCDM procedures for open-source ERP system selection is still minimal. Therefore, a research gap must be filled to understand better and develop more extensive and effective MCDM methods in open-source ERP system selection.

Various MCDM approaches have been explored in research on ERP system selection, with a particular emphasis on licensed ERP systems. However, there remains a need for additional literature focusing on the selection of open-source ERP systems, which offer distinctive advantages to resource-constrained organizations like SMEs [16]. Several studies on open-source ERP selection have attempted to address this issue by identifying various MCDM and fuzzy-based approaches to manage complexity and uncertainty in decision-making [45]. Notable procedures include a combination of DEMATEL, IF-ANP, and IF-AHP methods [31], as well as AHP [16], a combination of BWM and VIKOR [46], and a hybrid AHP-TOPSIS model [36]. Additionally, other methodologies have been proposed, such as integrating Pythagorean Fuzzy Set, Simple Additive Weighting, and VIKOR [47], along with the Rough Best Worst Method and Weighted Sum-Product [48]. These approaches provide practical solutions for efficiently evaluating and selecting open-source ERP systems.

Although various studies have made important contributions to ERP system selection, a significant weakness of previous research is its limitation in dealing with vagueness or uncertainty, particularly in the context of open-source ERP systems. Most previous studies use crisp or definite information, which poorly reflects the reality of complexity and uncertainty in open-source ERP development. These uncertainties include aspects such as the system's flexibility, the degree of adaptation to the organization's specific needs, and the dynamics of the role of the developer community. Moreover, previous research is still limited in exploring the integration of MCDM methods to address specific challenges in open-source ERP selection [49], [50]. These challenges include uncertainty in open-source development, the need for high flexibility, and the importance of the developer community's contribution as a key element in the success of open-source ERP implementation. This indicates the need for a more comprehensive approach that integrates MCDM methods to handle uncertainty and considers flexibility and the role of the developer community.

To address the research gap, this study aims to develop a new framework that integrates the MCDM method with a fuzzy-based approach in selecting open-source ERP systems in SMEs. This research proposes an MCDM procedure for open-source ERP system selection, addressing SMEs' unique challenges in Indonesia. SMEs often need more certainty and complexity in ERP system selection due to limited technical expertise, resource constraints, and the need to align software functionality with specific business processes. To tackle these challenges, this study integrates two decision analysis techniques: the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The proposed procedure leverages Fuzzy AHP to handle

subjective aspects and uncertainty in assessing ERP system selection criteria. This approach allows decision-makers to express preferences using fuzzy sets, which account for vagueness and variability in judgments [32]. The results of Fuzzy AHP are then integrated with TOPSIS to rank open-source ERP system alternatives based on their relative suitability. This integration enables a robust and systematic evaluation process that minimizes the impact of uncertainty while providing realistic and accurate recommendations for SMEs [35]. The proposed framework addresses the complexity of ERP system selection. It offers practical value for SMEs, enabling them to navigate technical and operational constraints effectively. It provides a holistic approach that aligns decision-making processes with the real-world needs of SMEs, ensuring the selection of an ERP system that supports their growth and competitiveness [41], [42].

This study significantly expands the criteria and sub-criteria for selecting an open-source ERP system. It addresses critical challenges SMEs face, such as resource limitations, operational scalability, and customization requirements in ERP implementation. Furthermore, it adds new insights by proposing an evaluation framework and offering a comprehensive approach to identify the most appropriate open-source ERP system by incorporating these new aspects. The proposed new framework integrating Fuzzy AHP and TOPSIS is implemented in the transportation service provider industry, which serves as a representative case for SMEs. The method proves effective in a real-world context, offering practical insights and actionable recommendations tailored to the needs of the industry. This approach directly addresses the shortcomings of previous research, which often focuses on proprietary ERP systems or requires comprehensive evaluation criteria for open-source alternatives. Essential insights for stakeholders include a systematic decision-making framework that reduces uncertainty, addresses multiple operational requirements, and aligns ERP system selection with strategic goals. This research improves the decision-making process by offering a model to implement when selecting open-source ERP systems for SMEs. It enables organizations to improve operational efficiency, reduce costs, and achieve greater competitiveness in their respective markets.

METHODS

A Based on the literature review, this research proposes an integrated method for open-source ERP system selection using Fuzzy AHP and TOPSIS approaches. This section describes the systematic stages of the proposed method, from criteria identification to ERP alternatives ranking, designed to address the challenges in ERP system selection for SMEs in Indonesia. This section systematically describes the proposed framework to support the selection process of open-source ERP systems in SMEs. This research integrates Fuzzy AHP and TOPSIS approaches as the primary methods. In addition, the data used in this research is obtained through literature review, focus group discussions with experts, and evaluation of open-source ERP alternatives. A case study of the application of these methods was conducted on a transportation service provider SME in Indonesia, which serves as a specific context to validate the proposed framework. The full details of this stage will be presented in the following sub-section.

The Proposed Integrated Fuzzy AHP-TOPSIS

This research methodology consists of four main stages: selecting an open-source ERP system and integrating the Fuzzy AHP and TOPSIS. The proposed method of choosing an open-source ERP system can be seen in Figure 1. The first stage is the Identification of criteria and sub-criteria for the selection of open-source ERP systems. In this stage, relevant criteria and supporting sub-criteria will be carefully defined to ensure completeness in evaluating ERP system alternatives. The second stage involves assessing the weights of these criteria and sub-criteria using fuzzy AHP. The use of fuzzy AHP allows for handling uncertainty and low levels of certainty in the decision-making process. This weight evaluation becomes the basis for determining the relative influence of each criterion on the selection of an open-source ERP system.

 DOI:10.25077/josi.v23.n2.p167-187.2024

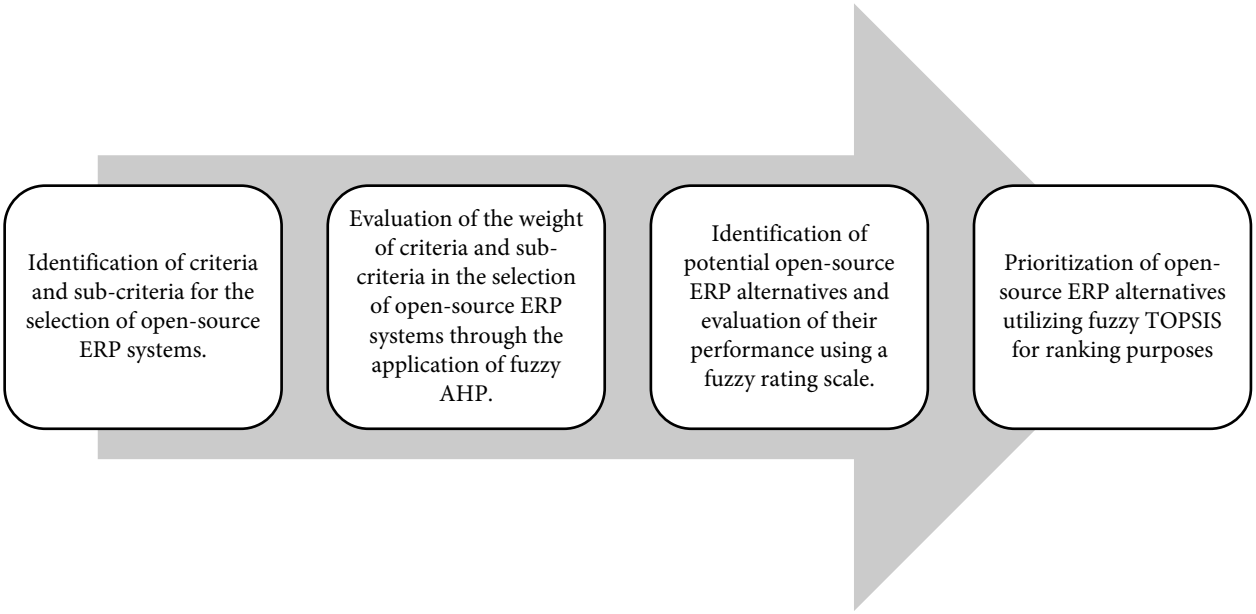

Figure 1. Proposed method of selecting an open-source ERP system

The third stage involves identifying potential open-source ERP system alternatives and evaluating their performance using a fuzzy rating scale. In this stage, each alternative will be assessed based on several predefined criteria and sub-criteria, considering the diverse levels of uncertainty that may occur. Finally, the fourth stage involves prioritizing open-source ERP system alternatives using fuzzy TOPSIS for ranking purposes. Each alternative will be compared with the ideal and harmful solutions to determine the priority order that best suits the predefined needs and preferences. Integrating fuzzy AHP and TOPSIS will provide more accurate and measurable results when selecting open-source ERP systems. Details of each stage of the Proposed Integrated Method in open-source ERP selection are presented in the following subsections.

Identification of Criteria and Sub-criteria for the Selection of Open-source ERP

The initial stage in the selection of open-source ERP systems begins with the process of identifying relevant criteria and sub-criteria. This process starts with a literature exploration to collect criteria and sub-criteria often used in selecting ERP systems, both open-source and licensed. The literature sources include previous studies, scientific articles, and industry reports on ERP system selection. From the results of this exploration, an initial list of criteria and sub-criteria was compiled as the basis for the assessment. To deepen and ensure the relevance of the criteria, a focus group discussion (FGD) was conducted involving experts from academia, industry practitioners, and ERP consultants. This discussion aimed to obtain diverse perspectives on the actual needs and priorities of open-source ERP selection. Experts provided assessments and inputs on the initial list of criteria and sub-criteria by considering the SME context and operational challenges faced.

In the discussion phase, the initial list of criteria obtained from the literature exploration was presented to the experts for in-depth evaluation. Each criterion and sub-criteria are evaluated based on its relevance, importance, and ability to support the open-source ERP selection process. If the criteria were less relevant, they were revised or eliminated. Conversely, new criteria that emerged from expert input were added to ensure the completeness of the evaluation framework. This process was conducted qualitatively through interactive discussions, resulting in consensus on the final criteria used in this study. This identification stage is the main foundation in developing the ERP selection method based on Fuzzy AHP-TOPSIS integration. With clearly defined criteria and sub-criteria, the proposed framework is highly reliable. It can be replicated in other industrial contexts.

Evaluation of the Weight of Criteria and Sub-criteria in Selecting Open-source ERP

In this part of the method, the weighting of criteria and sub-criteria selected for the selection of open-source ERP systems is carried out. The weighting is done using the Fuzzy AHP method. Fuzzy AHP is designed to overcome the weaknesses of the classic AHP procedure [26], [51], [52]. The main difference between AHP and Fuzzy AHP lies in replacing crisp values with fuzzy sets [53]. Previously, Fuzzy AHP has been successfully applied to solve various problems, such as software selection for performance analysis [54], [55] and supplier selection [25], [55]-[60].

In selecting proprietary ERP systems, Fuzzy AHP-TOPSIS has proven effective in ranking [41], [42]. Therefore, in this study, the proposed Fuzzy AHP procedure is adopted from the Fuzzy AHP methodology previously proposed by Kilic et al. [21]. This method was chosen to ensure the smoothness of the weighting process by utilizing the advantages of Fuzzy AHP in handling uncertainty and complexity in assessing criteria and sub-criteria. Thus, the detailed steps and procedures of this proposed Fuzzy AHP become the main foundation in the in-depth weighting analysis to support optimally selected open-source ERP systems. The weighting stages based on criteria and sub-criteria with the proposed fuzzy AHP are described as follows:

In the weighting of criteria and sub-criteria stage, the process begins by defining a *fuzzy pairwise comparison matrix* to represent the relative importance of the n criteria being compared against the objective of selecting an open-source ERP system. The values $\tilde{c}_{ij}$ and $1/\tilde{c}_{ij}$ in this matrix represent the relative importance between criteria i and j, respectively. The expert group ensures that the pairwise comparisons are based on a focused discussion for each criterion and sub-criteria. This pairwise comparison assessment uses a triangular fuzzy number scale, as listed in Table 1. This process provides a solid basis for generating an accurate fuzzy pairwise comparison matrix, which is then used to implement the Fuzzy AHP method to determine the weights of criteria and sub-criteria in selecting open-source ERP systems.

The Fuzzy AHP method selects open-source ERP systems in the Criteria Weighting step. This method involves the calculation of fuzzy weights for each criterion, which describes the level of importance of each criterion. One method used to obtain each criterion's fuzzy weights is the geometric mean method proposed by Buckley [61]. First, the geometric mean of the fuzzy comparison values of criterion I for each criterion is calculated using Equation (1). The utilization of AHP fuzzy weights with the geometric mean method in determining the importance of each criterion in the selection of open-source ERP systems has several significant advantages. This method provides a more accurate and controlled representation of the level of uncertainty in criteria assessment. By using the geometric mean of the fuzzy comparison values for each criterion, this method can overcome the uncertainty and complexity in the weighting process. In addition, this approach allows for more consistent and objective decision-making, as it captures the nuances of uncertainty that often occur in the subjective evaluation process. Next, the fuzzy weights of the i-th criterion, represented by triangular fuzzy numbers, are calculated with Equations (2) and (3). This approach aims to provide a more accurate representation of the level of importance of each criterion in the selection of open-source ERP systems.

Table 1. Variable Linguistic and Triangular Fuzzy Number of AHP

Code	Variable linguistic	Triangular Fuzzy Scale	Explanation
EI	Equal Importance	1,1,1	Equal contribution between two elements
MI	Moderate Importance	2,3,4	One element is more important than the other
SI	Strong Importance	4,5,6	One element is stronger than the other
VSI	Very Strong Importance	6,7,8	One element is more important than the other
EI	Extremely Importance	9,9,9	One element is absolutely more important than the other

 DOI:10.25077/josi.v23.n2.p167-187.2024

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{c}_{ij} \right)^{1/n} , i = 1,2, \dots, n \quad (1)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (2)$$

$$\tilde{w}_i = (lw_i, mw_i, uw_i) \quad (3)$$

The next step is to defuzzify the weights obtained in the fuzzy set. This process is carried out to convert the weights in the fuzzy set into crisp weights so that further comparisons can be made. According to research by Liu et al. **[53]**, one commonly used defuzzification method is the Center of Area (COA), or the centroid method. The main advantage of the COA method lies in its ability to produce a single value representing the center of mass of the fuzzy set. In the context of AHP, this procedure allows the conversion of fuzzy weights into crisp values, thus facilitating a direct comparison of criteria. The COA method is also intuitive and easy to understand, making it suitable for application in the context of open-source ERP system selection. COA's clarity of concept and ease of implementation make it an effective tool in addressing the complexity of criteria comparison in the context of Fuzzy AHP, thus positively facilitating a more structured and efficient decision-making process.

In the COA method, the nonfuzzy values M_i of fuzzy numbers $\tilde{w}_i$ can be calculated using Equation (4), where M_i is a nonfuzzy number, and the normalized weights N_i, are obtained through the normalization process. After obtaining each N_i, value, the global weights of all criteria M_i can be generated by multiplying the locally normalized criteria weights with the normalized weights of the corresponding dimensions. This process enables the acquisition of more concrete weights. It can be used to compare processes further when selecting open-source ERP systems.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad (4)$$

The weight evaluation process using Fuzzy AHP provides a more accurate and controllable representation of the importance of each criterion and sub-criteria in selecting open-source ERP systems. Thus, this method ensures more consistent and objective decisions, especially in conditions involving uncertainty and complexity of criteria assessment. The result of this stage is the priority weight for each criterion and sub-criteria, which will be used in the alternative evaluation stage using the Fuzzy TOPSIS method.

Identify Potential Open-source ERP Alternatives and Evaluate Their Performance

Potential open-source ERP system alternatives are identified in this stage, and their performance is evaluated using a fuzzy-based rating scale. This process begins with collaboration between managers, decision-makers, and a team of experts to determine a list of open-source ERP alternatives relevant to the company's needs and characteristics. The selection of these alternatives considers specific factors such as business scale, industry type, operational complexity, and resource limitations faced by SMEs.

Once the list of alternatives was determined, the performance evaluation process was conducted through FGDs involving experts. Experts are asked to provide an assessment of the performance of each open-source ERP alternative based on predetermined criteria and sub-criteria. This assessment is expressed in the form of linguistic variables, such as “Very Poor,” “Poor,” “Medium Poor,” “Fair,” “Medium Good,” “Good,” and “Very Good,” which are then converted into triangular fuzzy numbers. The linguistic scale and triangular fuzzy numbers are in Table 2.

This assessment is done for each criterion and sub-criteria on each alternative, which results in a fuzzy scoring matrix. This matrix represents the relative performance level of each open-source ERP system. This evaluation

Table 2. Variable Linguistic and Triangular Fuzzy Number for Performance Assessment

Variable Linguistic	Code	Triangular Fuzzy Number		
		Lower	Medium	Upper
Very Poor	VP	0	0	1
Poor	P	0	1	3
Medium Poor	MP	1	3	5
Fair	F	3	5	7
Medium Good	MG	5	7	9
Good	G	7	9	10
Very Good	VG	9	10	10

process is carried out to ensure that each alternative is comprehensively considered based on its actual performance against the criteria and sub-criteria. With the fuzzy rating scale approach, this method can capture uncertainty and variation in experts' perceptions, thus providing a more realistic and accurate representation of performance. The result of this stage is a fuzzy performance matrix that will be used as input to the TOPSIS calculation stage to determine the best open-source ERP alternative that best suits the needs of SMEs.

Prioritization of Open-source ERP Alternatives Utilizing Fuzzy TOPSIS

In ranking alternatives in the final stage of selecting an open-source ERP system, the fuzzy TOPSIS method is used. The basic concept of TOPSIS is that the desired alternative must have the shortest Euclidean distance from the positive ideal solution and the farthest distance from the negative ideal solution, where the positive ideal solution aims to minimize the cost criteria and maximize the benefit criteria [62]. In the context of this research, the application of fuzzy TOPSIS is carried out to rank alternatives in the open-source ERP system selection process. The fuzzy TOPSIS method used in this study follows the procedure proposed by Nădăban et al. [63]. The detailed steps of the fuzzy TOPSIS implementation will be described in the next section to provide a comprehensive understanding of ranking alternatives in selecting open-source ERP systems.

In prioritizing open-source ERP alternatives using the fuzzy TOPSIS method for ranking purposes, the first step involves determining the ranking value for each alternative. It is assumed that there is a decision group with k members, where the fuzzy ranking value of the k^{th} decision associated with alternative A_i against criterion C_j is represented by Equation (5).

$$\tilde{x}_{ij}^{k} = \left(a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}\right) \tag{5}$$

The second step in this research methodology involves calculating the aggregated fuzzy ratings for the alternatives. The aggregated fuzzy rating, denoted by $\tilde{x}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$, of the i^{th} alternative against the j^{th} criterion is obtained by applying Equation (6). This process involves aggregating the fuzzy values of each sub-criteria assessed previously. Using this approac, this research ensures a careful and thorough calculation to obtain the aggregated fuzzy rating, which will be the basis for the next step of prioritizing open-source ERP system alternatives using the fuzzy TOPSIS method.

$$a_{ij} = \min_{k}\left\{a_{ij}^{k}\right\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^{k}, c_{ij} = \max_{k}\left\{c_{ij}^{k}\right\} \tag{6}$$

The third step in this research methodology is to calculate the normalized fuzzy decision matrix. The normalized fuzzy decision matrix, denoted by $\tilde{R} = \left[\tilde{r}_{ij}\right]$, can be seen in Equations (7) and (8). This process aims to compile a

 DOI:10.25077/josi.v23.n2.p167-187.2024

decision matrix that can provide a more accurate representation of the relative weights of each criterion and sub-criteria that have been assessed so that it can be used effectively in the fuzzy TOPSIS calculation process to determine the priority and ranking of the evaluated open-source ERP system alternatives.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max_i \{c_{ij}\} \text{ (benefit criteria)} \tag{7}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ and } c_j^- = \min_i\{a_{ij}\} \text{ (cost criteria)} \tag{8}$$

The fourth step in this research methodology is to calculate the weighted normalized fuzzy decision matrix. This normalized fuzzy decision matrix, denoted as $\tilde{V} = (\tilde{v}_{ij})$, can be formulated using Equation (9). The weights w_j in this matrix are generated from the AHP fuzzy weighting process described in the previous section. This process involves normalizing the fuzzy weights obtained from fuzzy AHP to produce a decision matrix that reflects the relative importance of each criterion and sub-criteria in selecting open-source ERP systems.

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j \tag{9}$$

The fifth step in this method is to calculate the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS). FPIS and FNIS can be calculated based on Equations (10) and (11). This calculation aims to determine the positive and negative ideal solutions for evaluating open-source ERP systems. FPIS reflects the maximum desired value for each criterion, while FNIS reflects the minimum acceptable value. This step provides a foundation for measuring the extent to which each open-source ERP alternative approaches the positive ideal solution and how far it is from the negative ideal solution.

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \cdots, \tilde{v}_n^*) \text{ where } \tilde{v}_j^* = \max_i\{v_{ij3}\} \tag{10}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \cdots, \tilde{v}_n^-) \text{ where } \tilde{v}_j^- = \min_i\{v_{ij1}\} \tag{11}$$

The sixth step in this research is to calculate the distance from each alternative to FPIS and FNIS. The distance of each alternative can be calculated using Equation (12). Suppose is the distance from each alternative to FPIS and FNIS, respectively. This calculation process allows for determining how far each alternative is from the positive and negative ideal solutions in the context of Fuzzy TOPSIS. This step will obtain essential information for ranking open-source ERP alternatives based on previously identified criteria.

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \tag{12}$$

The seventh step in this methodology is to calculate the closeness coefficient (CC) for each alternative (CC_i) using Equation (13). This closeness coefficient is calculated for each alternative $((A_i)$ based on Equation (13). This calculation process measures the extent to which each alternative approaches the ideal solution in the context of open-source ERP system prioritization. By calculating this closeness coefficient, we can assign a relative ranking to each alternative, which will help determine its priority order in selecting open-source ERP systems. This method provides a systematic and measurable framework for evaluating and ranking the alternatives.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \tag{13}$$

The eighth step in this research is to prioritize the open-source ERP system alternatives using the Fuzzy TOPSIS method for ranking purposes. This process involves determining the closeness coefficient of each alternative. This

closeness coefficient reflects the extent to which an alternative is close to the ideal solution. The alternative with the highest closeness coefficient value is considered the best.

Case Application

This research focuses on a case study of open-source ERP system selection within an SME transportation service provider in Gresik City, Indonesia. The study involved collaboration with eight experts, including industry practitioners and academics. These experts played an important role in various research stages, including identifying criteria and sub-criteria, pairwise comparison assessment for criteria and sub-criteria, and performance evaluation of each open-source ERP system alternative considered in this study. The research began with an in-depth literature review on ERP system selection to identify relevant criteria and sub-criteria. The literature includes research addressing ERP system selection in general and open-source systems. This literature review resulted in an initial list of criteria frequently used in related research. Next, a focus group discussion (FGD) was conducted with experts to validate the initial list of criteria. These discussions identified the most relevant criteria and sub-criteria. They are classified into eight main criteria, with 26 sub-criteria, as shown in Table 3.

In the next stage, open-source ERP system alternatives were comprehensively identified. Through FGDs, experts successfully identified 11 open-source ERP alternatives relevant to be applied in the context of SMEs providing transportation services. The identified alternatives include: Adempiere (Alternative 1), Axelor (Alternative 2), Dolibarr (Alternative 3), EasyERP (Alternative 4), ERP5 (Alternative 5), ERPNext (Alternative 6), iDempiere (Alternative 7), Metasfresh (Alternative 8), MixERP (Alternative 9), Odoo (Alternative 10), and OFBiz (Alternative

Table 3. Criteria and Sub-criteria Selection of Open-source ERP

Main Criteria	Code	Sub Criteria	ID
Cost	Co	Consultant and implementation cost	Co1
		Support and maintenance cost	Co2
		Hosting cost	Co3
Functionality and Integration	FI	Number of free modules	FI1
		Availability of third-party modules	FI2
		Accommodating business processes	FI3
		Integration with satellite-based navigation system	FI4
		Integration level between modules	FI5
Time and Availability	TA	Update availability history	TA1
		Implementation time	TA2
Usage and Support	US	User-friendliness	US1
		Online help and tutorials	US2
		User Training and Adoption	US3
Data Management	DM	Ease of data migration	DM1
		Ease of maintenance	DM2
		Ease to customization	DM3
Reputation and Strategy Vendor	RS	Brand image	RS1
		Sustainability	RS2
		Potential for future strategy	RS3
System Quality	SQ	System reliability	SQ1
		Security	SQ2
		Reporting and Analytics	SQ3
		Data Backup and Disaster Recovery	SQ4
Integration and Scalability	IS	Multilingual and Multicurrency Support	IS1
		Mobile Access	IS2
		Cross module integration	IS3

 DOI:10.25077/josi.v23.n2.p167-187.2024

11). This identification process involved an in-depth analysis of each alternative's characteristics, advantages, and disadvantages. Furthermore, the performance assessment of each alternative open-source ERP system was also conducted through a series of focus group discussions to ensure that the selection was holistic and evidence-based. This identification process is done through an in-depth analysis of each ERP alternative's characteristics, advantages, and disadvantages. Furthermore, the performance evaluation of each ERP alternative is carried out using a fuzzy rating scale based on eight main criteria and 26 predetermined sub-criteria. This assessment is conducted in a series of FGDs to ensure the selection process is holistic, structured, and evidence based. Each alternative is assessed using a linguistic scale converted into triangular fuzzy numbers, as described in Table 2. This process produces a fuzzy scoring matrix that represents the relative performance of each alternative against the relevant criteria and sub-criteria.

RESULTS AND DISCUSSION

The Weight of Selection Criteria and Sub-criteria

In the results of this study, the weighting of criteria and sub-criteria for the selection of open-source ERP systems have been revealed using the Fuzzy AHP method. Table 4 presents the results of weighting criteria and sub-criteria

Table 4. Weighting Criteria and Sub-criteria for ERP System Selection

Criteria	Criteria Weight	Sub-criteria	ID	Local Weight	Global Weight	Rank
Cost	0.141	Consultant and implementation cost	CO1	0.084	0.012	22
		Support and maintenance cost	CO2	0.472	0.066	5
		Hosting cost	CO3	0.444	0.063	6
Functionality and Integration	0.127	Number of free modules	FI1	0.470	0.060	7
		Availability of third-party modules	FI2	0.156	0.020	16
		Accommodating logistics service business processes	FI3	0.039	0.005	25
		Integration with satellite-based navigation system	FI4	0.038	0.005	26
		Integration level between modules	FI5	0.297	0.038	11
Time and Availability	0.071	Update availability history	TA1	0.799	0.056	9
		Implementation time	TA2	0.201	0.014	21
Usage and Support	0.041	User-friendliness	US1	0.365	0.015	19
		Online help and tutorials	US2	0.486	0.020	14
		User Training and Adoption	US3	0.148	0.006	23
Data Management	0.248	Ease of data migration	DM1	0.388	0.096	3
		Ease of maintenance	DM2	0.380	0.094	4
		Ease to customization	DM3	0.232	0.057	8
Reputation and Strategy Vendor	0.033	Brand image	RS1	0.159	0.005	24
		Sustainability	RS2	0.506	0.016	18
		Potential for future strategy	RS3	0.454	0.015	20
System Quality	0.254	System reliability	SQ1	0.382	0.097	2
		Security	SQ2	0.387	0.098	1
		Reporting and Analytics	SQ3	0.078	0.020	15
		Data Backup and Disaster Recovery	SQ4	0.153	0.039	10
Integration and Scalability	0.087	Multilingual and Multicurrency Support	IS1	0.393	0.034	13
		Mobile Access	IS2	0.209	0.018	17
		Cross module integration	IS3	0.420	0.036	12

along with their weights, which help illustrate the level of importance of each factor in the overall context of ERP system selection. The main criteria, such as Cost, Functionality and Integration, Time and Availability, Usage and Support, Data Management, Vendor Reputation and Strategy, System Quality, and Integration and Scalability, have weights that reflect priorities in decision-making. The weighting analysis shows that System Quality and Data Management have significant weights of 0.254 and 0.248, emphasizing the importance of system quality and effective data management in ERP system selection. In addition, security emerged as a critical factor, with the highest global weight of 0.098. It indicates that these aspects should be the main focus of ERP system evaluation.

System quality is a key criterion in selecting open-source ERP systems for SMEs due to its crucial role in ensuring functionality, reliability, and ease of maintenance. For resource-constrained SMEs, a quality system provides the ability to manage complex business processes effectively and efficiently at a cost that remains affordable [64]. In addition, system quality contributes directly to ERP implementation success through ease of configuration, reliability, and stability in operation [15]. For SMEs, quality open-source systems also offer greater flexibility in customizing system functionality to their specific business needs, which becomes a competitive advantage over licensed systems [65]. Furthermore, the system quality advantage accelerates operational efficiency through better data integration, reduction of manual processes, and improved information accuracy. Thus, a quality open-source ERP system not only supports smooth operations but also ensures sustainable business competitiveness in the long run [66].

The significant weight of data management of 0.248 indicates the urgency of the need for effective data management in the context of ERP system selection. Good data management is fundamental to successfully implementing and operating ERP systems, given that SMEs often have limited resources. The Data Management criterion is key in selecting an open-source ERP system for SMEs because it ensures the integration, accuracy, and availability of information that supports business decision-making. Good data integration between departments enables SMEs to respond to market dynamics faster and be more adaptive to changing customer demands [14]. Data management's efficiency supports cost savings and minimizes the duplication of processes, which is often an obstacle for companies with limited resources [67]. The ability of ERP systems to improve supply chain transparency and resource management helps SMEs create more controlled and accountable business operations. In addition, flexibility in data management allows SMEs to scale operations according to the needs of sustainable growth in the future [68].

Furthermore, the finding that security is the critical factor with the highest global weight, 0.098 respectively, provides an in-depth understanding of the aspects that should be the main focus in ERP system evaluation. The high weight for security reflects the urgent need to protect sensitive data and secure system integrity. On the other hand, the highest weighted system quality indicates that SMEs must ensure that the selected ERP system has high features and performance to support their business operations properly. This finding is consistent with the paradigm shift in ERP system selection that considers cost factors and prioritizes critical aspects such as data management, security, and system quality. In an increasingly complex digital era, sustainability and agility in data management are crucial to success. At the same time, security and system quality are essential foundations to support business growth and development.

It is also important to note that the sub-criteria analysis identified security (SQ2) and reporting and analytics (SQ1) as the highest globally weighted sub-criteria, almost equally important in ERP system selection. On the other hand, sub-criteria such as multilingual and multicurrency support and integration with satellite-based navigation systems have the lowest global weights, indicating a lower level of relevance in the overall context. As an important note, ease of maintenance (DM2) emerges as a sub-criterion with a relatively high global weight of 0.094, indicating that the ease of maintenance of ERP systems has a high significance to the organization. In the context of cost, support and maintenance cost (CO2) is a primary consideration with a significant global weight of 0.066, indicating that this aspect is essential in calculating ongoing costs after system implementation.

 DOI:10.25077/josi.v23.n2.p167-187.2024

The finding that security (SQ2) and reporting and analytics (SQ1) have the highest global weights reflects the urgency of these aspects in selecting an ERP system. Security is a top priority, in line with the increasing digital security threats faced by organizations today. The continuity and integrity of data in the system are foundations that must be strictly maintained to protect sensitive information and user privacy. Security is a top priority in selecting open-source ERP systems for SMEs due to the increasing risk of data leakage and cyber-attacks that can significantly impact business operations [69]. A high level of security protects the integrity of operational and financial data, ensures smooth business processes, and builds customer trust as a critical asset for business sustainability [70]. Moreover, good data protection supports regulatory compliance. It enhances business competitiveness in the digital era, where transparency and data security are key demands [71]. Security factors are closely related to system qualities such as flexibility and data integration. While initial implementation costs can be minimized, system security and reliability have a more significant impact on supporting long-term operational efficiency than just initial cost savings [72].

Meanwhile, the sub-criteria with the lowest global weights, such as multilingual and multicurrency support and integration with satellite-based navigation systems, suggest that these elements have a lower impact on achieving the primary goal of ERP system selection. Multilingual and Multicurrency Support criteria tend to be ranked lower in the selection of open-source ERP systems for SMEs because the main focus of SMEs is operational efficiency and meeting basic business needs such as data integration, security, and ease of use [71]. Most SMEs operate within a local or regional scope, making the need for multilingual and multicurrency features less relevant than core functionality aspects. In addition, SMEs often have limited resources and prioritize low-cost and quick implementation. While these features are essential for global companies, SMEs targeting domestic markets rarely need this added complexity [72].

Ease of maintenance (DM2), which has a relatively high global weight, indicates that this aspect has great significance in maintaining the performance and availability of the ERP system. Ease of maintenance is closely related to operational efficiency and can minimize downtime that can harm organizational productivity. In the context of costs, the emphasis on support and maintenance costs (CO2) as a primary consideration with a significant global weight indicates that organizations place finance as a major factor in calculating ongoing costs after system implementation. It could be due to a desire to optimize spending and ensure that support and maintenance-related costs are controlled over time.

Alternatives Open-source ERP System

The results show that the score for each alternative open-source ERP system is obtained through the normalization of the closeness coefficient value, which is presented in Table 5. From the results of these calculations, it was found that Alternative 10 was ranked highest with a normalized value of 0.130. It shows that Alternative 10 has the most optimal performance compared to other alternatives based on predetermined criteria and sub-criteria, followed by Alternative 6, which is ranked second with a normalization value of 0.100. In contrast, Alternative 9 is ranked the lowest, with a normalized value of 0.067. This finding provides a strong indication regarding the suitability of Alternative 10 as the most suitable open-source ERP system to be implemented in the context of SMEs. In contrast, Alternative 9 tends to be less appropriate. This assessment helps provide a more transparent and objective picture of the open-source ERP system selection process, enabling more informed decision-making.

Odoo (alternative 10) outperforms other open-source ERP systems due to its high flexibility, robust system quality, and continuously improved security, making it an ideal solution for SMEs. Odoo (alternative 10) offers modularity that allows SMEs to select and customize features according to specific needs, ranging from inventory management to accounting, making it more cost-efficient to implement [73]. With its user-friendly interface and ease of

Table 5. Rank of Alternative Open-source ERP System based-on Fuzzy TOPSIS

Alternative	d^*	d^-	CC_j	Normalization	Ranking
Alternative 1	0.413	0.417	0.503	0.088	6
Alternative 2	0.434	0.407	0.484	0.085	7
Alternative 3	0.393	0.447	0.532	0.093	4
Alternative 4	0.440	0.400	0.476	0.083	9
Alternative 5	0.440	0.402	0.477	0.083	8
Alternative 6	0.358	0.473	0.569	0.100	2
Alternative 7	0.373	0.454	0.549	0.096	3
Alternative 8	0.442	0.401	0.475	0.083	10
Alternative 9	0.520	0.325	0.384	0.067	11
Alternative 10	0.211	0.612	0.743	0.130	1
Alternative 11	0.395	0.442	0.528	0.092	5

configuration, Odoo (alternative 10) can be implemented faster, reducing complexity for SMEs with limited resources [73]. In Indonesia, where cost efficiency is a top priority, Odoo, an open-source solution without license fees, supports small business sustainability with more affordable local support [74]. Moreover, Odoo's scalability (alternative 10) allows the system to evolve as SMEs grow, meeting the challenges of dynamic operational needs [74].

MixERP (Alternative 9) showed low performance in the open-source ERP system selection due to weaknesses in critical areas, especially in system security and quality. The system has limited security features, making it vulnerable to data leakage and cyberattacks. It is a significant concern for SMEs with limited resources. In addition, MixERP's system quality is considered less reliable regarding operational stability and data integration, causing obstacles in efficiently supporting complex business processes. These weaknesses make MixERP less suitable for SMEs that need a flexible, secure, and reliable ERP solution for sustainable growth.

Sensitivity Analysis

A sensitivity analysis was conducted to test the robustness of the ranking of open-source ERP systems in terms of changes in the weights of criteria and sub-criteria in three different scenarios, as presented in Table 6. This analysis aims to understand how criteria prioritization variations, such as an increased focus on cost or user-friendliness, affect the ranking of ERP system alternatives and ensure solution flexibility in the face of changing SME needs. In the first scenario, criteria weights are evenly distributed, emphasizing cost. In contrast, the second scenario increases system quality and security weights. Meanwhile, the third scenario prioritizes criteria related to flexibility and the availability of additional features such as user-friendliness and module integration.

The analysis results show Alternative 10 consistently maintains the highest ranking in all three scenarios with the highest closeness coefficient value. It confirms its flexibility and adaptability to changes in criteria focus, making it the most reliable choice for SMEs. In contrast, Alternative 6 showed competitive performance with stability in the second rank. At the same time, Alternative 9 remained in the lowest position, mainly due to weaknesses in security aspects and the availability of additional features. Changes in criteria weights, such as increased user-friendliness or cost-efficiency prioritization, resulted in significant ranking variations among the alternatives. It provides practical insight for SMEs that ERP system selection should consider criteria flexibility as priorities change over time. This sensitivity analysis allows SMEs to evaluate the impact of evolving strategic needs and ensure the selected ERP solution remains relevant and effective. Figure 2 presents a graphical visualization of the sensitivity analysis results to clarify the ranking changes between scenarios. This visualization shows the ranking shifts that occur under

 DOI:10.25077/josi.v23.n2.p167-187.2024

Table 6. Scenario Sensitivity Analysis of Open-source ERP System Selection

Sub-criteria ID	Sub-criteria	Scenario 1		Scenario 2		Scenario 3	
		Global Weight	Rank	Global Weight	Rank	Global Weight	Rank
CO1	Consultant and implementation cost	0.011	23	0.010	22	0.000	17
CO2	Support and maintenance cost	0.059	4	0.053	7	0.000	17
CO3	Hosting cost	0.055	7	0.050	8	0.000	17
FI1	Number of free modules	0.059	5	0.072	5	0.167	1
FI2	Availability of third-party modules	0.019	20	0.024	15	0.055	7
FI3	Accommodating logistics service business processes	0.005	25	0.006	25	0.014	15
FI4	Integration with satellite-based navigation system	0.005	26	0.006	26	0.014	16
FI5	Integration level between modules	0.037	15	0.045	10	0.105	3
TA1	Update availability history	0.100	1	0.068	6	0.158	2
TA2	Implementation time	0.025	18	0.017	20	0.040	12
US1	User-friendliness	0.046	14	0.018	18	0.042	10
US2	Online help and tutorials	0.061	3	0.024	14	0.056	6
US3	User Training and Adoption	0.019	22	0.007	23	0.017	13
DM1	Ease of data migration	0.048	10	0.077	3	0.000	17
DM2	Ease of maintenance	0.048	13	0.075	4	0.000	17
DM3	Ease to customization	0.029	16	0.046	9	0.000	17
RS1	Brand image	0.020	19	0.006	24	0.015	14
RS2	Sustainability	0.063	2	0.020	17	0.046	9
RS3	Potential for future strategy	0.057	6	0.018	19	0.041	11
SQ1	System reliability	0.048	12	0.078	2	0.000	17
SQ2	Security	0.048	11	0.079	1	0.000	17
SQ3	Reporting and Analytics	0.010	24	0.016	21	0.000	17
SQ4	Data Backup and Disaster Recovery	0.019	21	0.031	13	0.000	17
IS1	Multilingual and Multicurrency Support	0.049	9	0.041	12	0.095	5
IS2	Mobile Access	0.026	17	0.022	16	0.051	8
IS3	Cross module integration	0.052	8	0.044	11	0.102	4

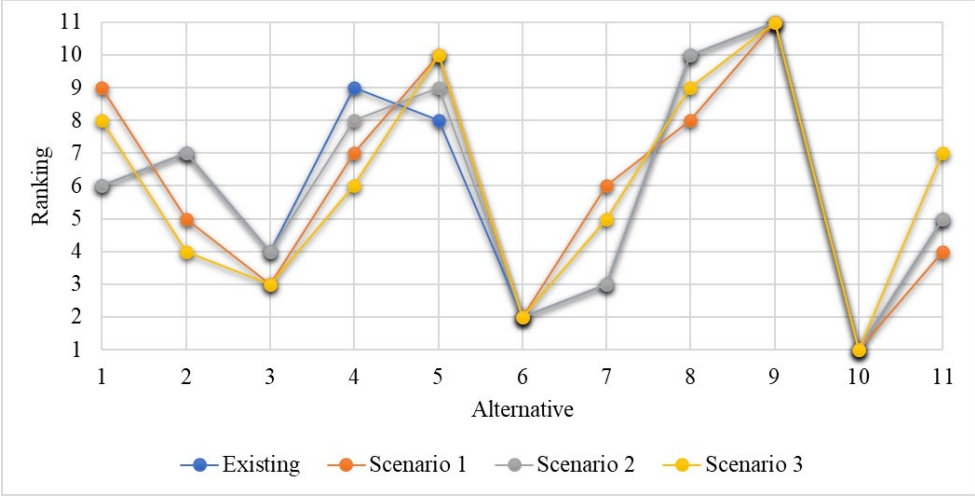

Figure 2. Sensitivity Analysis of open-source ERP system ranking

varying criteria weights, strengthening the understanding of the resilience of each ERP alternative to changes in assessment focus.

Managerial Implication

The results of this study provide clear and relevant managerial implications for SMEs, particularly in the decision-making process regarding the implementation of open-source ERP systems. With limited resources, SME managers should prioritize key aspects such as system quality, data management, and security in ERP investments. Emphasizing these criteria will ensure an efficient ERP system implementation and support business growth in the long run.

System quality is a key guide for managers when choosing an ERP system. Good quality ensures functionality, reliability, and ease of maintenance, reducing operational costs and the risk of implementation failure. Managers are advised to invest time in evaluating the system's stability, module integration, and developer community support capabilities. Furthermore, effective data management should be a priority, as real-time data integration improves decision-making accuracy and operational efficiency. Managers must focus on systems that enable easy data migration and ongoing maintenance to support business flexibility. Security has a strategic role that cannot be ignored. With the highest global weight of 0.098, security protects the integrity of company data and customer trust. Managers should prioritize ERP systems that offer comprehensive security features, such as automatic data backup, data encryption, and protection against cyberattacks. In addition, this research emphasizes the importance of system scalability in supporting SMEs' future growth. SMEs can sustainably improve their competitiveness by choosing an ERP system that is flexible and adaptable to business development. The sensitivity analysis in this study shows that shifts in criteria prioritization, such as an increased focus on cost or user-friendliness, can affect the ranking of ERP systems. Therefore, managers are advised to periodically revisit the prioritization of criteria according to evolving business needs.

CONCLUSION

This This research successfully achieved its objective of proposing a robust Multi-Criteria Decision Making (MCDM) framework for selecting open-source ERP systems by integrating Fuzzy AHP and TOPSIS methods, providing a structured and reliable approach for decision-making under uncertainty. The findings emphasize the critical roles of system quality, data management, and security as the most influential factors in supporting SMEs' operational efficiency, data integration, and business process optimization. For transportation service provider SMEs, the proposed model identifies flexible and reliable solutions, such as Odoo, which can effectively adapt to their unique business requirements. These insights offer practical implications for SME managers, highlighting the importance of investing in ERP systems that ensure reliability, security, and scalability. However, this study underscores the need for future research to adopt dynamic criteria that reflect the evolving needs of SMEs and involve broader stakeholder engagement through methods like surveys and in-depth interviews to enhance the validity of findings. Expanding the framework's application to various industry sectors, incorporating external factors like technological advancements and market trends, and conducting long-term implementation studies will further refine the model's adaptability and practical relevance. Therefore, future studies can build on this research to offer more comprehensive and sustainable solutions for SMEs, ensuring their competitiveness in an ever-changing business environment..

ACKOWLEDGMENT

The authors would like to extend their heartfelt gratitude to all individuals and organizations whose contributions were instrumental in the completion of this research. Furthermore, the authors acknowledge with thanks the efforts

of the anonymous reviewers, whose insightful suggestions and constructive critiques significantly improved the manuscript. Their expertise and commitment are sincerely valued and appreciated.

CONFLICT OF INTEREST

The author declares that there are no conflicts of interest regarding the authorship or publication of this research.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article.

Reference

[1] M. Al-Mashari, "Enterprise resource planning (ERP) systems: a research agenda," Industrial Management & Data Systems, vol. 102, no. 3, pp. 165-170, 2002. doi: 10.1108/02635570210421354.

[2] O. Velcu, "Exploring the effects of ERP systems on organizational performance," Industrial Management & Data Systems, vol. 107, no. 9, pp. 1316-1334, 2007. doi: 10.1108/02635570710833983.

[3] P. Deb, D. Bhattacharya, I. Chatterjee, A. Saha, A. R. Mishra, and S. H. Ahammad, "A Decision-Making Model with Intuitionistic Fuzzy Information for Selection of Enterprise Resource Planning Systems," IEEE Transactions on Engineering Management, pp. 1-15, 2022. doi: 10.1109/TEM.2022.3142315.

[4] E. Fernando, S. P. H. Kriswanto, and S. Wifasari, "Enterprise Resource Planning Systems: The Business Backbone," presented at the 2021 The 5th International Conference on E-Commerce, E-Business and E-Government, Rome, Italy, 2021. doi: 10.1145/3471988.3471990.

[5] E. J. Umble, R. R. Haft, and M. M. Umble, "Enterprise resource planning: Implementation procedures and critical success factors," *European Journal of Operational Research*, vol. 146, no. 2, pp. 241-257, 2003. doi: 10.1016/S0377-2217(02)00547-7.

[6] S. Shukla, P. K. Mishra, R. Jain, and H. C. Yadav, "An integrated decision-making approach for ERP system selection using SWARA and PROMETHEE method," *International Journal of Intelligent Enterprise*, vol. 3, no. 2, pp. 120-147, 2016. doi: 10.1504/IJIE.2016.077633.

[7] E. E. Karsak and C. O. Özogul, "An integrated decision-making approach for ERP system selection," *Expert Systems with Applications*, vol. 36, no. 1, pp. 660-667, 2009. doi: 10.1016/j.eswa.2007.09.016.

[8] X. Liao, Y. Li, and B. Lu, "A model for selecting an ERP system based on linguistic information processing," *Information Systems*, vol. 32, no. 7, pp. 1005-1017, 2007. doi: 10.1016/j.is.2007.01.003.

[9] V. Botta-Genoulaz, P. A. Millet, and B. Grabot, "A survey on the recent research literature on ERP systems," *Computers in Industry*, vol. 56, no. 6, pp. 510-522, 2005. doi: 10.1016/j.compind.2005.02.004.

[10] J. May, G. Dhillon, and M. Caldeira, "Defining value-based objectives for ERP systems planning," *Decision Support Systems*, vol. 55, no. 1, pp. 98-109, 2013. doi: 10.1016/j.dss.2012.12.036.

[11] K. E. Elfaki, R. D. Handoyo, and K. H. Ibrahim, "The Impact of Industrialization, Trade Openness, Financial Development, and Energy Consumption on Economic Growth in Indonesia," *Economies*, vol. 9, no. 4, p. 174, 2021. doi: 10.3390/economies9040174.

[12] H. Hernita, B. Surya, I. Perwira, H. Abubakar, and M. Idris, "Economic Business Sustainability and Strengthening Human Resource Capacity Based on Increasing the Productivity of Small and Medium Enterprises (SMEs) in Makassar City, Indonesia," *Sustainability*, vol. 13, no. 6, p. 3177, 2021. doi: 10.3390/su13063177.

[13] A. Terminanto, A. N. Hidayanto, and B. Maulana, "Development, configuration and implementation open-source ERP in manufacturing modul with accelerated Sap method," *International Journal of Management*, vol. 10, no. 3, pp. 77-98, 2019.

[14] M. F. Ibrahim and Y. S. Dharmawan, "Implementation of Open-Source ERP-Based Fleet Management System on SMEs Transportation Service Provider," *Jurnal RESTI* (*Rekayasa Sistem dan Teknologi Informasi*), vol. 6, no. 5, pp. 883-890, 2022.

[15] A. Benlian and T. Hess, "Comparing the relative importance of evaluation criteria in proprietary and open-source enterprise application software selection–a conjoint study of ERP and Office systems," *Information Systems Journal*, vol. 21, no. 6, pp. 503-525, 2011. doi: 10.1111/j.1365-2575.2010.00363.x.

[16] S. Tasnawijitwong and T. Samanchuen, "Open-source ERP selection for small and medium enterprises by using analytic hierarchy process," in *2018 5th International Conference on Business and Industrial Research* (ICBIR), 2018, pp. 382-386. doi: 10.1109/ICBIR.2018.8391210.

[17] D. Maditinos, D. Chatzoudes, and C. Tsairidis, "Factors affecting ERP system implementation effectiveness," *Journal of Enterprise Information Management*, vol. 25, no. 1, pp. 60-78, 2012. doi: 10.1108/17410391211192161.

[18] O. Alaskari, R. Pinedo-Cuenca, and M. M. Ahmad, "Framework for implementation of Enterprise Resource Planning (ERP) Systems in Small and Medium Enterprises (SMEs): A Case Study," *Procedia Manufacturing*, vol. 55, pp. 424-430, 2021. doi: 10.1016/j.promfg.2021.10.058.

[19] P. S. Tan, S. S. G. Lee, and A. E. S. Goh, "Multi-criteria decision techniques for context-aware B2B collaboration in supply chains," *Decision Support Systems*, vol. 52, no. 4, pp. 779-789, 2012. doi: 10.1016/j.dss.2011.11.021.

[20] H. S. Kilic, S. Zaim, and D. Delen, "Selecting 'The Best' ERP system for SMEs using a combination of ANP and PROMETHEE methods," *Expert Systems with Applications*, vol. 42, no. 5, pp. 2343-2352, 2015. doi: 10.1016/j.eswa.2014.10.034.

[21] H. S. Kilic, S. Zaim, and D. Delen, "Development of a hybrid methodology for ERP system selection: The case of Turkish Airlines," *Decision Support Systems*, vol. 66, pp. 82-92, 2014. doi: 10.1016/j.dss.2014.06.011.

[22] O. Alaskari, R. Pinedo-Cuenca, and M. M. Ahmad, "Framework for Selection of ERP System: Case Study," *Procedia Manufacturing*, vol. 38, pp. 69-75, 2019. doi: 10.1016/j.promfg.2020.01.009.

[23] Svensson and A. J. I. Thoss, "Risk Factors When Implementing ERP Systems in Small Companies," *Information*, vol. 12, no. 11, p. 478, 2021. doi: 10.3390/info12110478.

[24] D. M. Utama, A. A. Putri, and I. Amallynda, "A Hybrid Model for Green Supplier Selection and Order Allocation: DEMATEL, ANP, and Multi-criteria Goal Programming Approach," *Jurnal Optimasi Sistem Industri*, vol. 20, no. 2, pp. 147-155, 2021. doi: 10.25077/josi.v20.n2.p147-155.2021.

[25] A. Amallynda, R. A. T. Hidayatulloh, and D. M. Utama, "Supplier selection utilizing fuzzy-AHP and PROMETHEE: A case study in garment industry," *AIP Conference Proceedings*, vol. 2453, no. 1, p. 020041, 2022. doi: 10.1063/5.0078785.

[26] T. Baroto, D. M. Utama, and M. F. Ibrahim, "Green supplier selection and order allocation using AHP-SAW and goal programming," *AIP Conference Proceedings*, vol. 2453, no. 1, p. 020044, 2022. doi: 10.1063/5.0078790.

[27] M. F. Ibrahim, T. Laurensia, and D. M. Utama, "Integration AHP and MOORA for sustainable supplier selection during the COVID-19 pandemic era: A case study," *AIP Conference Proceedings*, vol. 2674, no. 1, p. 030012, 2023. doi: 10.1063/5.0114015.

[28] J. Park and H. Y. Jeong, "The QoS-based MCDM system for SaaS ERP applications with Social Network," *The Journal of Supercomputing*, vol. 66, no. 2, pp. 614-632, 2013. doi: 10.1007/s11227-013-0901-0.

[29] A. Mubin, D. M. Utama, and R. C. Nusantara, "Manufacturing Sustainability Assessment Comprising Physical and Mental Workload: An Integrated Modified SVSM and AHP Approach," *Process Integration and Optimization for Sustainability*, vol. 7, no. 1, pp. 407–417, 2022. doi: 10.1007/s41660-022-00234-1.

[30] D. M. Utama, N. Ardiyanti, and A. A. Putri, "A new hybrid method for manufacturing sustainability performance assessment: a case study in furniture industry," *Production & Manufacturing Research*, vol. 10, no. 1, pp. 760-783, 2022. doi: 10.1080/21693277.2022.2134325.

[31] A. Hinduja and M. Pandey, "An Integrated Intuitionistic Fuzzy MCDM Approach to Select Cloud-Based ERP System for SMEs," *International Journal of Information Technology & Decision Making*, vol. 18, no. 06, pp. 1875-1908, 2019. doi: 10.1142/S0219622019500360.

[32] I. Jafarnejad, M. Ansari, H. R. Youshanlouei, and M. Mood, "A hybrid MCDM approach for solving the ERP system selection problem with application to steel industry," *International Journal of Enterprise Information Systems (IJEIS)*, vol. 8, no. 3, pp. 54-73, 2012. doi: 10.4018/jeis.2012070104.

[33] G. T. Temur and B. Bolat, "A robust MCDM approach for ERP system selection under uncertain environment based on worst case scenario," *Journal of Enterprise Information Management*, vol. 31, no. 3, pp. 405-425, 2018. doi: 10.1108/JEIM-01-2017-0005.

[34] Q. N. Naveed, S. Islam, M. R. N. M. Qureshi, A. M. Aseere, M. A. A. Rasheed, and S. Fatima, "Evaluating and Ranking of Critical Success Factors of Cloud Enterprise Resource Planning Adoption Using MCDM Approach," IEEE Access, vol. 9, pp. 156880-156893, 2021.

[35] Amirkabiri and M. Rostamiyan, "Development of a hybrid methodology (MCDM) for ERP system selection (Case study: Mahan Airlines)," *Revista Publicando*, vol. 5, no. 15, pp. 1180-1196, 2018.

[36] M. R. Uddin, A. A. Noman, F. Tasnim, N. Nafisa, and S. Hossain, "A Hybrid MCDM Approach based on AHP, and TOPSIS to select an ERP system in Bangladesh," in *2021 International Conference on Information and Communication Technology for Sustainable Development (ICICT4SD)*, 2021, pp. 161-165. doi: 10.1109/ICICT4SD50815.2021.9396932.

[37] T. Gürbüz, S. E. Alptekin, and G. Işıklar Alptekin, "A hybrid MCDM methodology for ERP selection problem with interacting criteria," *Decision Support Systems*, vol. 54, no. 1, pp. 206-214, 2012. doi: 10.1016/j.dss.2012.05.010.

[38] Z. Ayağ and A. Yücekaya, "A fuzzy ANP-based GRA approach to evaluate ERP packages," *International Journal of Enterprise Information Systems (IJEIS)*, vol. 15, no. 1, pp. 45-68, 2019. doi: 10.4018/IJEIS.2019010103.

[39] Y. Kazancoglu and S. Burmaoglu, "ERP software selection with MCDM: application of TODIM method," *International Journal of Business Information Systems*, vol. 13, no. 4, pp. 435-452, 2013. doi: 10.1504/IJBIS.2013.055271.

[40] D. Rouyendegh and T. E. Erkan, "ERP system selection by AHP method: case study from Turkey," *International Journal of Business and Management Studies*, vol. 3, no. 1, pp. 39-48, 2011.

[41] T. Dalyan, I. Otay, and M. Gülada, "Interval-Valued Pythagorean Fuzzy AHP&TOPSIS for ERP Software Selection," in *Intelligent and Fuzzy Systems*, Cham, 2022, pp. 702-710: Springer International Publishing. doi: 10.1007/978-3-031-09176-6_78.

[42] N. V. Thanh, "Designing a MCDM Model for Selection of an Optimal ERP Software in Organization," *Systems*, vol. 10, no. 4, 2022. doi: 10.3390/systems10040095.

[43] H. Garg, J. Vimala, S. Rajareega, D. Preethi, and L. Perez-Dominguez, "Complex intuitionistic fuzzy soft SWARA-COPRAS approach: An application of ERP software selection," *AIMS Mathematics*, vol. 7, no. 4, pp. 5895-5909, 2022. doi: 10.3934/math.2022330.

[44] K. Hansen, M. Haddara, and M. Langseth, "Exploring Multi-Criteria Decision-Making Methods in ERP Selection," *Procedia Computer Science*, vol. 219, pp. 879-888, 2023. doi: 10.1016/j.procs.2023.01.032.

[45] F. Ibrahim, T. Kurrahman, and D. M. Utama, "Open-source ERP systems selection: An integrated method based on fuzzy AHP-TOPSIS," *Journal of Logistics, Informatics and Service Science*, vol. 10, no. 4, pp. 234-249, 2023.

[46] K. A. Dawood, A. A. Zaidan, K. Y. Sharif, A. A. Ghani, H. Zulzalil, and B. B. Zaidan, "Novel multi-perspective usability evaluation framework for selection of open source software based on BWM and group VIKOR techniques," *International Journal of Information Technology & Decision Making*, vol. 22, no. 01, pp. 187-277, 2023. doi: 10.1142/S0219622023500070.

[47] G. Büyüközkan and F. Göçer, "Evaluation of software development projects based on integrated Pythagorean fuzzy methodology," *Expert Systems with Applications*, vol. 183, p. 115355, 2021. doi: 10.1016/j.eswa.2021.115355.

[48] B. Cao et al., "A new integrated rough multi-criteria decision-making model for enterprise resource planning software selection," *PeerJ Computer Science*, vol. 10, p. e2096, 2024. doi: 10.7717/peerj-cs.2096.

[49] G. Adriana and I. Amalia-Elena, "Content Analysis on the ERP Technology Implementation," in *Proceedings of the Brawijaya International Conference on Economics, Business and Finance 2021 (BICEBF 2021)*, 2022, pp. 210-221: Atlantis Press. doi: 10.2991/aebmr.k.220128.027.

[50] N. Bhatt, S. Guru, S. Thanki, and G. Sood, "Analysing the factors affecting the selection of ERP package: a fuzzy AHP approach," *Information Systems and e-Business Management*, vol. 19, no. 2, pp. 641-682, 2021. doi: 10.1007/s10257-020-00495-1.

[51] D. M. Utama, "AHP and TOPSIS Integration for Green Supplier Selection: A Case Study in Indonesia," in *The International Conference on Industrial Automation, Smart Grid and its Application (ICIASGA) 2020 Jawa Timur, Indonesia*, 2021, vol. 1845, no. 1, p. 012015: IOP Publishing. doi: 10.1088/1742-6596/1845/1/012015.

[52] D. M. Utama, M. S. Asrofi, and I. Amallynda, "Integration of AHP-MOORA Algorithm in Green Supplier Selection in the Indonesian Textile Industry," in *Virtual Conference on Engineering, Science and Technology (ViCEST) 2020, Kuala Lumpur, Malaysia*, 2021, vol. 1933, no. 1, p. 012058: IOP Publishing. doi: 10.1088/1742-6596/1933/1/012058.

[53] Y. Liu, C. M. Eckert, and C. Earl, "A review of fuzzy AHP methods for decision-making with subjective judgements," *Expert Systems with Applications*, vol. 161, p. 113738, 2020. doi: 10.1016/j.eswa.2020.113738.

[54] A. H. Afolayan, B. A. Ojokoh, and A. O. Adetunmbi, "Performance analysis of fuzzy analytic hierarchy process multi-criteria decision support models for contractor selection," *Scientific African*, vol. 9, p. e00471, 2020. doi: 10.1016/j.sciaf.2020.e00471.

[55] L. Che, Y. Zhang, J. Wang, and M. Bai, "A New Method for Deriving Weights in Group Fuzzy Analytic Hierarchy Process and Evaluation Measures," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 7941-7946, 2020. doi: 10.1016/j.ifacol.2020.12.2135.

[56] J. Y. Ho, J. Ooi, Y. K. Wan, and V. Andiappan, "Synthesis of wastewater treatment process (WWTP) and supplier selection via Fuzzy Analytic Hierarchy Process (FAHP)," *Journal of Cleaner Production*, vol. 314, p. 128104, 2021. doi: 10.1016/j.jclepro.2021.128104.

[57] A. K. Kar, "A hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network," *Journal of Computational Science*, vol. 6, pp. 23-33, 2015. doi: 10.1016/j.jocs.2014.11.002.

[58] O. Kilincci and S. A. Onal, "Fuzzy AHP approach for supplier selection in a washing machine company," *Expert Systems with Applications*, vol. 38, no. 8, pp. 9656-9664, 2011. doi: 10.1016/j.eswa.2011.01.159.

[59] D. S. Wijaya and D. S. Widodo, "Evaluation Supplier Involve on Food Safety and Halal Criteria using Fuzzy AHP: A Case Study in Indonesia," *Jurnal Teknik Industri*, vol. 23, no. 1, pp. 67-78, 2022. doi: 10.9744/jti.23.1.67-78.

[60] M. Djunaidi, C. D. Utami, A. K. Alghofari, and H. Munawir, "Selection of furniture raw material suppliers using fuzzy analytical hierarchy process," *Jurnal Teknik Industri*, vol. 20, no. 1, pp. 12-21, 2019. doi: 10.9744/jti.20.1.12-21.

[61] J. J. Buckley, "Fuzzy hierarchical analysis," *Fuzzy Sets and Systems*, vol. 17, no. 3, pp. 233-247, 1985. doi: 10.1016/0165-0114(85)90090-9.

[62] C. Natalia, I. P. Surbakti, and C. W. J. Oktavia, "Integrated ANP and TOPSIS Method for Supplier Performance Assessment," *Jurnal Teknik Industri*, vol. 21, no. 1, pp. 34-45, 2020. doi: 10.9744/jti.21.1.34-45.

[63] S. Nădăban, S. Dzitac, and I. Dzitac, "Fuzzy TOPSIS: A General View," *Procedia Computer Science*, vol. 91, pp. 823-831, 2016. doi: 10.1016/j.procs.2016.07.088.

[64] L. Aversano, I. Pennino, and M. Tortorella, "Evaluating the Quality of Free/Open Source ERP Systems," in *Proceedings of the 15th International Conference on Enterprise Information Systems - Volume 3: ICEIS*, 2013, pp. 75-83. doi: 10.5220/0004430000750083.

[65] D. Kowanda, M. Firdaus, and R. Pasaribu, "Opportunity of free open source ERP system as a competitive advantage for small and medium enterprise," in *Proceedings of the 2012 International Conference on Business and Information*, 2012, pp. 195-206.

[66] S. Wang and H. Wang, "A Survey of Open Source Enterprise Resource Planning (ERP) Systems," *International Journal of Business & Information*, vol. 9, no. 1, pp. 1-15, 2014.

[67] M. Hashim and P. V. Malik, "An Alternative Framework of Open Source Enterprise Resource Planning (ERP) System for Small and Medium Enterprise (SME)," *International Refereed Journal of Reviews and Research*, vol. 5, no. 1, pp. 1-5, 2018.

[68] T. Mladenova, "Open-source ERP systems: an overview," in *2020 International Conference Automatics and Informatics (ICAI)*, pp. 1-6, IEEE, 2020. doi: 10.1109/ICAI50593.2020.9311331.

[69] J. Manzoor, A. Waleed, A. F. Jamali, and A. Masood, "Cybersecurity on a budget: Evaluating security and performance of open-source SIEM solutions for SMEs," *PLOS ONE*, vol. 19, no. 3, p. e0301183, 2024. doi: 10.1371/journal.pone.0301183.

[70] S. Gupta and S. C. Misra, "Moderating effect of compliance, network, and security on the critical success factors in the implementation of cloud ERP," *IEEE Transactions on Cloud Computing*, vol. 4, no. 4, pp. 440-451, 2016. doi: 10.1109/TCC.2015.2415792.

[71] A. Ghallab, A. Almuzaiqer, A. Al-Hashedi, A. Mohsen, K. Bechkoum, and W. Aljedaani, "Factors Affecting Intention to Adopt Open Source ERP Systems by SMEs in Yemen," in *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, pp. 1-7, IEEE, 2021. doi: 10.1109/ICECCME52200.2021.9591104.

[72] C. J. Stefanou, "SMEs and FOS-ERP systems: Risks and opportunities," in *Grid and Cloud Computing: Concepts, Methodologies, Tools and Applications*, IGI Global, 2012, pp. 1468-1478. doi: 10.4018/978-1-4666-0879-5.ch509.

[73] N. Limantara and F. Jingga, "Open source ERP: ODOO implementation at micro small medium enterprises: (A case study approach at CV. XYZ in module purchasing and production)," in *2017 International Conference on Information Management and Technology (ICIMTech)*, pp. 340-344, IEEE, 2017. doi: 10.1109/ICIMTech.2017.8273530.

[74] A. Aditya and H. F. Efendi, "Business Process Analysis and Implementation of Odoo Open Source ERP System in Inventory, Purchasing and Sales Activities," *Procedia of Social Sciences and Humanities*, vol. 3, pp. 349-357, 2022. doi: 10.21070/pssh.v3i.168.